



# The environmental handprint approach to assessing and communicating the positive environmental impacts

Final report of the Environmental Handprint project

Saija Vatanen | Kaisa Grönman | Katri Behm |  
Tiina Pajula | Laura Lakanen | Heli Kasurinen |  
Risto Soukka | Lotta Hepo-oja | Kim Lindfors |  
Matias Alarotu

# **The environmental handprint approach to assessing and communicating the positive environmental impacts**

Final report of the Environmental Handprint project

---

Saija Vatanen, Katri Behm, Tiina Pajula, Lotta Hepo-oja, Kim Lindfors, Matias Alarotu

VTT

Kaisa Grönman, Laura Lakanen, Heli Kasurinen, Risto Soukka

LUT

ISBN 978-951-38-8752-0

VTT Technology 392

ISSN-L 2242-1211

ISSN 2242-122X (Online)

DOI: 10.32040/2242-122X.2021.T392

Copyright © VTT 2021

JULKAISIJA – PUBLISHER

VTT

PL 1000

02044 VTT

Puh. 020 722 111

<https://www.vtt.fi>

VTT

P.O. Box 1000

FI-02044 VTT, Finland

Tel. +358 20 722 111

<https://www.vttresearch.com>

## Preface

This is the final report of the Environmental Handprint project (2018–2021). The project was carried out in close cooperation between VTT and LUT. Responsibilities of the participating organizations and researchers were as follows: Saija Vatanen (VTT) acted as the project manager and coordinated the work. In LUT, Kaisa Grönman acted as a project manager and Risto Soukka as the responsible leader.

The environmental handprint approach was developed by Kaisa Grönman (LUT), Tiina Pajula (VTT), Saija Vatanen (VTT), Risto Soukka (LUT), Heli Kasurinen (LUT), Laura Lakanen (LUT) and Katri Behm (VTT) and it is presented in Chapter 2. The water handprint concept was developed by Katri Behm, Tiina Pajula and Heli Kasurinen. The water handprint concept is presented in Chapter 3. The nutrient handprint development was done by Heli Kasurinen, Laura Lakanen, Kaisa Grönman, Risto Soukka, Katri Behm, and Tiina Pajula. This is presented in Chapter 4. Chapter 5 presents the air quality handprint developed by Laura Lakanen, Kaisa Grönman, Risto Soukka and Heli Kasurinen. The resource handprint presented in Chapter 6 was developed by Saija Vatanen, Tiina Pajula, Katri Behm, Matias Alarotu (VTT), Kaisa Grönman, Heli Kasurinen, Risto Soukka, and Laura Lakanen. Chapter 7 presents the handprint in organizations, which was developed by Saija Vatanen, Tiina Pajula, Kaisa Grönman, Risto Soukka, Lotta Hepo-oja (VTT) and Kim Lindfors (VTT). A project handprint concept developed by Kaisa Grönman, Laura Lakanen, Risto Soukka, Saija Vatanen and Tiina Pajula is presented in Chapter 8. Chapter 9 describes the recommendations for handprint communication, and it is based on the Carbon handprint guide ([www.handprint.fi](http://www.handprint.fi)). Chapter 10 presents the final conclusions and discussion on handprint concept.

The project was mainly funded by Business Finland. The project's industrial partners were: Andritz Oy, Biolan Oy, Borealis Polymers Oy, Ekox Finland Oy, Gasum Oy, HyXo Oy, Lassila&Tikanoja Oyj, Neste Oyj, Nordic Investment Bank, Outotec Oy, Paptic Oy, Pääkaupunkiseudun Kierrätyskeskus Oy, UPM-Kymmene Oyj, Semantum Oy, Sitra and StoraEnso Oyj. The intention of the project was to create calculation and communication guidelines for quantifying positive environmental impacts of a product, organization, or a project.

This report presents the main findings of the project and the results from the case studies in which a handprint was calculated for different products, organizations, and projects.

# Contents

<b>Preface</b> .....	<b>3</b>
<b>1. Introduction</b> .....	<b>5</b>
<b>2. The environmental handprint</b> .....	<b>7</b>
<b>3. Water handprint</b> .....	<b>15</b>
3.1 Steps in the water handprint calculation.....	15
3.2 Case study: water treatment technology .....	17
<b>4. Nutrient handprint</b> .....	<b>23</b>
4.1 Steps in the nutrient handprint calculation.....	24
4.2 Case study: recycled nutrient product .....	27
4.3 Case study: wastewater treatment service .....	37
<b>5. Air quality handprint</b> .....	<b>46</b>
5.1 Steps in the air quality handprint calculation .....	47
5.2 Case study: paraffinic renewable diesel, HVO .....	49
<b>6. Resource handprint</b> .....	<b>56</b>
6.1 Steps in the resource handprint calculation.....	57
6.2 Case study: pulp washing system .....	59
6.3 Case study: moss-based gardening soil.....	66
6.4 Case study: recycled plastic.....	72
6.5 Case study: computer remanufacturing.....	77
<b>7. Handprint in organizations</b> .....	<b>83</b>
7.1 Steps in the organizational handprint calculation .....	84
7.2 Case study: second-hand items .....	86
7.3 Case study: packaging from renewable materials .....	92
<b>8. Project handprint</b> .....	<b>97</b>
8.1 Steps in the project handprint calculation .....	97
8.2 Case study: leaching plant in a copper smelter .....	99
<b>9. Handprint communication</b> .....	<b>103</b>
9.1 Checklist for planning and preparing handprint communication .....	105
<b>10. Conclusions and discussion</b> .....	<b>107</b>
<b>References</b> .....	<b>109</b>

## Appendices

Appendix A: The handprint frameworks of case studies

# 1. Introduction

In the Environmental Handprint project (2018–2021), VTT Technical Research Centre of Finland Ltd. and LUT University have continued the work started in the Carbon Handprint project (2016–2018) and widened the handprint approach from the carbon handprint and climate impact to consider additional environmental impacts including: water, nutrients, air quality, and resources. In addition, the handprint concept is discussed from organizational and project perspectives. In this report, each handprint is first described on a theoretical level and then demonstrated with 1–4 practical examples.

The framework for the environmental handprint is presented in Chapter 2. The framework follows the carbon handprint approach described in the Carbon handprint guide (Pajula et al. 2021) but is modified to fulfil the needs of the other environmental impacts. Thus, the same framework applies to all handprint approaches, i.e. the water, nutrients, air quality and resource handprint. Further, project and organization related handprints can be evaluated with the same framework.

Chapter 3 describes the water handprint approach. Water usage can consume water volumes or degrade water quality in a specific area. Due to the often global value chains of products, water impacts relate to several local conditions during a product's life cycle. Water footprint calculations are ISO standardized (ISO 14046) and consider both scarcity/availability of water and water quality aspects. The water handprint approach follows the same principles presented in ISO 14046. Both water scarcity and water quality aspects are demonstrated with a water treatment plant case study.

Nutrients, such as nitrogen, phosphorus, and potassium, are currently used in unsustainable ways, i.e. nutrients are released into the environment in reactive forms, which cause environmental impacts such as water eutrophication. The nutrient handprint approach is presented in Chapter 4, describing how improvements in nutrient cycles can create positive environmental impacts. The calculation is demonstrated with two cases, first with a recycled nutrient product and then with a wastewater treatment service.

Chapter 5 describes how reduced amounts of emissions to atmosphere can be considered as an air quality handprint. Air pollution e.g. in the form of particles, ozone and nitrogen oxides cause health problems and have environmental impacts on ecosystems. The impacts may occur at a local level especially in densely populated areas with a lot of traffic, but the air pollutants also drift from the emission locations with air currents and wind. The concept is tested with a case study comparing emissions from a renewable fuel to the emissions from a fossil diesel source.

Resource efficiency related to both material and energy resources is an interesting topic and companies long for indicators to describe the benefits of e.g. circular economies and ecosystems and the use of renewable materials and energy. In this project, the resource handprint concept was developed, and it is presented in Chapter 6. The concept is demonstrated with 4 different case studies, including a pulp

washing system, gardening soil made from mainly renewable materials, waste and side-streams, plastic recycling and finally computer remanufacturing.

Chapter 7 explains how the handprint concept can be used in organizations. This requires a broader consideration than a product handprint, and a full variety of products/services provided by the organization must be considered. Organizational handprints should not be used to compare different companies to each other, but the intent is to show potential benefits of an organizations' products, to provide a full understanding of the environmental impacts of the product portfolios to the company itself, and to provide tools for communication of environmental impacts to different stakeholders.

In Chapter 8, the handprint concept is applied to projects which aim to improve the state of the environment. Environmental handprints can be important tools for example, when evaluating environmentally-friendly investment decisions or when retrospectively evaluating the outcomes of projects. All environmental impact categories and indicators presented in the environmental handprint guidelines are applicable to the project handprint.

Chapter 9 presents the principles that need to be followed when handprint results are communicated to stakeholders and other public.

Finally, conclusions and other remarks are given in Chapter 10.

## 2. The environmental handprint

The framework for the environmental handprint provides general guidelines on assessing water, nutrient, air quality, resource, organizational and project handprints. The framework is modified from the carbon handprint assessment guidelines introduced by Pajula et al. (2018). However, additional steps have been added compared to the original methodology to enable the assessment of new environmental impact categories as well as organizational and project handprint approaches.

The framework is presented in **Figure 1**. The environmental handprint assessment process consists of four stages and 13 steps, which are conducted from above downwards. However, the quantification of a handprint is an iterative process, and it is essential to return to previous steps to update them according to the findings in subsequent steps. In the framework, there are guidelines for every step, which provide instructions on the most relevant issues to be considered. In some steps, there are several alternatives of which the most relevant ones are chosen. Like the carbon handprint approach, the environmental handprint is also tightly linked to the LCA methodology.

In the framework, the first stage defines the scope of the study, identifies relevant environmental impacts and their indicators of the case in question, and specifies the operating environment for the study. The first stage is specific to a handprint assessment when compared to a traditional LCA assessment. The subsequent stage includes typical LCA steps, after which the calculation of footprints and handprints is conducted. The final stage concentrates on communication of the results.

In the following the **general guidelines for assessing environmental handprints** are presented step by step.



	<b>Define the scope of the studied solution</b>	<b>Product</b> (goods, service, material, component)	<b>Organisation</b> (product or service portfolio)	<b>Project</b> (a non-recurrent activity to reach the preferred outcome in a defined time frame)
Stage 1	<b>Identify potential handprint contributors</b>	Description, how the studied solution may achieve footprint reductions		
	<b>Identify the environmental impacts in question and their potential indicators</b>	<b>Climate change</b> GHG emissions	<b>Resources</b> e.g. ADP (elements and fossil fuels), cumulative energy demand	<b>Water</b> e.g. scarcity, eutrophication, acidification, toxicity
			<b>Nutrients</b> N/P/K balance and eutrophication, in addition e.g. toxicity, acidification	<b>Air quality</b> e.g. PM <sub>10</sub> , PM <sub>2.5</sub> , NO <sub>x</sub> , SO <sub>2</sub> , VOC, health impacts, POCP
	<b>Identify users and beneficiaries of the studied solution</b>	Identify potential or actual customers or other parties that may benefit from the studied solution		
	<b>Define the baseline</b>	Reference case that best represents the conditions (most likely) to occur in the absence of the studied solution		
Stage 2	<b>Define the functional unit</b>	The measure of the function the studied solution delivers in a relevant time frame in the use <input type="text"/>		
	<b>Define the system boundaries</b>	The relevant and similar life cycle stages of the studied and the baseline solution		
	<b>Define data needs and sources</b>	Identifying representative and accessible data of the studied and the baseline solution representing the similar geographical and time-related coverage		
Stage 3	<b>Calculate the footprints</b>	Calculate footprints of the studied and the baseline solution based on relevant ISO-standards where applicable		
	<b>Calculate the handprint</b>	Difference of the footprints calculated		
Stage 4	<b>Identify the relevant indicators to be communicated</b>	Confirmation of the most relevant indicators that accurately and justly represent the results and should thus be communicated		
	<b>Consider critical review of the handprint</b>	Recommended in B2C communications, and mandatory if the results are intended for comparative assertions to be disclosed to the public as instructed in the ISO standards 14044 and 14026.		
	<b>Communicate the results</b>	Communicating the results respecting appropriateness, clarity, credibility, and transparency		

**Figure 1.** Framework for the environmental handprint assessment.

## Stage 1: Handprint requirements

### Step 1: Define the scope of the studied solution

In the first step the scope of the studied solution is defined and described accurately. The studied solution refers to a studied object, which can replace a baseline solution, may create environmental benefits and of which the potential handprint will be assessed. The studied solution can be a product or a service, an organization, or a project. The studied solution is created or enabled by a provider, typically a company or an organization who thus receives the handprint as the actor enabling a change for the better.

### Step 2: Identify potential handprint contributors

The aim of this step is to identify, how the studied solution will generate environmental benefits by reducing the footprint of the users. One must identify what potential mechanisms are evident in the studied solution that may result in a footprint

reduction compared to the baseline solution. There might be many factors simultaneously that change and estimating the overall effect at a glance might be difficult. To gain a better understanding of the potential handprint, a preliminary assessment and screening of possible factors contributing to the footprint can be carried out. This can be done using rough data and modelling. Alternatively, an expert panel consisting of industrial and sustainability experts can be called together to discuss and evaluate possible footprint reduction pathways. Only a full handprint quantification will show whether the selected product will have a handprint in reality. The hypothesis is important, however, in order to define a properly grounded baseline and product system boundaries, as described in the steps below. (Pajula et al. 2021)

### Step 3: Identify the environmental impacts in question and their potential indicators

In this step it is identified which environmental impacts are relevant concerning the studied solution and which indicators should be considered during the handprint assessment. The framework for the environmental handprint provides guidelines for assessing handprints concerning the environmental impacts of climate change, resources, water, nutrients, and air quality, and provides examples of relevant indicators for every impact. Not all the impacts and indicators are relevant in every case, and in some cases, there might be several relevant impact categories and indicators. Relevant indicators are chosen based on previously identified handprint contributors. However, some other indicators than those listed in the framework might also be relevant to include in an assessment based on the special characteristics of a studied solution. As an exception, in nutrient handprint assessment there are some obligatory indicators that are always included in the calculation. Additionally, instructions for the resource handprint assessment give strong suggestions for indicators to be included in the calculation.

### Step 4: Identify the users and beneficiaries of the studied solution

Guidelines for identifying the customers as in the carbon handprint assessment apply (Pajula et al. 2021). Users are those who benefit from the improvements in environmental performance, such as customers, both B2B and B2C, or other stakeholders. Identifying all the users or beneficiaries of the studied solution is important in order to understand the handprint contributors and footprint reductions of the users or customers. In some case the users cannot be identified, or there may be several simultaneously. In these cases a system approach would be the best way to explore handprint creation. This is to say, that system expansion may be needed and the changes in footprints need to be examined at the system level.

## Step 5: Define the baseline

Setting the baseline correctly in the handprint assessment is crucial as it has significant effects on the results. The baseline is a reference case that best represents the conditions most likely to occur in the absence of a studied solution.

The baseline and the studied solution should both deliver the same function and be used for the same purpose in the defined time period and geographic region. The baseline and the studied solution must be assessed in a consistent manner in terms of data quality, representativeness, conservativeness, system boundaries, and assumptions. Similarly, they should be communicated respecting appropriateness, clarity, credibility, and transparency.

The baseline chosen as a reference case should be communicated accurately. Reporting should include at least a description of activities included in the baseline, system boundaries, as well as the technological, geographical and time related scope, in addition to the coverage of the assessment. Users or those who benefit from the baseline need to be identified and reported. Additionally, one should describe the selection process of the baseline and uncertainties in the baseline or in its selection process and estimate the influence of uncertainties on the results. Additionally, a statement of the validity of the baseline over time and used data should be made.

More instructions for defining the baseline are described in the carbon handprint guidelines (Pajula et al. 2021).

## Stage 2: LCA requirements

### Step 6: Define the functional unit

A functional unit can be defined as the measure of the function the studied solution delivers in a relevant time frame to the user. The functional unit serves as the basis for quantifying the performance of the studied solution and its primary purpose is to provide a reference as a basis for an evaluation of the footprint calculation. This reference is necessary to ensure comparability of the studied solution to the baseline solution. A system may have several possible functions and hence, multiple functional units may be needed simultaneously. The selected ones strongly depend on the users and how the benefits are created. More information about defining the functional unit can be found in ISO 14040 (2006), ISO 14044 (2006), ISO 14046 (2014) and ISO 14067 (2018). Guidelines for defining the functional unit as in the carbon handprint assessment also apply.

### Step 7: Define the system boundaries

Guidelines for defining system boundaries as in the carbon handprint assessment apply. According to Pajula et al. (2021) the system boundaries define the unit processes to be included in the system. Ideally, the product system should be modelled in such a manner that inputs and outputs at its boundaries are elementary flows

(drawn from the environment and released into the environment). However, the exclusion of life-cycle stages, processes, inputs, or outputs within the system under study is permitted if they do not significantly change the overall conclusions of the study. The selection of the system boundaries has to be consistent with the goals of the study and equal in the baseline and studied solutions. The criteria used in establishing the system boundaries should be explained. In the handprint approach the whole life cycle of the studied solution should be included in the system. Setting the system boundaries is elaborated in ISO 14040-44, ISO 14046 and ISO 14067.

#### Step 8: Define the data needs and sources

After setting the system boundaries the data needs are identified and data is collected. The aim is to identify representative and accessible data of the studied and baseline solution representing a similar geographical and time-related coverage.

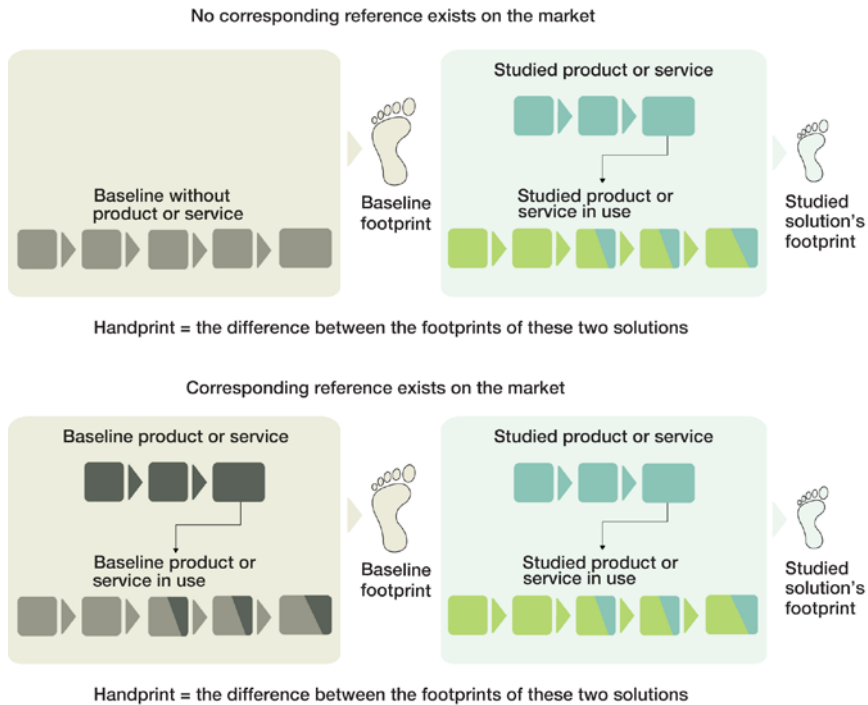
Data on the main handprint contributors must reflect an actual existing operating environment in both the baseline and the studied solution. Furthermore, the data for the baseline solution and the studied solution require the same timeframe. When there is variation in operations related to the calculations over time, then data must be collected over an appropriate time period to establish the average outcome of the studied indicator.

The data used should be representative in terms of geographical, time-related, and technological coverage, as well as being precise and complete, as determined in ISO 14040-44, ISO 14046 and ISO 14067.

### **Stage 3: Quantification of the handprint**

#### Step 9: Calculate the footprints

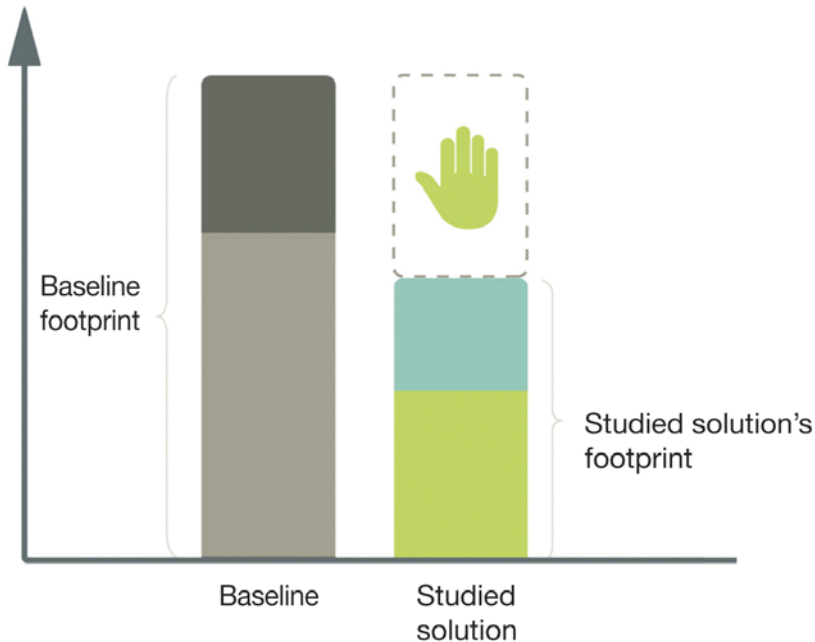
Using equal functional units, the footprints of the studied and the baseline solutions are calculated over the life cycle based on relevant ISO standards where applicable. The handprint is created if the footprint is smaller when applying the studied solution than it is when using the baseline product or service, see **Figure 2**. Each environmental indicator identified as relevant earlier, should be counted separately.



**Figure 2.** The studied product or service provider receives a handprint equivalent to the achieved footprint reduction. In the upper case no corresponding reference or alternative product or service exist on the market.

### Step 10: Calculate the handprint

In this step the footprints of the two systems are compared. If the footprint of the studied solution is smaller than the footprint of the baseline solution, a handprint has been created. A handprint can be created either by offering a solution with a lower footprint than the baseline solution (representing the turquoise bar in the offered solution in **Figure 3**) or by helping the user to reduce the footprint of their processes (representing the green bar in **Figure 3**), or both. In the case of some environmental impacts, e.g. water, nutrient and resource impacts, the handprint is not a single indicator. Consequently, controversial results, i.e. both positive and negative changes, may occur. In case a reduction is achieved in one indicator but there is an increase in another, the results must be communicated transparently.



**Figure 3.** A handprint can be created by offering solutions with a lower footprint in comparison to the solutions used in the baseline or by helping the user to reduce the footprint of their processes.

#### **Stage 4: Communication**

##### Step 11: Identify the relevant indicators to be communicated

The aim of this step is to confirm the most relevant indicators that accurately and justly represent the results and should thus be communicated. However, the indicators must represent the real situation of the assessment and indicators with negative changes should be transparently communicated.

##### Step 12: Consider a critical review of the handprint

The guidelines for the carbon handprint assessment apply. Handprint communications may be intended for business-to-business or business-to-consumer communications. ISO standard 14040-44 on LCA requires a critical review if the study is intended to be used for a comparative assertion intended for disclosure to the public. ISO 14026 on the communication of footprint information has requirements for comparative footprints respectively. To be in line with these requirements, a critical review is strongly recommended if the handprint communications are to be used for business-to-consumer communication and the handprint quantification is based on a comparative footprint relative to another organization's products (Pajula et al. 2021).

A critical review is a helpful way to verify the calculation process and results and is recommended in all situations. To keep the procedure leaner, an independent reviewer may also be internal to the organization that conducted the handprint study, for example in the case of business-to-business communications (Pajula et al. 2021).

### Step 13: Communicate the results

The results must be communicated transparently, comprehensively, and reliably. As a handprint can be assessed for many purposes, communication should be customized based on communicative needs. It should be kept in mind that a handprint is bound to a specific timeframe and conditions and should be communicated related to them. The handprint is valid as long as the data used for the calculation is representative of the examined situation.

At this point an appropriate communication unit needs to be selected. Communication units depend on the studied indicators, and an informative and representative reference unit may also be something other than the functional unit used in the calculations.

Detailed guidance on the handprint communication can be found in Chapter 9 in this report.

### **3. Water handprint**

Water is an essential natural resource with limited availability. While the greenhouse gases released during a life cycle of a product have a global impact on the climate, the impacts related to water occur at the watershed level and are thus dependent on local conditions. This needs to be considered when water-related environmental impacts are assessed.

Water demand is increasing, and thus sustainable water management is required at local, regional, and even international levels. Even though water impacts are local, the global value chains of products may lead to impacts in many different countries and areas. Water usage may consume (quantity aspect) or degrade (quality aspect) water, and the impacts can be dependent on temporal and regional conditions. Potential environmental impacts related to water are assessed with water footprint calculations which are based on life cycle assessment. These should follow ISO standards 14046 “Environmental management—Water footprint—Principles, requirements and guidelines” and 14073 “Environmental management—Water footprint—Illustrative examples on how to apply ISO 14046”.

Water handprint calculations are based on water footprint assessments. The same calculation rules apply as described for the water footprint in ISO standards 14046 and 14073. Thus, a comprehensive water handprint assessment considers all environmentally relevant attributes or aspects of the natural environment, human health and resources related to water, including water availability and water degradation (ISO 14046). The handprint assessment starts with the goal and scope definition, followed by a water footprint inventory analysis, impact assessment and interpretation of the results of both solutions that are to be compared, i.e., the studied solution and the baseline solution. The impacts studied can include, for example, water availability, water scarcity, water eutrophication, water acidification, and water ecotoxicity footprints.

In this project, the concept of a water handprint was demonstrated as a water scarcity handprint (water quantity) and a water eutrophication handprint (water quality). A water scarcity handprint means that the water scarcity is improved in someone else’s value chain. The water quality handprint means that the water quality is improved in someone else’s value chain.

#### **3.1 Steps in the water handprint calculation**

Water handprint calculations are based on the water footprint calculations according to the water footprint standard ISO 14046. The stages and steps up to calculating the water handprint are discussed in the following.

##### **Define the scope of the studied solution**

The studied solution that potentially creates a water handprint and replaces the baseline solution should be accurately described.



## Identify potential handprint contributors

A water handprint aims to communicate positive changes related to water scarcity or water quality. If primary water consumption is reduced or fewer emissions into the water are released, a handprint may be created.

## Identify the environmental impacts in question and their potential indicators

Water usage can involve consumption or degradation. Water consumption considers water that is removed from a watershed by removing and then releasing the water into another watershed, by evaporation, or by removing water within a product. Degrading water use means that the quality of water is reduced due to water emissions. Water quality can be measured using typical water-related environmental impacts used in life cycle assessment, e.g. by measuring the acidification potential, eutrophication potential, or water toxicity potential. Consumptive water use is studied in the water scarcity handprint and water quality changes are studied in the water quality handprint.

## Identify the users and beneficiaries of the studied solution

Guidelines for identifying the customers as specified in the general guidelines apply. Users or beneficiaries are those who benefit from changes in water consumption or water quality.

## Define the baseline

Guidelines for defining the baseline as specified in the general guidelines apply.

## Define the functional unit

Guidelines for defining the functional unit as specified in the general guidelines apply.

## Define the system boundaries

Guidelines for defining the system boundaries as specified in the general guidelines apply.

## Define the data needs and sources

Guidelines for defining data needs as specified in the general guidelines apply.

## Calculate the footprints

Using equal functional units, the indicators over the life cycle of the two systems are calculated. Each indicator identified as relevant earlier, in defining the scope, are counted separately.

## Calculate the handprint

By comparing the footprints of the studied and baseline solutions indicator by indicator, it can be found whether the studied solution reduces the water volumes used or emission amounts released. The water handprint is not a single indicator. Consequently, controversial results, i.e., both positive and negative changes, may occur. In case a reduction is achieved in one indicator but there is an increase in another, the results must be communicated transparently.

## Identify the relevant indicators to be communicated

The communications should clearly indicate, which kind of water handprint is studied, as described for water footprint standard ISO 14046.

## Consider critical review of the handprint

The general guidelines apply.

## Communicate the results

The general guidelines apply.

### **3.2 Case study: water treatment technology**

This case study considers HyXo's water purification technology used in a water treatment plant in a mining company located in Northern Finland. Input water streams to the water treatment plant include water from underground mining, i.e., used drilling water and leaked groundwater, and drainage water from open mining. The technology and the water treatment plant were considered for the studied solution since the water could also be treated using wetlands. Water treatment in the wetlands was thus considered for the baseline solution. The framework of the study is described in Appendix A.

## Define the scope of the studied solution

The study considers water purification technology by the company HyXo used in a water treatment plant of a mining company called Sotkamo Silver.

## Identify potential handprint contributors

The studied technology removes impurities and nutrients from wastewater and enables the reuse of water and smaller emissions to receiving water bodies. The purified water from the water treatment plant can be used in enrichment processes of the mining company. This recycled water replaces the primary water intake. By removing solid matter, dissolved minerals/metals and nutrients, the water treatment technology affects the water emissions and thus can achieve a water quality handprint in several impact categories.

## Identify the environmental impacts in question and their potential indicators

The main aim of the technology is to remove solid matter and dissolved minerals from the incoming water before the water is released into the environment through the wetlands. In addition, a share of the output water from the water treatment plant can be used in the enrichment process, replacing the primary water intake from a surface water source. This is assessed as a water scarcity handprint calculation.

In addition, nitrogen removal technology removes nitrogen compounds, i.e., ammonium ions, nitrate, and nitrite from the wastewater. A quality handprint was demonstrated in this report as a change in the eutrophication potential as an example, achieved with the nitrogen removal technology. Other environmental impacts were not considered.

## Identify the users and beneficiaries of the studied solution

The customers of the water treatment technology are companies that have a water treatment plant with a need to remove solid matter, dissolved minerals, and nutrients from the wastewater. In the case example, a Finnish mining company Sotkamo Silver was the customer.

## Define the baseline

The water from the studied underground and open mining operations could be directed to wetlands directly. Thus, water treatment via the wetlands was considered as the baseline, even though the area of wetlands would need to be increased with the planned/increased mining capacity in the near future. In practice, wetlands are not considered a water purification technology, so they are sufficient only if the area is large enough for the water treatment needs. Additional treatment processes might be needed. For the quality assessment, estimations on environmental permits for nitrogen emissions for similar sized mines were treated as a baseline (Aluehallintavirasto 2014a, 2014b and 2020).

## Define the functional unit

Since the water streams from the mines and the activity and purification potential of the wetlands depend on the season and outside temperature, the functional unit was chosen to represent the water amounts treated within a year (12 months) to represent average results achieved with the technology.

## Define the system boundaries

The system boundaries of the water scarcity handprint included all water streams related to the water treatment plant and the primary water stream related to the enrichment processes. Water consumed in the production of the water chemicals is included within the system boundaries. The mining operations, the enrichment process, and the leachates from other areas of the mining company were excluded.

For the water quality handprint, the system boundaries were expanded to include mining operations, wetlands, and the treatment of the sludge from the water treatment plant, since they might affect the water emissions unlike the water consumption as such.

### Define data needs and sources

For the water scarcity handprint, water consumption volumes were needed for all unit processes within the system boundaries. The water streams of the mining operations were collected from the environmental permit document of the mining company, which also stated the amounts of water treatment chemicals used per year. The environmental permits guide the water purification actions of companies and are thus a reliable and comprehensive source of documents for water-related data. The water consumption during the production of chemicals was taken from the Ecoinvent database. In addition, the scarcity factors for each water consumption location are needed. These factors are provided as the AWaRe (Available Water Remaining) methodology by Boulay et al. (2018).

A comprehensive water quality handprint calculation would require more data than just the water scarcity calculations. Several water quality measurements would be needed for water input and output streams of the water treatment plant to consider possible seasonal differences in the water streams and water treatment plant operations. Additionally, measurements would be needed for input and output waters of wetlands without a water treatment plant (baseline solution) and with the water treatment plant (studied solution). These measurements should also represent the average behaviour of the wetlands, i.e., the seasonal variation should be considered. In addition, the sludge from the water treatment plant needs to be treated, and the water emissions related to that should be considered. This is difficult in practice, however, since the water treatment sludge is treated together with the sand from the enrichment processes in the mining company. However, to demonstrate the quality handprint, the eutrophication potential was considered in this study.

The values used in the calculations were based on estimations on environmental permits for nitrogen emissions for similar sized mines and on the efficiency of removing nitrogen from wastewater using a biological water treatment plant. It was assumed that in the studied solution, all the wastewater would be biologically treated to remove as much nitrogen as possible with the highest purification efficiency. Thus, the calculation does not necessarily represent a real situation but the highest possible potential to create a handprint.

### Quantification: Calculate the footprints and the handprint

#### **Water scarcity footprints**

In the baseline solution, no water is circulated from the mining operations for enrichment, since there is no water treatment plant. The amount of water from the primary source is 35m<sup>3</sup>/h. The amount of water consumed in the mining company

and the local scarcity factor from the AWaRe were multiplied to calculate the baseline solution water scarcity footprint. The water scarcity footprint of the baseline solution is 275,940 m<sup>3</sup>-world eq. / year.

In the studied solution, 12 m<sup>3</sup>/h water from the treatment plant is circulated for enrichment, while 23 m<sup>3</sup>/h water is supplied from the primary source. Primary water consumption in the mining company and the production of water treatment chemicals were considered. The amount of water consumed in each location and local scarcity factors from the AWaRe were multiplied to calculate the water scarcity footprint of the studied solution. The water scarcity footprint of the studied solution was 181,693 m<sup>3</sup>-world eq. / year.

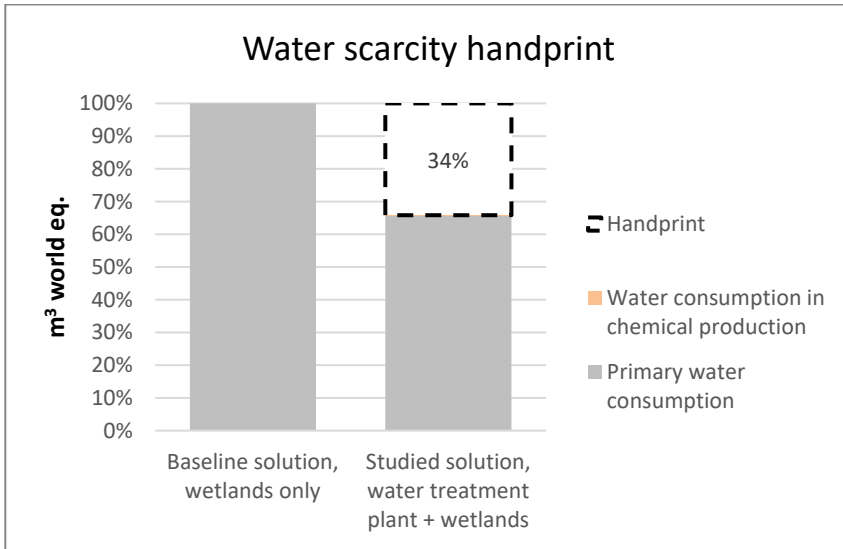
### **Water quality footprints**

In the baseline solution, nitrogen compounds are only removed by the biogenic activity occurring at the wetlands. The removal efficiency is strongly dependent on the weather conditions such as the outside temperature, but according to the field measurements, the wetlands removed approximately 87% of the NH<sub>3</sub>-N and 3% of NO<sub>2</sub>+NO<sub>3</sub>-N (Source: Sotkamo Silver). The estimated baseline is 7,000 kg N emissions and 40 kg P emissions per year, which are converted to PO<sub>4</sub><sup>3-</sup> eq. with the CML 2001 general eutrophication impact factors. The water quality footprint of the baseline solution is thus 730 kg PO<sub>4</sub><sup>3-</sup> eq. / year.

In the studied solution, nitrogen is removed after the water treatment plant in a biogenic water treatment process before directing the wastewater to the wetlands. The removal efficiency of the process is c. 75% NH<sub>4</sub>-N and c. 78% NO<sub>2</sub>+NO<sub>3</sub>-N (Kilpeläinen 2020). When this is combined with the wetlands nitrogen removal, the water quality footprint of the studied solution is c. 270 kg PO<sub>4</sub><sup>3-</sup> eq. / year.

### **Water scarcity handprint**

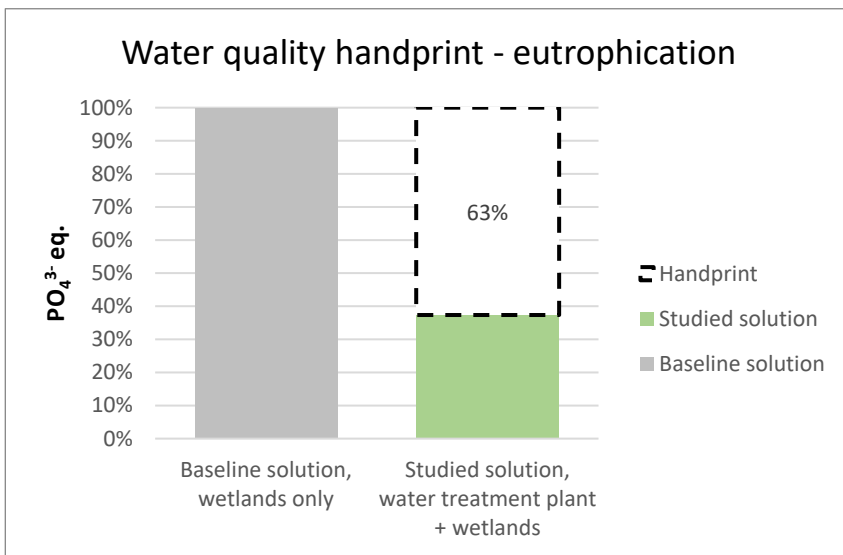
The water scarcity handprint is 94,247 m<sup>3</sup> world eq. / year, meaning 34% of the water demand. The results are also presented in **Figure 4** below.



**Figure 4.** Water scarcity handprint of the HyXo technology.

**Water quality handprint**

The water quality handprint is 460 kg PO<sub>4</sub><sup>3-</sup> eq. / year, meaning a 63% reduction of the eutrophication potential. The results are also presented in **Figure 5** below.



**Figure 5.** Water quality handprint of the HyXo technology in terms of the eutrophication potential.

### Identify the relevant indicators to be communicated

The water scarcity and water quality in terms of the eutrophication potential may be communicated.

### Consider critical review of the handprint

A critical review was not conducted, as this case was done for the purpose of developing the water handprint approach.

### Communicate the results

The results should be communicated respecting the appropriateness, clarity, credibility, and transparency. Water scarcity was communicated in terms of the world  $m^3$  eq./year, and the eutrophication potential in terms of the  $kg PO_4^{3-}$  eq.

## 4. Nutrient handprint

Nutrients, such as nitrogen (N), phosphorus (P) and potassium (K) are key elements of agricultural activities and the global food system. However, they are currently not managed sustainably. Vast quantities of nutrients are lost from the nutrient cycle and are no longer available for human exploitation. Simultaneously, the demand for virgin nutrients is increasing.

Rockström et al. stated in 2009 that the conversion of atmospheric N<sub>2</sub> to reactive nitrogen and the loss of phosphorus from the nutrient cycle are beyond or close, respectively, to the safe planetary boundary (Rockström et al. 2009). Further, in their revisited planetary boundaries, Steffen et al. (2015) stated that anthropogenic interference with the nutrient cycles is well beyond the safe limits, including both the biological fixation of nitrogen on an industrial scale and phosphorus flows from freshwater systems into the oceans (globally) and from fertilizers to erodible soils (regionally) (Steffen et al. 2015).

The inefficient use of nutrients, and consequent nutrient losses into the environment lead to increasing demand for virgin nutrient resources. Sutton et al. (2013) estimate an average 80% loss of consumed N and 25-75% loss of consumed P nutrients into the environment. Lost nutrients (no longer available for controlled human use for example in food production) cause detrimental impacts in the receiving environment. Losses occur into water bodies via, for example, wastewater flows or fresh irrigation water leakages from the fields, or into the atmosphere from biological nitrification-denitrification (ND) processes or combustion processes or into the soil. The environmental impacts of nutrients include eutrophication etc.

There are two aspects of nutrient use that can be considered in environmental sustainability assessments: one is related to resource-efficient nutrient use and one is related to the environmental impacts of nutrient flows.

The nutrient footprint has been previously defined by Grönman et al. (2016) and Ypyä et al. (2015). They defined the nutrient footprint of a production chain through nutrient inputs and outputs in the production chain, further dividing inputs into virgin and recycled nutrients and outputs into losses and nutrients further utilized. They recommended nitrogen and phosphorus footprints to be defined separately due to the different behaviour of N and P in soil-plant-animal systems. Such a mass-balance-based nutrient footprint could be combined with an assessment of the eutrophication impacts to obtain a more comprehensive picture of nutrient use. However, eutrophication impacts as such are not included in the nutrient footprint. (Grönman et al. 2016.) In contrast, the work on the nitrogen footprint, initiated by Leach et al. (2012), highlights the importance of the environmental impacts of nutrient (in their case, reactive nitrogen) emissions.

The following nutrient handprint methodology is based on the work by Grönman et al. (2016) and Ypyä et al. (2015), complemented with an environmental impact assessment. The nutrient handprint aims to highlight the positive impacts that can be achieved in nutrient cycles and the environmental impacts of nutrient emissions through novel solutions provided to customers. The following section specifies the



guidance for quantifying a nutrient handprint in general. The guidance is based on two case studies. The case studies, based on the circular economy principles and industrial symbioses, demonstrate how a nitrogen nutrient handprint could be generated.

## **4.1 Steps in the nutrient handprint calculation**

The stages and steps in calculating the nutrient handprint are discussed in this section.

### Define the scope of the studied solution

The studied solution potentially creating a nutrient handprint and replacing the baseline solution should be accurately described.

### Identify potential nutrient handprint contributors

Mechanisms that improve the use efficiency of nutrient resources or change the quality of nutrient inputs or outputs may contribute to creating a nutrient handprint and should be identified. Improvements can be made on the input and/or output side. Contributors, for example, increase the use of recycled nutrients, reduce the use of virgin nutrients, and enhance nutrient recycling or reduce nutrient losses in the system under consideration. Nutrient cycles can be positively affected, for example, by introducing novel sources of recycled nutrients and novel output nutrient utilization opportunities that contribute to creating a circular economy. Technologies that help to optimize nutrient use (e.g. as fertilizers) and to reduce nutrient consumption could also be handprint contributors. Solutions that reduce or prevent nutrient emissions to the environment also help reducing their environmental impacts.

### Identify the environmental impacts in question and their potential indicators

It should be specified, which nutrient is under consideration, for example, nitrogen, phosphorus, or potassium. A quantifier should be used to identify, which nutrient handprint is under consideration: for example, a nitrogen nutrient handprint.

A nutrient handprint assessment always includes an assessment of changes in the nutrient balance of the system. The nutrient balance includes virgin and recycled nutrient inputs and nutrient outputs lost from the nutrient cycle or continuing in the nutrient cycle. A nutrient handprint assessment also always includes an assessment of changes in the eutrophication potential of the system. In addition, other potentially relevant environmental impact indicators, such as the acidification potential, should be defined. Other indicators may be locally important or related to specific nutrients.

## Identify the users and beneficiaries of the studied solution

Guidelines for identifying the users as specified in the general guidelines apply. Users or beneficiaries are those who benefit from changes in nutrient cycles, such as replacing virgin nutrients by recycled nutrients or reducing nutrient losses. There may be also additional parties that benefit from the studied solution.

## Define the baseline

Guidelines for defining the baseline as specified in the general guidelines apply.

## Define the functional unit

Guidelines for defining the functional unit as specified in the general guidelines apply.

## Define the system boundaries

At least the unit processes of the user and product or service provider must be included. Modelling the fate of nutrients and responsible nutrient use may require wide system boundaries. The system boundaries can be set, for example, between unit processes under human control and the natural environment. Modelling the conversion and fate of nutrients further in the environment is a complicated issue, which may or may not be included within the system boundaries according to the purpose of the study.

System expansion may be required when quantifying the nutrient handprint. If it is assumed that a nutrient handprint can be achieved by replacing virgin nutrients by recycled nutrients, alternative uses of the recycled nutrients must be included in the baseline solution to make sure there are no superior alternative uses for the recycled nutrients. And vice versa, when the total nutrient inputs can be reduced by replacing some recycled nutrients with virgin nutrients, it is acceptable if superior uses for the recycled nutrients exist.

## Define data needs and sources

Nutrient flows often vary in time, so it is recommended that a certain year is selected and nutrient data throughout the year is collected. Temporal variations in nutrient flows represent a major uncertainty in the results if the time range is not sufficiently long, taking into account possible variations. In case of changes in data (for example, due to process changes), the nutrient handprint needs to be recalculated.

## Calculate the nutrient footprints

The nutrient footprint consists of the nutrient footprint profile, which is a compilation of indicator values that always includes the four nutrient balance indicators (virgin and recycled inputs, lost and continuing outputs) and the eutrophication potential in the baseline and studied solution. Optionally, the nutrient footprint further includes other environmental impact indicator values if they are relevant to the specific case.

## Calculate the nutrient handprint

Because the nutrient footprint profile comprises several indicators, a wide combination of changes in the indicator values in the baseline and studied solution is possible, and the changes may seem controversial. Therefore, clear criteria describing in which cases a nutrient handprint can be created and what determines the magnitude of the nutrient handprint is required.

A nutrient handprint can be created if one or more nutrient handprint criteria are fulfilled and preconditions are met. The nutrient handprint criteria are related to the nutrient balance indicators. Those of the three handprint criteria that are fulfilled, determine the magnitude of the nutrient handprint if additional preconditions are also met. The magnitude of the nutrient handprint is calculated from the differences between the baseline and the studied solution for those nutrient balance indicators that fulfill the nutrient handprint criteria.

Nutrient handprint criteria:

1. Less total nutrient inputs (virgin + recycled) are required in the studied solution than baseline solution.
2. Virgin nutrient inputs are reduced in the studied solution in comparison to the baseline solution.
3. The ratio of nutrient outputs that continue in the nutrient cycle to nutrient outputs lost from the nutrient cycle must be larger in the studied solution than baseline solution.

Additional preconditions:

- Input preconditions
  - If the output criterion (3) is fulfilled, the input situation must not get worse in the studied solution than baseline solution.
  - When replacing virgin nutrients with recycled nutrients, there must not be superior alternative uses for the recycled nutrients.
  - When reducing the total nutrient inputs by replacing recycled nutrients with virgin nutrients, there must be superior alternative uses for the recycled nutrients.
- Output preconditions
  - If input criteria (1 and/or 2) are fulfilled, the output situation must not get worse in the studied solution than the baseline solution.
  - When nutrient outputs that continue in the nutrient cycle decrease in the studied solution in comparison to the baseline solution, the ratio of the continuing nutrient outputs to lost nutrient outputs must be at least equal in the studied solution as in the baseline solution.
- The eutrophication potential must not increase in the studied solution in comparison to the baseline solution.
- Other environmental impacts (if relevant) must not increase in the studied solution in comparison to the baseline solution.

## Identify the relevant indicators to be communicated

In addition to the magnitude of the nutrient handprint based on handprint criteria-fulfilling changes in the nutrient balance, changes in the whole nutrient balance must be transparently included in communications, as well as information about fulfilled preconditions and changes in the eutrophication potential, and, if relevant, changes in other environmental impact indicators in the baseline and studied solution.

The communications should clearly indicate, which nutrient handprint criteria are fulfilled, and which changes in the nutrient balance, thus, contribute to the magnitude of the nutrient handprint. In addition, the communications should clearly state, which nutrient handprint preconditions are fulfilled, and thus, enable nutrient handprint creation.

## Consider critical review of the nutrient handprint

The general guidelines apply.

## Communicate the results

The general guidelines apply.

## **4.2 Case study: recycled nutrient product**

The case study examined nutrient flows in a system where a recycled nutrient product from Gasum was used in a pulp and paper mill wastewater treatment plant (WWTP). The case study was conducted to support the development of the nutrient handprint method. Gasum produces biogas through anaerobic digestion from biodegradable waste. In addition to biogas, the process also generates a nutrient-rich digestate, which can be re-processed into nutrient products. In this case study, ammonia water was used in the calculations as a nutrient product. Production of ammonia water requires centrifugation of the digestate to remove water, and additionally, an evaporation and stripping process must be conducted to concentrate the nutrients in final product. Ammonia water is high in nitrogen (N) and can be used in activated WWTP sludge as a supplementary form of nitrogen instead of virgin urea. The customer in this case was the WWTP at UPM Kaukas in Lappeenranta, where virgin urea is traditionally added to wastewater for a sufficient concentration of nitrogen to maintain proper microbial activity. In this case study the use of ammonia water in the WWTP was compared to the use of synthetic urea.

## Define the scope of the studied solution

The studied solution was the recycled nutrient product, ammonia water, produced in the Gasum biogas plant.

## Identify potential nutrient handprint contributors

Gasum reduces the nutrient N footprint of pulp and paper mills by offering a recycled nitrogen product (ammonia water) for the wastewater treatment process. Recycled nitrogen substitutes virgin urea.

## Identify the environmental impacts in question and their potential indicators

Nitrogen (N) was identified as a relevant nutrient in this case study because the UPM WWTP needs to add nitrogen to the process. Other nutrients were excluded.

As stated in the nutrient handprint guidelines previously, the nutrient handprint assessment includes a calculation of changes in the nutrient balance of the system, that is to say, quantifying virgin and recycled input nutrients, nutrients continuing in the nutrient cycle and nutrients lost from the nutrient cycle. Additionally, an assessment of changes in the eutrophication potential of the system must be included in the calculation. In this case, also the carbon handprint was identified as a relevant indicator, because the production of urea is highly energy intensive.

## Identify the users and beneficiaries of the studied solution

Ammonia water can be used in forest industry wastewater treatment as a supplementary form of nitrogen instead of virgin urea. The customer in this case was the WWTP at UPM Kaukas pulp and paper mill, which is an activated sludge WWTP. At the UPM mill the wastewater contains a sufficient concentration of phosphorus but additional nitrogen is needed to add to ensure optimal microbial activity.

## Defining the baseline

The use of urea at UPM Kaukas WWTP was used as a baseline solution. Virgin urea is produced with the Haber-Bosch process, which is an industrial nitrogen fixation process. The process converts atmospheric nitrogen ( $N_2$ ) to ammonia ( $NH_3$ ) from a reaction with hydrogen ( $H_2$ ). Ammonia and carbon dioxide then react under high temperature and pressure to form urea (Modak 2011). The urea can be used as an additive form of nitrogen in a WWTP plant.

## Define the functional unit

In this study the functional unit of wastewater treated per day in the UPM Kaukas WWTP was used. This corresponds to 94,846  $m^3$  of wastewater per day. The required amount of supplementary nitrogen in the WWTP is 447 kg per day. The units used in the calculations were  $kg_N/d$  for the nitrogen balance indicators, kg phosphate equivalents/d for the eutrophication potential and  $kgCO_2$  equivalents for the carbon handprint.

## Define the system boundaries

The system boundaries include the production of synthetic urea, processing of digestate and reject water in Gasum to produce ammonia water, UPM Kaukas WWTP processes and the combustion of sludge from WWT in the combined heat and power (CHP) plant. The transportation of urea and ammonia water was included in the eutrophication potential and carbon handprint calculations. The eutrophication potential was calculated up to the gate of the UPM plant.

Biogas production has been excluded from the calculation because digestate from biogas production was identified as waste and consequently, no emissions are allocated to the input digestate. In addition to ammonia water, Gasum has a biogas plant that produces nutrient-rich dry matter from a centrifugation process and nutrient concentrate, which is rich in nitrogen and phosphorus (NP concentrate). In the calculations, the nitrogen flows in the studied solution were allocated between these three products based on the nitrogen mass flows.

The system boundaries are illustrated in **Figure 6**. Blue arrows indicate recycled nitrogen inputs, the nutrient content of which is taken into further use and human exploitation (Grönman et al. 2016) and the purple arrow indicates virgin nitrogen input into the system. Red arrows indicate nitrogen flows that are lost from the nutrient cycle. Lost nitrogen means those nitrogen flows that are lost into the environment as emissions or through incineration/landfilling and that are no longer directly available for human exploitation (Ypyä et al. 2015; Grönman et al. 2016). The green arrow indicates a nitrogen flow that continues in the nutrient cycle: nitrogen in the soil produced by the composting facility is further used by humans. The system boundaries are set so that they show where nitrogen first enters the environment from the industrial processes. Further nitrogen pathways into the environment are not taken into account. Yellow arrows indicate intermediate nitrogen flows between the processes that are inside the system boundaries.

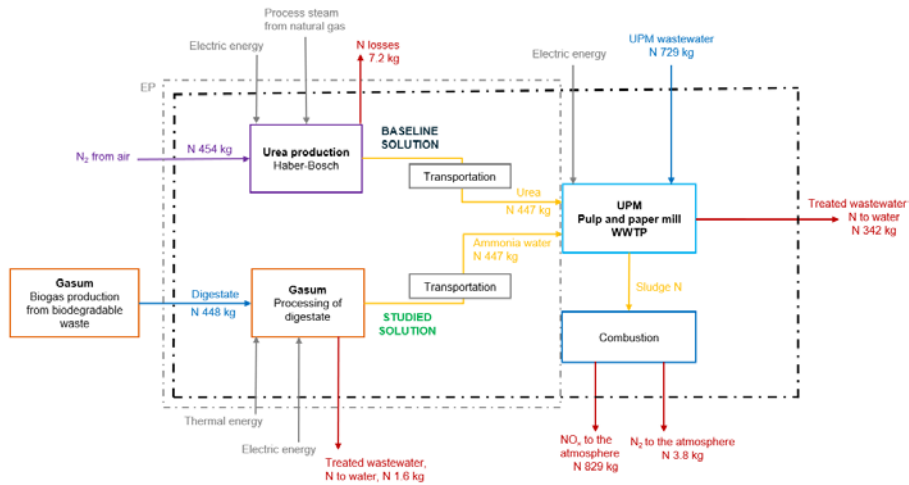


Figure 6. System boundaries.

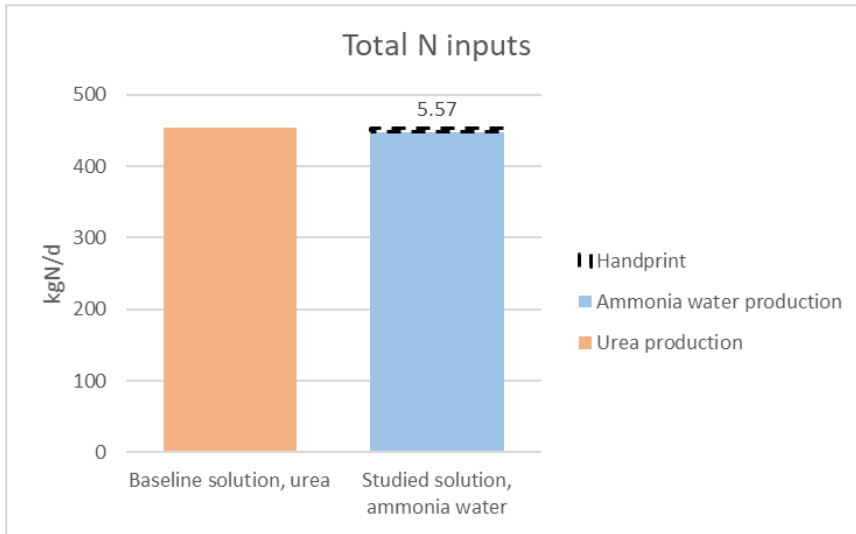
## Define data needs and sources

The data needed for the calculation consists of the Gasum digestate treatment processes, the UPM WWTP, urea production, the means of transport, and the transportation distances of ammonia water and urea. Gasum and UPM provided primary data from their own processes. Secondary data from the GaBi database was used to model the production of urea. For the eutrophication potential (EP), CML 2001 and for the carbon handprint calculation GWP100 characterization factors were used.

The primary data concerning ammonia water from Gasum was from years 2019 and 2020 and it was derived from their Turku biogas plant. The data also contained some estimated values for the biogas plant production after undergoing an extension. Primary data from UPM on sludge combustion and composting were from 2017–2019. Although there was some temporal incoherency in the data and not all the values were exact, the data quality was estimated to be adequate for the case study calculation and method development.

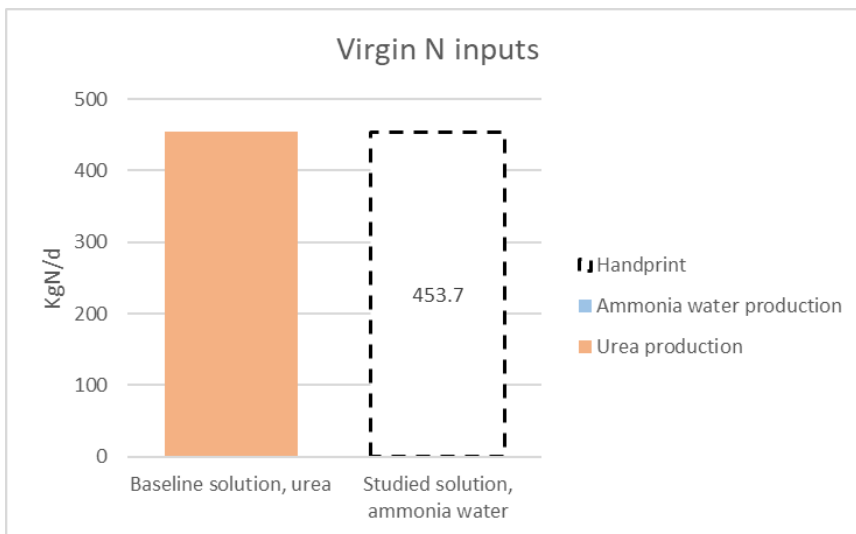
## Quantification: Calculate the footprints and the handprint

**Figure 7** represents the total nitrogen input to the baseline and the studied solutions in kilograms of nitrogen per wastewater treated in a day at the UPM WWTP (94,846  $m^3$ ). In the baseline solution 453.7 kg of nitrogen was needed to produce required amount of urea to fulfil the need for nitrogen in the UPM WWTP, whereas in the studied solution 448.2 kg of nitrogen was used. The total nitrogen input was reduced by 5.57  $kg_N/d$  in the studied solution compared to the baseline solution. This reduction fulfils the first input nutrient handprint criterion.



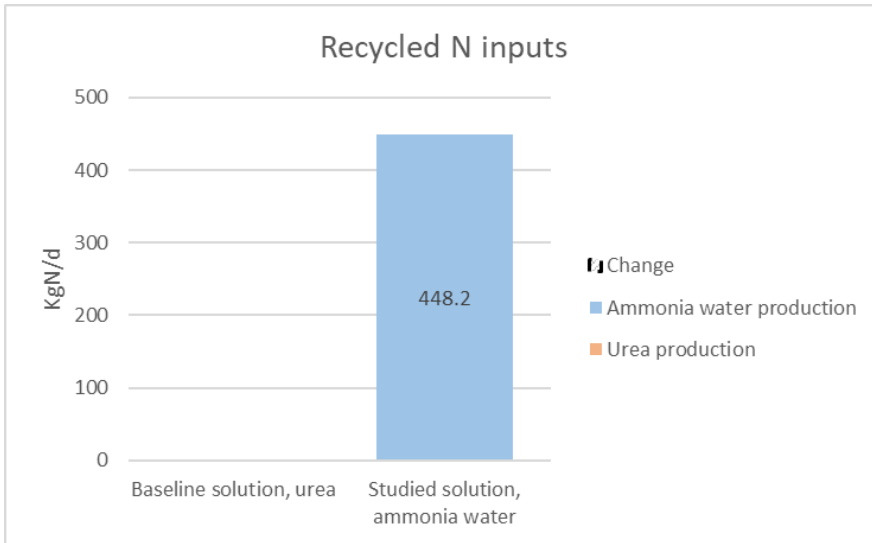
**Figure 7.** Total N inputs in the baseline and studied solution.

Virgin and recycled nitrogen inputs are illustrated in **Figures 8 and 9**. In the baseline solution all the input nitrogen used in the urea production is virgin, whereas in the studied solution only recycled nitrogen is used to produce ammonia water. Consequently, the reduction in virgin nitrogen input is 453.7 kg/d in the studied solution when compared to the baseline solution and the second input nutrient handprint criterion is fulfilled.



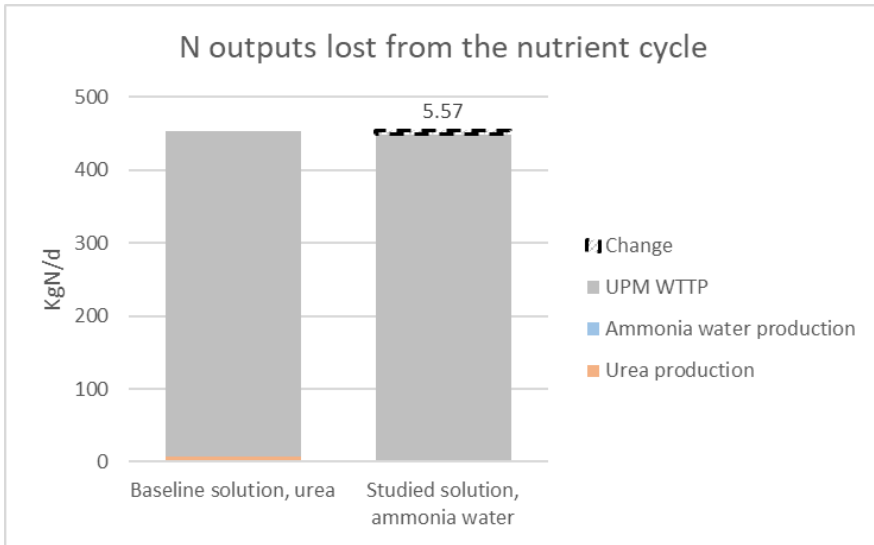
**Figure 8.** Virgin nitrogen inputs in the baseline and the studied solutions.





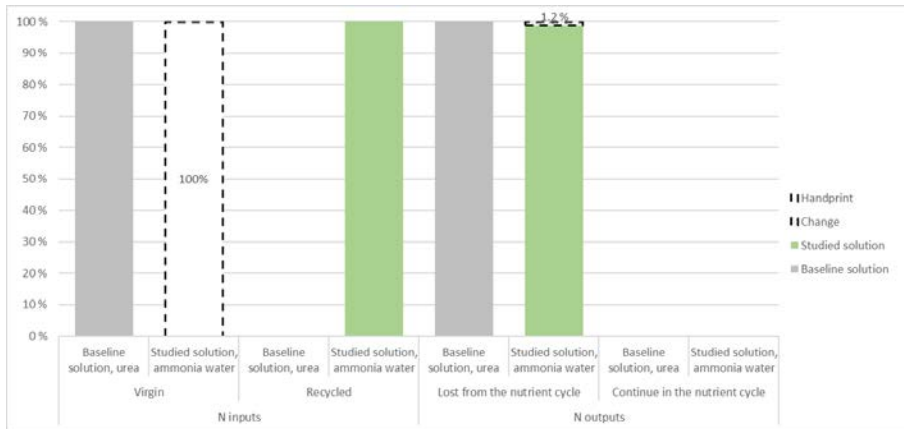
**Figure 9.** Recycled N inputs in the baseline and the studied solutions.

As stated earlier, the total amount of input nitrogen was lower in the studied solution compared to the baseline solution, and hence, also the nitrogen lost from the nutrient cycle was lower in the studied solution than in the baseline solution. In total, in the baseline solution 5.57 kgN/d less nitrogen was lost when compared to the baseline solution. In both solutions all of the input nitrogen was lost from the nutrient cycle. However, as illustrated in **Figure 10**, almost all the losses were due to wastewater treatment process.



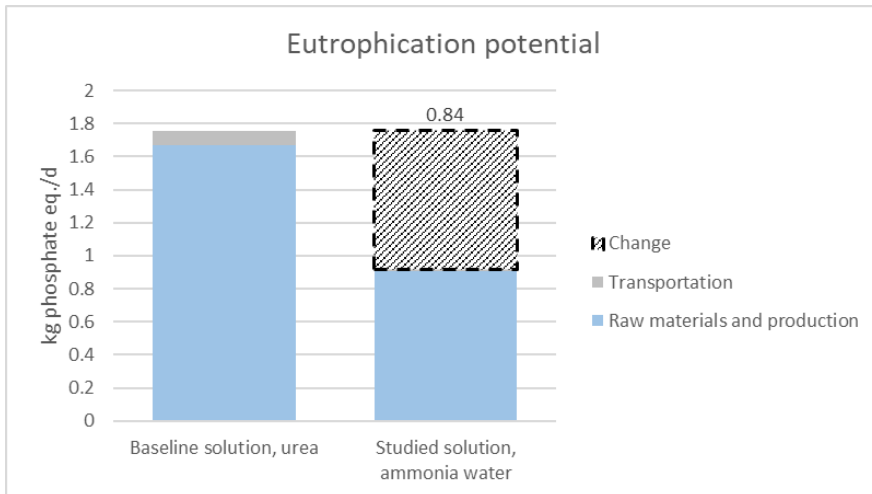
**Figure 10.** Nitrogen outputs in the baseline and the studied solutions.

**Figure 11** represents the total nitrogen balance in percentages. In the baseline solution all the nitrogen used in urea production is atmospheric nitrogen ( $N_2$ ), which has been converted to a more reactive form ( $Nr$ ) and can be considered a virgin nutrient. In contrast, in the studied solution all the input nitrogen is recycled. In both solutions all the nitrogen is lost from the nutrient cycle, but in the studied solution 1.2% less nitrogen is lost due to lower amount of input nitrogen.



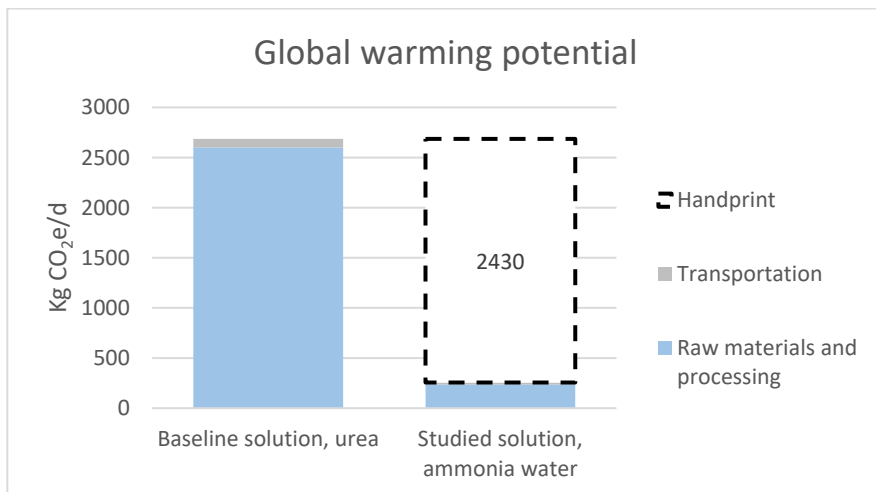
**Figure 11.** Total nitrogen balance in the baseline and the studied solutions.

The eutrophication potential of the baseline and the studied solutions are presented in **Figure 12** for different life-cycle stages. The eutrophication potential in the baseline solution is 1.76 kg/d and in the studied solution it is 0.92 kg/d. Raw material acquisition and production make up most of the eutrophication potential in both solutions, whereas the share of transportation is proportionally low.



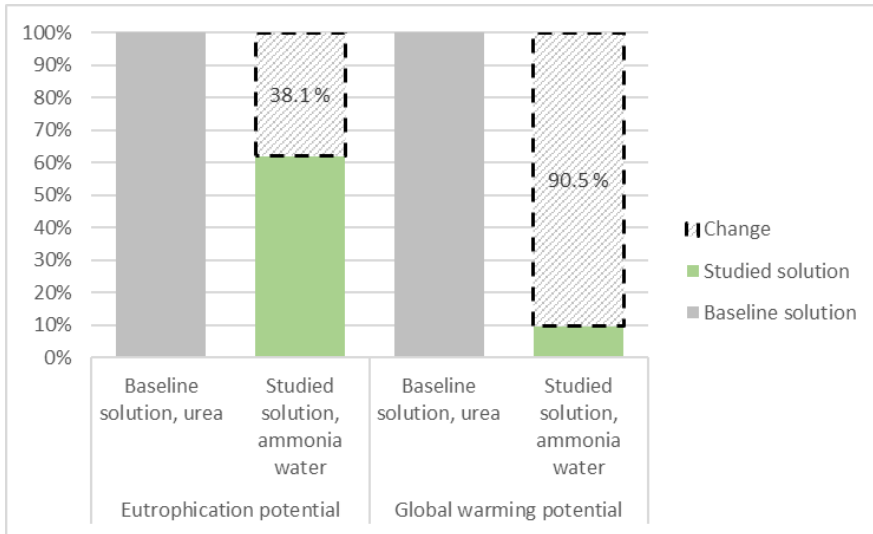
**Figure 12.** Eutrophication potential of the baseline and the studied solutions for each process.

The carbon handprint was identified as a relevant indicator in this case even though it does not affect nutrient handprint creation. The carbon footprints of urea and ammonia water were calculated using GaBi software. The carbon footprints of urea and ammonia water were divided into different life cycle stages, which are shown in **Figure 13**. The functional unit in both cases is the wastewater treated per day in the UPM WWTP. The carbon footprint for urea is 2,686 kg CO<sub>2</sub>e/d and for ammonia water 256 kg CO<sub>2</sub>e/d. Thus, the global warming potential for the studied solution is 2,430 kg CO<sub>2</sub>e/d lower than in the baseline solution.



**Figure 13.** Carbon footprints and the carbon handprint of the baseline and the studied solutions for each process.

In the nutrient handprint calculation, the eutrophication potential is a precondition for the handprint creation. That is to say, the eutrophication potential is not permitted to increase in the studied solution in comparison to the baseline solution. In this case, the global warming potential was also identified as a relevant indicator and hence, it should be lower in the studied solution than in the baseline solution to fulfil handprint preconditions. In **Figure 14** the eutrophication potential and global warming potential are represented as percentages. The eutrophication potential is 38.1% lower and the global warming potential is 90.5% lower in the studied solution than in the baseline solution. This fulfils the environmental impact preconditions for the nutrient handprint calculation.



**Figure 14.** Eutrophication potential and global warming potential of the baseline and the studied solutions.

The case study examined whether a nutrient handprint would be created when virgin urea was replaced by recycled nitrogen nutrient. According to the nitrogen balance calculations, in total, fewer nutrient inputs are required in the studied solution than in the baseline solution. In addition, in the studied solution only recycled nitrogen is used as an input, whereas in the baseline solution all the input nitrogen is virgin. However, in neither solution do any nutrients continue in the cycle, but as the nutrient handprint criterion states, a handprint can be still created if other criteria are fulfilled. The eutrophication potential and carbon handprint are lower in the studied solution than in the baseline solutions, which also supports handprint creation. In summary, the nutrient handprint prerequisites are fulfilled in Case 1 and a nutrient handprint has been created.

In Case 1 the magnitude of the nitrogen handprint can be derived from the amount of replaced virgin nutrients and the change in the total requirement for nitrogen. In the studied solution virgin nitrogen is replaced 100% by recycled urea or in kilograms, 454kg less virgin N is needed. In addition, in the studied solution 1.2% or 5.6kg less input nitrogen is needed compared to the baseline solution.

#### Identify the relevant indicators to be communicated

The general guidelines of the nutrient handprint apply and have been demonstrated above.

## Consider critical review of the nutrient handprint

A critical review was not conducted, as this case was done for the purpose of developing the nutrient handprint approach.

## Communicate the results

The general guidelines apply. In addition, suitable communication units include kgN/d for changes in the N balance, kg phosphate equivalents/d for the eutrophication potential, kg CO<sub>2</sub> equivalents/d for the carbon handprint and all changes in %.

### **4.3 Case study: wastewater treatment service**

The nutrient handprint method development was supported by a further case study from a different perspective. In contrast to the case study in Section 4.2, the wastewater treatment plant (WWTP) of UPM Kaukas pulp and paper mill is in this case not the customer but provides the studied solution, i.e. a wastewater treatment service.

The UPM Kaukas WWTP is an activated sludge WWTP. UPM's wastewater treatment process consists of wastewater pre-treatment, flow equalization, primary sedimentation, a two-phase aeration process, secondary sedimentation, and sludge thickening and mixing. The core of the activated sludge process is biological treatment, driven by microbes and aeration, followed by a sedimentation tank, in which the activated sludge is separated from the wastewater effluent by gravitational settling. Part of the settled activated sludge, which consists mostly of microbial biomass, is removed from the process as excess sludge and part is returned to the aeration process to ensure process functionality. Furthermore, a sufficient nutrient concentration in the wastewater is required for the aeration. The phosphorus content of UPM Kaukas wastewater is sufficient to maintain optimal microbial activity, but in contrast, nitrogen needs to be added to the wastewater at this stage. Conventionally, UPM has used synthetic urea to cover the nitrogen requirement. However, UPM has been searching for alternative, recycled nitrogen sources to the WWTP and found one potential source from a local composting plant.

The local composting plant produces wastewater that requires treatment at a WWTP before it can be released into the environment and that is also rich in nitrogen nutrient suitable for the WWTP process. In this case, the local composting plant is the customer that uses the wastewater treatment service of UPM instead of a service provided by a municipal WWTP that does not require nitrogen nutrient addition. In comparison to the case study in Section 4.2, the role of UPM WWTP changes in the current case study. In Section 4.2, Gasum provided the studied solution, a recycled nutrient product, to UPM WWTP as its customer, whereas in this case study, UPM WWTP provides a wastewater treatment service to the local composting plant, creating a solution that should benefit both parties. Gasum is not included in this case study.

## Define the scope of the studied solution

The studied solution is the wastewater treatment service at UPM WWTP.

## Identify potential nutrient handprint contributors

The main contributor to the nutrient handprint is that UPM is able to utilize the composting plant wastewater in its own process, replacing virgin nitrogen input, whereas the wastewater would burden the baseline old municipal WWTP that already operates at its maximum capacity. Thereby, UPM offers a more responsible solution for treating the wastewater for the customer, the composting plant.

## Identify the environmental impacts in question and their potential indicators

The case study is limited to nitrogen. Other nutrients, such as phosphorus, are excluded. This case study considers the impacts on nitrogen resources at the inventory level. That is, the nitrogen balance of the system, including recycled and virgin nitrogen inputs and nitrogen outputs continuing in or lost from the nutrient cycle, were considered. Furthermore, the eutrophication potential was used as an environmental impact indicator, while other environmental impacts were excluded.

## Identify the users and beneficiaries of the studied solution

The case study focused on an actual customer of UPM: a local composting facility that produces nitrogen-rich wastewater. The nitrogen-rich wastewater originates from the composting process, in which the ammonia content of composting exhaust gases is removed by exhaust gas washers, creating wastewater rich in ammonium sulphate. Currently, the exhaust gas washer wastewater is considered as waste, not a valuable material for the composting facility. It must be treated at a wastewater treatment plant before release into the environment. UPM aims to offer a more sustainable way for its customer to treat the wastewater than the municipal wastewater treatment plant. UPM itself benefits from the nitrogen-rich composting wastewater, which reduces the need for urea input into its treatment process. The studied solution also benefits the municipal WWTP, where nitrogen loading is reduced.

## Define the baseline

In the baseline solution the exhaust gas washer wastewater from the composting plant was treated at the municipal WWTP.

## Define the functional unit

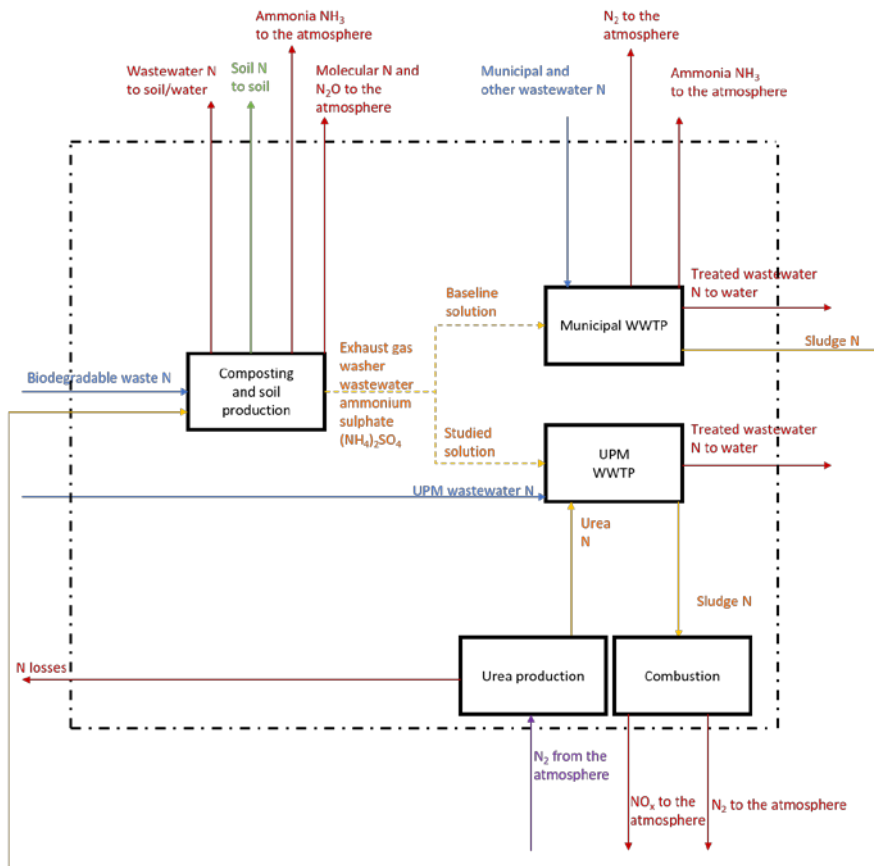
The calculations are conducted in kg<sub>N</sub>/d and kg phosphate equivalents/d. The function is to treat the daily exhaust gas washer wastewater production at the composting facility. The composting plant produces 8.64 m<sup>3</sup> of exhaust gas washer wastewater daily and the wastewater contains 155.52 kg of nitrogen.

## Define the system boundaries

The system boundaries include the composting facility and its soil production, the municipal WWTP, the UPM WWTP, urea production and the combustion process, which treats UPM's sludge and is located at the same industrial site as UPM. System expansion included both the municipal and UPM WWTPs in both the baseline and the studied solution.

**Figure 15** shows the system boundaries. Blue arrows indicate recycled nitrogen inputs, the nutrient content of which is taken into further use and for human exploitation (Grönman et al. 2016) and the purple arrow shows virgin nitrogen input into the system. Red arrows indicate nitrogen flows that are lost from the nutrient cycle. Lost nitrogen means those nitrogen flows that are lost into the environment as emissions or through incineration/landfilling and that are no longer directly available for human exploitation (Ypyä et al. 2015; Grönman et al. 2016). The green arrow indicates a nitrogen flow that continues in the nutrient cycle: nitrogen in the soil produced by the composting facility is further used by humans. The further fate and conversion of nitrogen in the environment is excluded. Yellow arrows indicate intermediate nitrogen flows between the processes that are within the system boundaries.





**Figure 15.** System boundaries (WWTP = wastewater treatment plant).

### Define data needs and sources

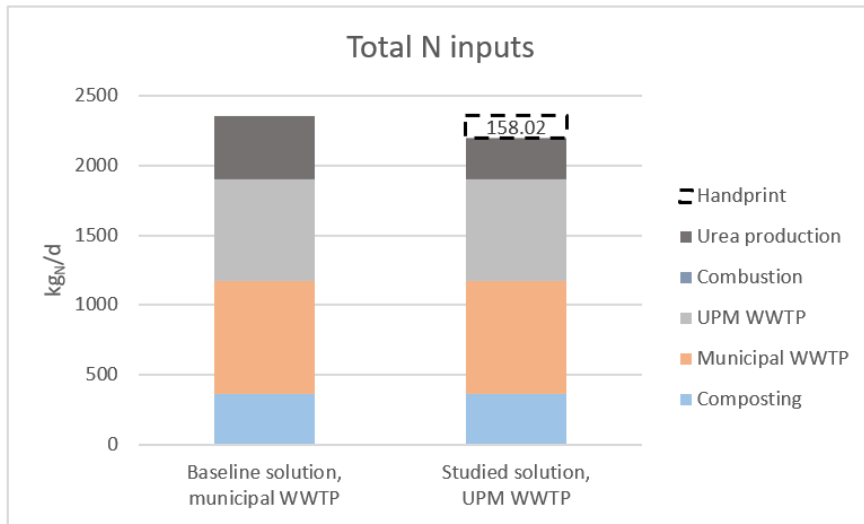
Data from the composting, municipal WWTP, UPM WWTP, urea production and combustion plant were required. UPM provided primary data from its own process, as well as for the combustion process and from the composting process as for those aspects relevant for UPM. Additional primary data was received directly from the composting facility. Secondary data from the literature, mainly environmental permit documents, were used for the municipal WWTP. The urea production was based on processes available in the LCA software GaBi. Furthermore, research reports provided additional supporting secondary data for modelling all of the processes.

Due to different primary and secondary data sources, data was not temporally coherent between the different processes. Most data was from 2014–2019. However, supporting literature from as early as 2000 was used. The primary data from UPM, including data on the combustion and composting processes was from 2017–2019. The municipal WWTP data was mostly from 2014–2018. Although the data

was neither fully from primary sources nor temporally coherent, the data quality was deemed to be sufficient for conducting the case study for exemplary purposes, and thereby, developing the nutrient handprint approach and guidance.

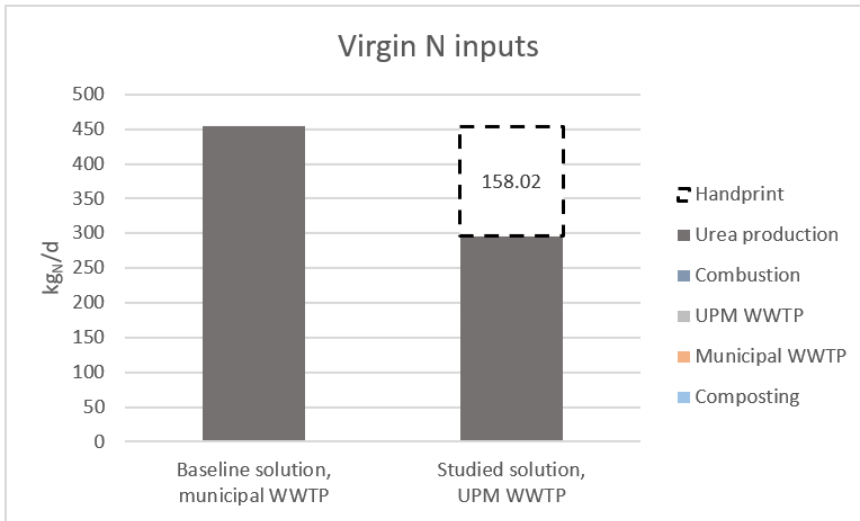
Quantification: Calculate the footprints and the handprint

The total nitrogen inputs to the system were reduced by 158 kg/d in the studied solution in comparison to the baseline solution as shown in **Figure 16**. This change fulfils the first input nutrient handprint criterion.

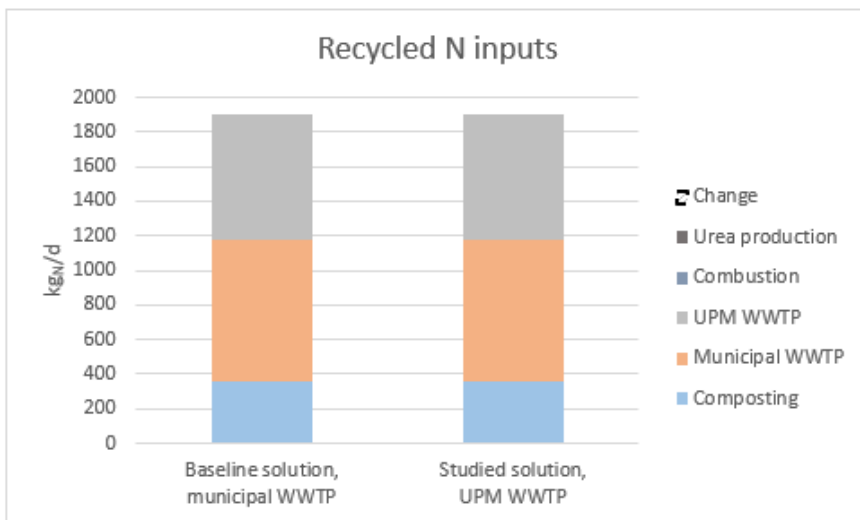


**Figure 16.** Total N inputs in the baseline and studied solution by process.

The reduction in the total inputs is wholly due to the reduction in virgin nitrogen inputs for urea production as can be seen in **Figure 17**. **Figure 18** shows that recycled nutrient inputs to the system remain unchanged between the baseline and studied solution. That is, the virgin urea inputs were not replaced by any additional inputs, but the recycled intermediate nitrogen flow in the exhaust gas washer wastewater is redirected to UPM instead of to the municipal WWTP. The reduction in virgin N inputs fulfils the second input nutrient handprint criterion.

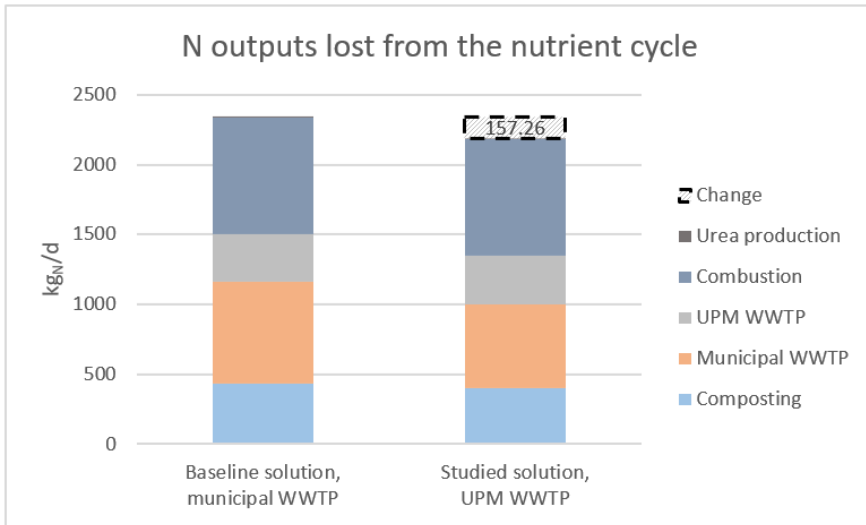


**Figure 17.** Virgin N inputs in the baseline and studied solution for each process.

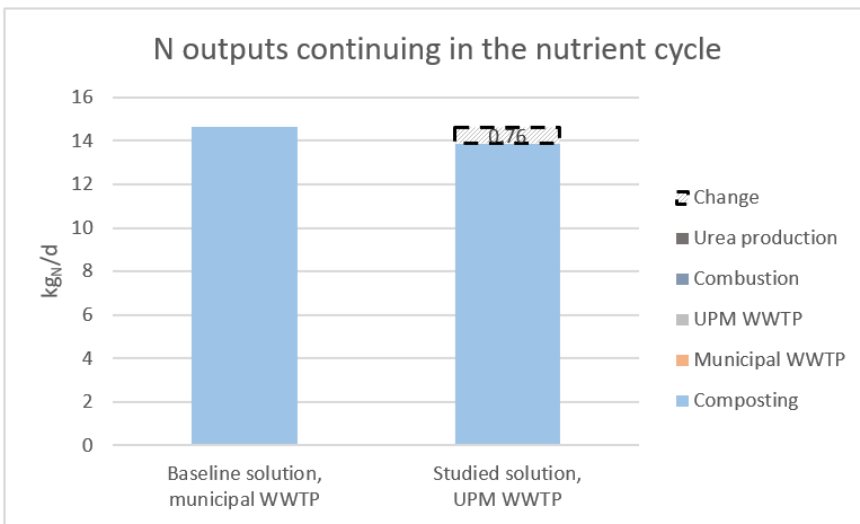


**Figure 18.** Recycled N inputs in the baseline and studied solution for each process.

Due to the reduction in total nutrient inputs, on the output side, both N outputs lost from the nutrient cycle and N outputs that continue in the nutrient cycle are reduced in the studied solution. **Figure 19** shows the change in lost outputs and **Figure 20** shows the change in continuing outputs.



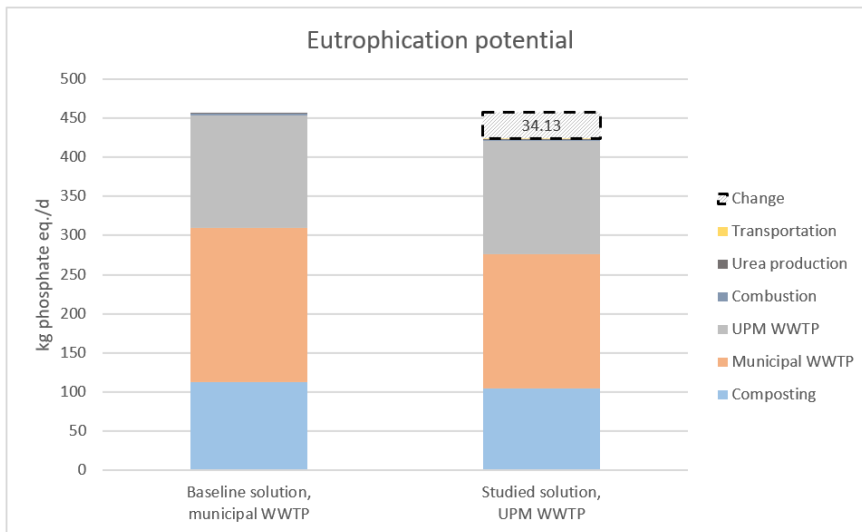
**Figure 19.** N outputs lost from the nutrient cycle in the baseline and studied solution for each process.



**Figure 20.** N outputs continuing in the nutrient cycle in the baseline and studied solution for each process.

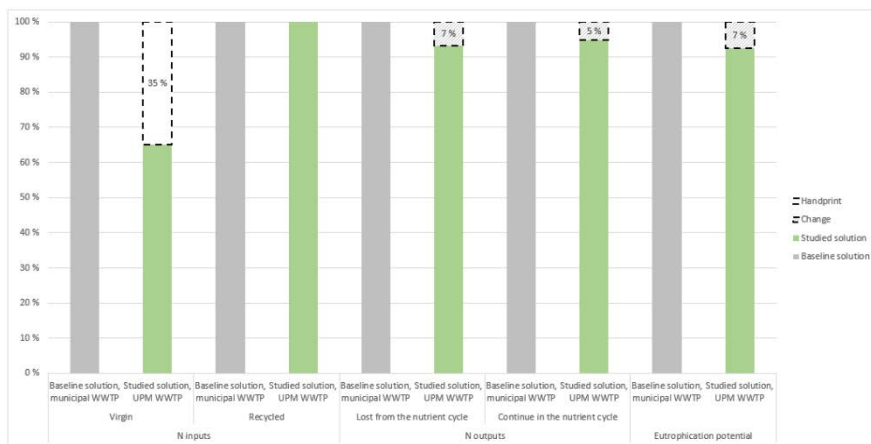
On the output side, the ratio of continuing to lost nutrients remains the same in the studied solution as in the baseline solution. The ratio, thus, meets the handprint precondition, which enables handprint creation for the input side. The output nutrient handprint criterion is not fulfilled, so a handprint was not created for the output side.

**Figure 21** shows the change in the eutrophication potential of the system. The eutrophication potential decreased in the studied solution compared to the baseline solution. Thereby, the handprint precondition related to eutrophication is fulfilled.



**Figure 21.** Eutrophication potential in the baseline and studied solution for each process.

**Figure 22** shows changes in the nitrogen balance and eutrophication potential of the whole system in %.



**Figure 22.** The nitrogen balance and eutrophication potential in the baseline and studied solution. WWTP = wastewater treatment plant.

In summary, both input nutrient handprint criteria are fulfilled, the precondition on the output side on the ratio of continuing to lost nutrients is met, and the precondition related to the eutrophication potential is met. Therefore, a nitrogen nutrient handprint is created. The nitrogen nutrient handprint is 158 kg<sub>N</sub>/d, which equals the reduction in both the total nutrient inputs and virgin nutrient inputs. The reduction (handprint) is 35% of the baseline total N inputs and virgin N inputs. The results are subject to uncertainties due to the temporal incoherence of the data and assumptions made in the calculations.

#### Identify the relevant indicators to be communicated

The general guidelines of the nutrient handprint apply and have been demonstrated above.

#### Consider critical review of the nutrient handprint

A critical review was not conducted, as this case was done of the purpose of developing the nutrient handprint approach.

#### Communicate the results

The general guidelines apply. In addition, suitable communication units include kgN/d for changes in the N balance, kg phosphate equivalents/d for the eutrophication potential and all changes in %.

## 5. Air quality handprint

Air pollution is a major environmental health problem globally causing approximately 4.2 million premature deaths a year (WHO 2018). Air pollutants cause respiratory, vascular and heart diseases and have adverse effects on ecosystems and the climate (EEA 2018). Local air quality is the sum of many factors and is affected, for example, by emission levels, a time of a year, weather conditions and geographic features. Additionally, some air pollutants are transported long distances with air currents. (THL 2020)

Ambient (outdoor) air pollutants are typically particulate matter (PM), ozone (O<sub>3</sub>), nitrogen dioxide (NO<sub>2</sub>) and sulphur dioxide (SO<sub>2</sub>) (WHO 2018).

PM<sub>2.5</sub> has been regarded as the most important air pollutant affecting human health (WHO 2018). In Finland, in 2015, PM<sub>2.5</sub> emissions caused approximately 1,600 premature deaths (Lehtomäki et al. 2018). Particulate matter includes solid and liquid particles of organic and inorganic substances, such as heavy metals, carbon compounds, sulfurs, and carcinogens (WHO 2018). Small scale wood combustion, energy production, and traffic are the main domestic emission sources of PM<sub>2.5</sub> (Hänninen et al. 2016). In addition, fine aerosol particles can be transported over long distances with air currents (Niemi et al. 2004). For example, in Helsinki, 50% of the observed PM<sub>2.5</sub> may be accounted for by long-range transport of particles (Vallius et al. 2003).

Ozone at the ground level is a major contributor to asthma-related health issues (WHO 2018). Ozone, a secondary pollutant, is formed when nitrogen oxides caused by vehicles and industry, and volatile organic compounds (VOCs) caused by vehicles, solvents, industry, and natural sources react with sunlight. This is referred to as the photochemical ozone reaction potential or summer smog (WHO 2018). In Finland, spring and summer are favorable times for ozone creation. Long-range ozone can reach Finland from central and southern Europe on southern air currents. The limits for ozone concentrations in the air is exceeded in Finland annually, but still quite rarely (Ministry of Environment Finland 2019).

Nitrogen oxides (NO<sub>x</sub>) are defined as a sum of nitric oxide (NO) and nitrogen oxide (NO<sub>2</sub>) (EEA 2019). At high concentrations, NO<sub>2</sub> can cause inflammation of the respiratory passages. Reduced lung function growth and symptoms of bronchitis in asthmatic patients have been observed to be caused by NO<sub>2</sub> (WHO 2018). Airborne NO<sub>x</sub> is mainly emitted from anthropogenic sources, especially from combustion processes. Fuel combustion for energy production and traffic are the major sources of NO<sub>x</sub> emissions in Finland (HSY 2016). In the case of NO<sub>2</sub>, in Finland, more than half of human exposure is caused by local sources and a share of long-range transport is rather low (Korhonen 2017).

Sulphur dioxide can cause issues in the respiratory system, lungs and can irritate the eyes. High SO<sub>2</sub> levels may lead to cardiac disease and increased mortality. When combined with water, sulfuric acid is formed. Acid rain is a main cause of deforestation (WHO 2018). Sulphur dioxide is formed when fuels with sulphur con-

tent are used in energy production and industrial processes. International co-operation has reduced SO<sub>2</sub> emissions clearly from the 1980s. Nowadays in Finland higher SO<sub>2</sub> emissions usually result from the malfunction of industrial processes or long-range emissions from the Kola Peninsula. (FMI n.d.)

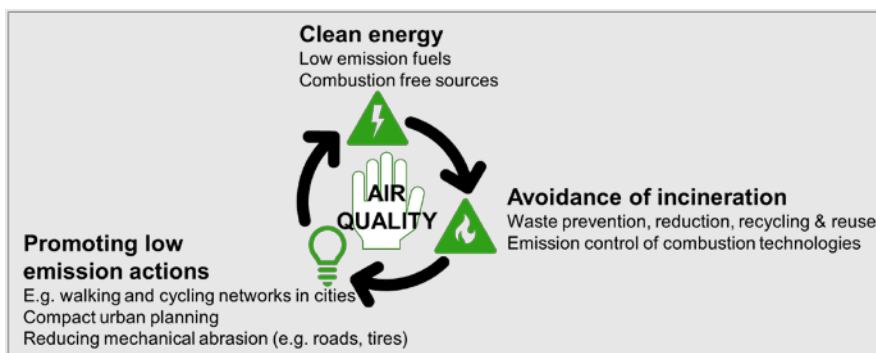
## 5.1 Steps in the air quality handprint calculation

### Define the scope of the studied solution

The studied solution that potentially reduces air pollutant emissions and thus creates potentially an air quality handprint should be accurately described.

### Identify the air quality handprint contributors

The air quality handprint aims to communicate the reduction of substances such as PM, O<sub>3</sub>, NO<sub>x</sub> and SO<sub>2</sub> due to a studied solution. **Figure 23** presents possible contributing mechanisms that may have positive impacts on local air quality. As combustion processes are the main source of air pollutants, efforts to avoid and reduce fuels that release air pollutants is key to creating an air quality handprint. In addition, preventing emissions from occurring by prioritizing renewable energy, energy efficiency, waste prevention, non-motorized transport, etc. can contribute towards an air quality handprint. Especially in Finland, the particulate emissions caused by tire and road wear, as well as sanding are topical issues. Solutions preventing mechanical abrasion-related dust could also achieve an air quality handprint.



**Figure 23.** Possible contributors to an air quality handprint.

### Identify the environmental impacts in question and their potential indicators

Not all air pollutants are relevant in every air quality handprint assessment. Therefore, one should first consider based on the case at hand, which substances are important to include. This should be done with the whole life cycle in mind, as in some cases different substances may be more relevant in different life cycle phases.



Neglecting one substance in order to communicate the air quality handprint of another substance is not allowed.

In this framework an air quality handprint is assessed at the inventory level and none of environmental impact categories are included. The challenge is that many of the impacts are related to concentrations, whereas the calculations are based on emissions. An assessment of the health responses of a population would demand relating observed concentrations to the population response. Putting the emission results into the context of concentrations or air quality limits would be more informative, but will require much more effort, in some cases even requiring air quality dispersion models. This would allow the consideration of different local emission sources and also taking the long-range transport of emissions into account. The assessment and inclusion of air pollutant concentrations in the calculations would provide the possibility to extend the results also to the mid-point and end-point levels, for example to the impacts on human health.

### Identify the users and beneficiaries of the studied solution

Poor outdoor air quality can be considered to be a local environmental impact. Released emissions affect the people, flora, and fauna in the immediate proximity, and to some extent via long-range transport. Therefore, when assessing the air quality handprint throughout the entire life cycle, usually the customer of the studied solution may be affected only by the use phase emissions. However, the handprint mentality urges the inclusion of the whole life cycle of the product, and thus the final customer is carrying the entire burden also from previous life cycle stages. To better serve different customers throughout the life cycle, it may be useful to divide the result presentation based on the geographical location point of emission release.

### Define the baseline

Guidelines for defining the baseline as specified in the general guidelines apply.

### Define the functional unit

Guidelines for defining the functional unit as specified in the general guidelines apply.

### Define the system boundaries

Guidelines for defining the system boundaries as specified in the general guidelines apply.

### Define data needs and sources

Guidelines for defining the data needs as specified in the general guidelines apply.

In addition, some remarks concerning temporal and geographical coverage should be taken into account. Firstly, the examination period should be long enough to include any occurring differences in and between the studied and the baseline

solutions. For example, the climate, weather, and population density affect the momentary air quality and therefore, a period of one year is recommended in order to include the effect of local variables. Besides, the geographical coverage should be wide enough to cover the key locations of the life cycle of the handprint and the baseline solution.

#### Calculate the air quality footprints

Using equal functional units, the emissions over the life cycle of the two systems should be calculated. Each substance identified as relevant earlier, are counted separately.

#### Calculate the air quality handprint

By comparing the total emissions of the two systems substance by substance, one can determine whether the studied solution can reduce the amount of emissions. If so, an air quality handprint is created for that substance. In case a reduction is achieved in one substance but there is an increase in another, the results must be communicated transparently. It may be reasonable to carry out further research, to find out which change is more significant in terms of health impacts, for example.

#### Identify the relevant indicators to be communicated

The general guidelines apply.

#### Consider critical review of the nutrient handprint

The general guidelines apply.

#### Communicate the results

The general guidelines apply.

## **5.2 Case study: paraffinic renewable diesel, HVO**

A case study of a fuel produced by Neste was conducted to support the air quality handprint method development. The examined fuel was paraffinic renewable diesel made of used cooking oil (hydrotreated vegetable oil, HVO). This study is briefly explained below. More thorough description of the air quality handprint of HVO produced by Neste can be found in the article published by Lakanen et al. (2021).

#### Define the scope of the studied solution

The studied solution is a renewable diesel fuel made from used cooking oil (HVO) made of used cooking oil. HVO is a paraffinic renewable diesel fuel with zero aromatics and meets the requirements of the EN 15940 standard and available as neat 100% renewable fuel, without a need to blend to fossil fuel.

### Identify potential air quality handprint contributors

The hypothesis is, that due to the properties of HVO, the combustion process in a vehicle's engine will be cleaner compared to a conventional diesel engine.

### Identify the environmental impacts in question and their potential indicators

The substances investigated were NO<sub>x</sub> and PM<sub>2.5</sub> at the inventory level. NO<sub>x</sub> and PM<sub>2.5</sub> emissions, especially from diesel-powered vehicles, are a major source of these compounds in urban areas and have been identified as being very harmful to human health.

### Identify the users and beneficiaries of the studied solution

Air pollutants have various detrimental effects on human health and hence, local emission reductions may benefit all inhabitants in the area, where emissions reductions occur. However, also identifying customers of the product is important when assessing the potential handprint. The customers using the fuel were narrowed down to diesel-driven passenger car owners and to a city or community willing to reduce their local air emissions. The vehicles under examination were diesel-powered passenger cars from three different Euro regulation tiers (Euro 4, 5 and 6). Euro 0–3 diesel passenger cars as well as heavy traffic vehicles were excluded from the study because no recent laboratory emission measurements were available.

Based on the end-users, the study was set geographically in Finland and limited to the diesel fuel sold and used in passenger cars in the Helsinki area. Mäkelänkatu (a street in Helsinki) was chosen as the example street due to the good availability of data.

### Define the baseline

The baseline product is fossil diesel used for the same purpose. The baseline diesel contained 7% biocomponents in volume, in this case biodiesel (FAME, fatty acid methyl ester), which is in line with current European fuel standards that allow up to 7% biodiesel volume in fossil fuel diesel (EN 590:2013, 2017).

### Define the functional unit

The calculation was performed on based on a one-kilometre drive per vehicle representing Euro 4, 5 or 6 diesel passenger cars at two temperatures (-7°C and +23°C). When considering the customer to be a city, the functional unit included the actual fleet size driving one-kilometre distance on Mäkelänkatu during 2018.

### Define the system boundaries

The examination included the entire life cycle of the examined fuels, from the well to wheel. However, the results are presented separately for the production phase

(well-to-tank) and use phase (tank-to-wheel), as those emissions occur in different geographical locations.

#### Define data needs and sources

As the hypothesis is that the air quality handprint is created as the studied fuel is combusted in the vehicle's engine, it is important that the measured primary data is used to support this. Laboratory emission measurements were performed with a WLTC test cycle for the HVO and conventional diesel fuel. The same Euro 4, 5, and 6 vehicles were used for both fuels, and the tests were performed at two temperatures (-7°C and +23°C).

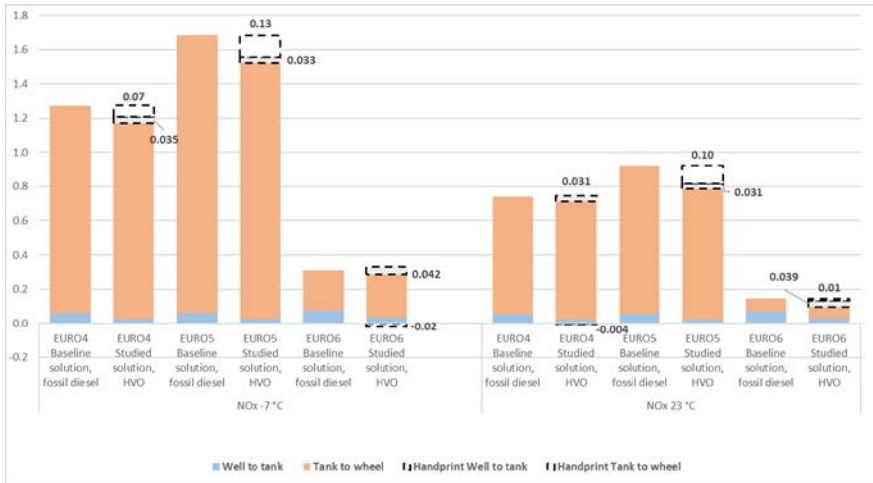
Primary data from Neste was used concerning the production of the HVO fuel. The baseline diesel production was modelled using secondary data from GaBi (2016).

Mäkelänkatu-specific data represented actual measured data: passenger car data was measured by the City of Helsinki in 2018, the share of different Euro classes was measured by Traficom (2018) and the average daily temperatures were taken from the Finnish Meteorological Institute (FMI) measurement point at Kaisaniemi in Helsinki in 2018.

#### Quantification: Calculate the footprints and the handprint

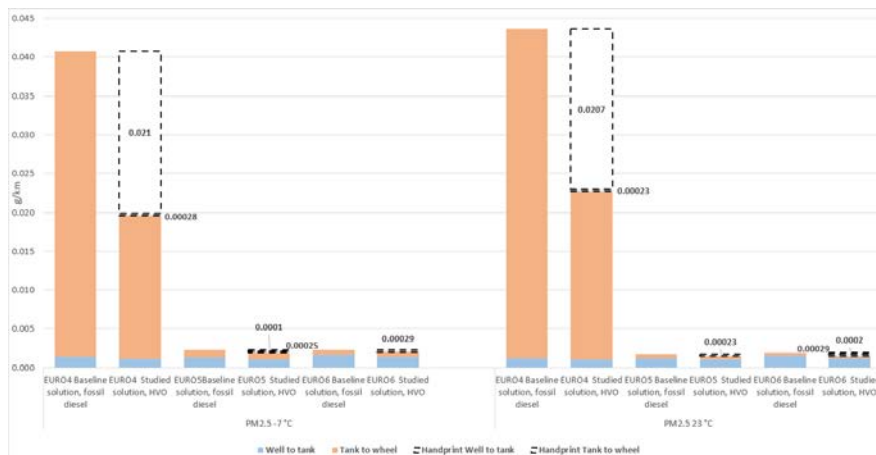
In the following figures, the results for the air quality handprint study are presented separately for NO<sub>x</sub> and PM<sub>2.5</sub> during a one-kilometre drive for Euro 4, 5 and 6 diesel passenger cars and additionally, for the one-kilometre drive in Mäkelänkatu with the actual car fleet, with the mileage and ambient temperatures based on the year 2018 values. In these figures the life cycle of the conventional diesel fuel and HVO is divided into a well-to-tank phase and tank-to-wheel section. Correspondingly, the handprint is presented in these phases to show, where the improvement occurs.

**Figure 24** illustrates the results of the NO<sub>x</sub> emissions for Euro 4, 5, and 6 diesel passenger cars for a one-kilometre drive in two different temperatures. The difference of NO<sub>x</sub> emissions of the baseline and the studied solutions is also presented as a handprint in the figure. In all cases the HVO fuel has lower life-cycle NO<sub>x</sub> emissions than the baseline diesel. The emissions are slightly higher in colder temperatures (-7°C). The results show that the life-cycle NO<sub>x</sub> emissions are lower for the Euro 6 car compared to the Euro 4 and 5 vehicles for both baseline fuel and HVO fuel, which is due to more efficient NO<sub>x</sub> filters in newer cars.



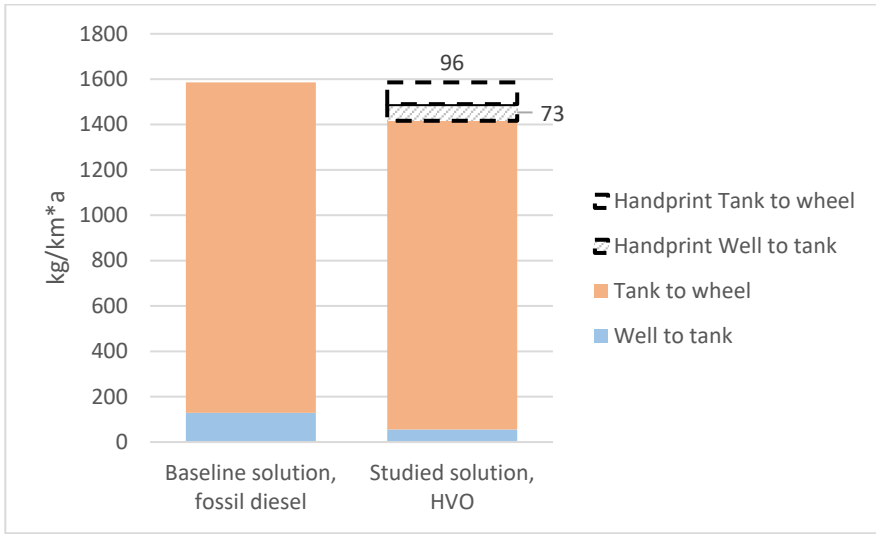
**Figure 24.** NO<sub>x</sub> emissions for the baseline and the studied solution in [g NO<sub>x</sub>/km] during a one-kilometre drive for Euro 4, 5 and 6 diesel passenger cars at two different temperatures.

**Figure 25** shows the PM<sub>2.5</sub> emissions for Euro 4, 5, and 6 diesel passenger cars for a one-kilometre drive at two different temperatures. According to the results, the PM<sub>2.5</sub> emission reduction was the most significant in the case of the Euro 4 cars and, in particular, in tank to wheel emissions. Fine particulate emissions from the Euro 5 and 6 cars were lower for both the baseline fuel and HVO due to more advanced filtering technology. Consequently, especially in Euro 6 cars with advanced emission control technology the benefit of using HVO is marginal in terms of air quality.



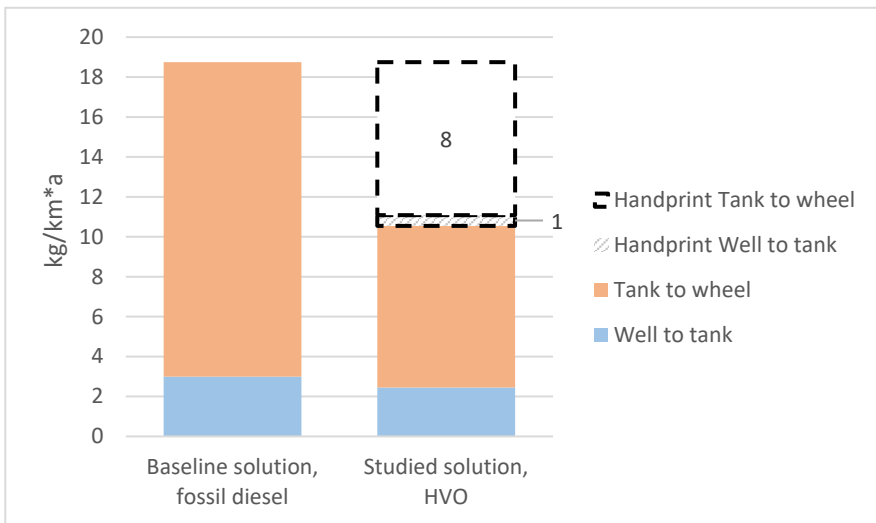
**Figure 25.** PM<sub>2.5</sub> emissions for the baseline and the studied solution in [g PM<sub>2.5</sub>/km] during a one-kilometre drive of Euro 4, 5 and 6 diesel passenger cars at two different temperatures.

**Figures 26 and 27** present the results throughout the year 2018. The annual values are shown for the vehicle fleet driving for a one-kilometre distance on Mäkelänkatu. The resulting emissions are calculated based on the average daily temperatures in 2018. When examining the results of the emissions reductions in kilograms, the NO<sub>x</sub> emissions reduction is significantly higher than the PM<sub>2.5</sub> reduction. In percentages, the PM<sub>2.5</sub> emission amount was nearly halved with the renewable diesel. **Figure 26** shows that the NO<sub>x</sub> reduction, or in other words, the one-year NO<sub>x</sub> handprint for the HVO fuel is 169 kg or 10.7% for the defined fleet.



**Figure 26.** NO<sub>x</sub> emissions and the NO<sub>x</sub> handprint in [kg NO<sub>x</sub>/km\*a] for a one-kilometre drive on Mäkelänkatu for the studied fleet based on the 2018 values.

When using the HVO fuel, the PM<sub>2.5</sub> emissions reduction was 9 kg or 48% for the defined fleet (**Figure 27**) when compared to conventional diesel.



**Figure 27.** PM<sub>2.5</sub> emissions and PM<sub>2.5</sub> handprint [kg PM<sub>2.5</sub>/km\*a] in a one-kilometre drive on Mäkelänkatu with the studied fleet based on the year 2018 values.

### Identify the relevant indicators to be communicated

The general guidelines of the air quality handprint apply and have been demonstrated above.

### Consider critical review of the nutrient handprint

A critical review was not conducted, as this case was done of the purpose of developing the air quality handprint approach.

### Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. The air quality handprint should be communicated separately for different air pollutant compounds. Suitable communication units include  $\text{kgNO}_x/\text{a}$  or  $\text{gNO}_x/\text{km}$  and respectively  $\text{kgPM}_{2.5}/\text{a}$  or  $\text{gPM}_{2.5}/\text{km}$ .



## 6. Resource handprint

The transition toward more circular and resource efficient products and companies increases the demand for positive resource indicators and associated environmental impacts. So far, even a generally accepted definition of resource efficiency does not exist yet. The resource efficiency platform of the European Commission describes resource efficiency as using the Earth's limited resources in a sustainable manner while minimizing impacts on the environment. This "allows us to create more with less and to deliver greater values with less input" (European Commission).

As resource efficiency is considered a key element for circularity and sustainability, suitable methods to address the sustainability of resource use are increasingly needed.

Resource indicators are often classified into three categories:

1. Energy: measures how much energy is consumed during the product life cycle
2. Materials: measures the amounts of raw materials consumed during the product life cycle
3. Environmental: measures the environmental impacts of the product life cycle

For some indicators, these classifications may overlap. Resource efficiency is a multidimensional entity since multiple resources are needed during a product's life cycle whereas economic efficiency can be measured by one single indicator and unit, money. In most cases, more resource efficient operation is also economically beneficial, but it is possible that those two objectives conflict, for example the minimization of waste streams can be associated with higher costs.

Life cycle assessment plays an important role since there is a notable lack of consensus across impact assessment methods concerning resource depletion in LCA. Nonetheless, the extent to which current life cycle impact assessment methods are capable of answering resource sustainability challenges is widely debated. In the last 30 years, a number of methodologies and indicators for resource depletion have been developed, some including economic aspects related to abiotic and biotic resource consumption. In the context of assessing resource efficiency, there is the tendency to adopt indicators simply based on mass aggregation. Different methodological approaches under the LCA framework have been used so far to address the impacts of resource depletion.

The resource handprint identifies positive impacts with respect to resource efficiency. In this project several indicators were tested as to how they indicate resource consumption and its impact on the environment, including: the abiotic depletion potential (elements and fossil); cumulative energy demand; resource use (renewable and non-renewable); the carbon footprint; primary/secondary resource use; toxic waste; land use; critical materials; and recycled material content.

The abiotic depletion potential of elements (ADPe) considers the use of non-renewable materials. It includes critical materials with high characterization factors and other more common abiotic materials with lower characterization factors. When renewable or secondary/recycled materials are used instead of primary non-renewable ones, the ADPe should be decreased. However, in some cases this indicator might not be relevant, e.g., if the studied product does not include non-renewable materials and the ADPe is only related to the infrastructure during the life cycle. In these cases, careful consideration should be given to make sure that the impacts are correctly interpreted, if this impact is included in the study.

The abiotic depletion potential of fossil fuels (ADPf) considers non-renewable energy, but it does not include renewable energy resources, which should be also considered when resource efficiency is studied. Thus, the cumulative energy demand (CED) is a good support for ADPf, since it includes all the primary energy resources used in the value chain.

The recycled material content and primary/secondary material content focus only on the products, not life cycles, which is not enough from the handprint perspective. The amount of toxic waste is not seen as a relevant resource indicator, even though it might have important environmental impacts that can be covered in full LCA studies. Additionally, land use is an important resource aspect, but it is still under development as an indicator. It is closely connected to other environmental aspects, such as climate change, eutrophication, biodiversity, etc. and thus it can be partly considered in other life cycle assessment indicators.

Based on four case studies of this project and the reasoning described above, four indicators were chosen to indicate the resource handprint: the abiotic depletion potential (elements); the abiotic depletion potential (fossil); the cumulative energy demand; and the carbon footprint. The abiotic depletion potential of elements can be left out if it is not relevant in the value chain. It should be remembered, though, that a full LCA is often recommended to be studied instead of just one environmental aspect, to make sure that the impacts are not shifted from one impact category to another.

## **6.1 Steps in the resource handprint calculation**

The stages and steps up to calculating the resource handprint are discussed in the following.

### Define the scope of the studied solution

The studied solution that potentially creates a resource handprint and replaces the baseline solution should be accurately described.

### Identify potential handprint contributors

The resource handprint aims to communicate the reduction in the abiotic depletion potential (elements), abiotic depletion potential (fossil), cumulative energy demand

and the carbon footprint due to a studied solution. E.g., technologies with improved energy efficiency in the use stage, products made from recycled or renewable materials instead of fossil-based ones, or the remanufacturing of products might have a resource handprint.

#### Identify the environmental impacts in question and their potential indicators

Not all resource indicators are relevant in every resource handprint assessment. Therefore, based on the case at hand, the first need is to consider which indicators are important to include. This should be done with the whole life cycle in mind, as in some cases different resources may be more relevant in different life cycle phases.

#### Identify the users and beneficiaries of the studied solution

Identify potential or actual customers or other parties that may benefit from the studied solution.

#### Define the baseline

Guidelines for defining the baseline as specified in the general guidelines apply.

#### Define the functional unit

Guidelines for defining the functional unit as specified in the general guidelines apply.

#### Define the system boundaries

Guidelines for defining the system boundaries as specified in the general guidelines apply.

#### Define data needs and sources

Guidelines for defining data needs as specified in the general guidelines apply.

#### Calculate the resource footprint

Using equal functional units, the indicators over the life cycle of the two systems are calculated. Each indicator identified relevant earlier, in defining the scope, are counted separately.

#### Calculate the resource handprint

By comparing the footprints of the studied and baseline solution indicator by indicator, it can be determined whether the studied solution reduces the amount of emissions. The resource handprint is not a single indicator. Consequently, controversial results, i.e. both positive and negative changes, may occur. In case a reduction is

achieved in one indicator but there is an increase in another, the results must be communicated transparently.

Identify the relevant indicators to be communicated

The general guidelines apply.

Consider critical review of the handprint

The general guidelines apply.

Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. The abiotic depletion of fossil fuels and cumulative energy demand are reported as MJ values. The abiotic depletion of elements is reported in terms of the kg Sbe. While the climate change is reported in terms of the kg CO<sub>2e</sub>.

## **6.2 Case study: pulp washing system**

The case study focused on pulp washing systems that the engineering firm Andritz delivers to pulp mills. The studied solution was called “Washer 1” and the baseline solution “Washer 2”. The pulp washing affects the pulp mill material and energy balance in many ways that depend on the used technology. The hypothesis of the study was that lower resource use could be achieved with Washer 1 when considering the system over the whole life cycle. The framework of the case study is presented in Appendix A.

Define the scope of the studied solution

A pulp washing system that reduces chemicals and energy consumption in a pulp mill.

Identify potential handprint contributors

Pulp washing is an essential part of the pulping process. This study focused on brown stock washing where the cooking chemicals are removed from the pulp. At the beginning of the pulping process, wood chips are first impregnated and then cooked with the chemicals sodium hydroxide and sodium sulphate. In the cooking process, the wood breaks down into cellulose and lignin, and in the washing phase, the lignin and the cooking chemicals are removed from the cellulose. This liquid containing lignin and chemicals is called black liquor, and it is utilized as a fuel at the mill. The lignin is burned to provide energy and the chemicals are recovered to be used again in the cooking, and the cellulose continues onwards to the bleaching phase.

Pulp washing affects the material and energy balance in multiple ways, and thus the resource efficiency of the mill. Efficient washing enables a high recovery rate of

the chemicals, which reduces the need for new make-up chemicals. Additionally, fewer bleaching chemicals are needed in the subsequent process steps if the cellulose contains as few black liquor solids as possible. On the other hand, when more water is used to achieve a better washing result, the black liquor dilutes, which affects the energy production system. Black liquor needs to have a solids content of over 60% before feeding it to the recovery boiler, and excess water needs to be evaporated. This consumes energy that could otherwise be sold out or used on the mill site. Thus, pulp washing is a complex trade-off between the pulp quality, energy production, and chemical consumption and recovery. The resource efficiency of a mill can be improved with a well-designed washing system.

### Identify the environmental impacts in question and their potential indicators

The impacts studied were the abiotic depletion potential (elements), abiotic depletion potential (fossil), cumulative energy demand and the carbon footprint.

### Identify the users and beneficiaries of the studied solution

The washing systems are large pieces of equipment that consist of multiple washers, and they are installed at the mill site. Thus, the customers are the pulp companies who are building new mills or upgrading existing mills.

### Define the baseline

Washer 2 technology is a common pulp washing system that is implemented in several pulp mills.

### Define the functional unit

The functional unit of the study was the annual production of the pulp mill producing bleached pulp and excess energy sold to the grid. To provide this function, the baseline solution required one large Washer 2 and six small Washer 2 units, and the studied solution consisted of two large Washer 1 and three small Washer 1 units.

### Define the system boundaries

The system boundaries included the equipment production covering the whole value chain from raw material extraction to manufacturing, transportation to the mill site, pulp mill operations that are affected by the washing process, chemical production and transportation to the site, and equipment disposal. In addition, the avoided electricity production was covered in the studied solution.

The value chain operations that remained the same in the baseline and studied solutions were not considered which is not our recommended way to evaluate a handprint. This simplification was made because of the complexity of the studied operational framework (pulp mill). For example, forestry operations were not included because it was assumed that the different washing systems would not affect

the pulp yield, and thus the same amount of wood would be processed in both systems. When considering the chemicals used in the pulping process, only those with a difference between the baseline and the studied solution were considered.

Concerning the geographical boundaries, it was assumed that the pulp mill was located in the Guangdong province in southeast China. The baseline equipment was assumed to be produced in China, whereas the handprint equipment is produced in Finland and transported to China. The pulping chemicals were assumed to be produced in China, and the electricity profile was the average grid mix for the Guangdong province.

### Define data needs and sources

To create a life cycle model and calculate the impact assessment results for the whole value chain within the system boundaries, data was needed for all the life cycle stages at the unit process level. Andritz provided primary data on the equipment manufacturing, including material and energy usage, and how the use of washing systems affects the material and energy balances at the mill. The Ecoinvent database (version 3.5) was used as the data source for the production of raw materials, chemicals, electricity, and fuels, as well as for the end-of-life treatment of the equipment. Transportation data was sourced from the VTT LIPASTO database.

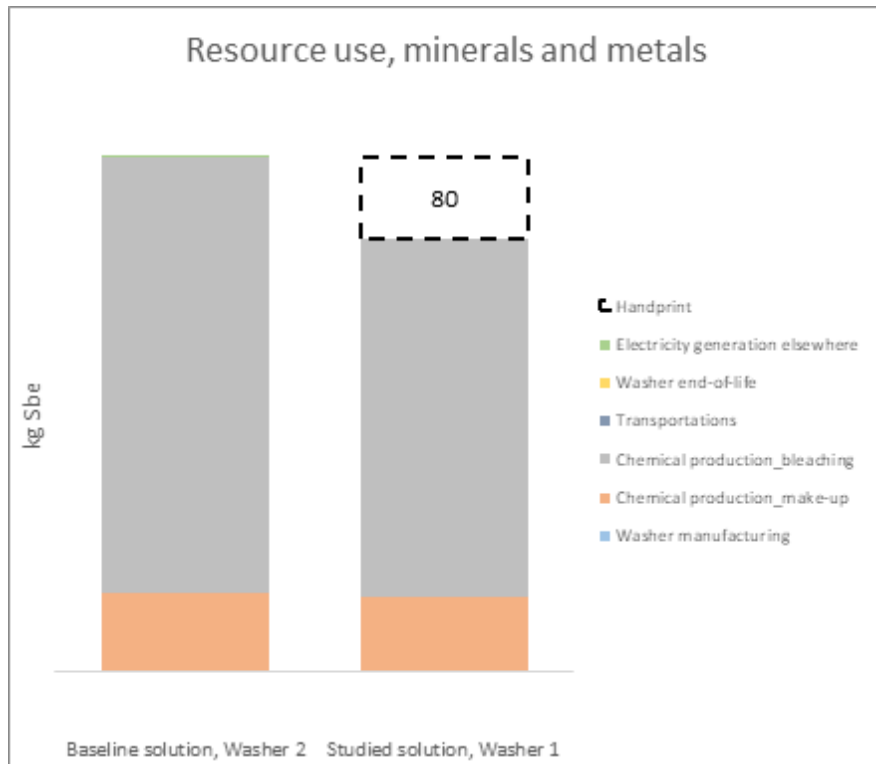
Special attention was paid to the production of chlorine dioxide, one of the bleaching chemicals, that turned out to have a large contribution to the overall results. Data on the state-of-the-art technology was sourced from the KnowPulp e-learning environment, as database data was not available. This data covered the gate-to-gate inventory for chlorine dioxide production, and the raw material production data was sourced from Ecoinvent.

### Quantification: Calculate the footprints and the handprint

The life cycle impact assessment results were calculated in four impact categories determine if a handprint was created with the studied solution. The results were calculated for the annual production volumes of the pulp mill, and the results are presented as absolute figures. Relative results were not calculated since only the differences between the solutions were considered, which prevents assessing the relative significance, e.g., at the pulp mill level. Due to the complex operational framework, the results do not present the footprints of the solutions but the impacts of the simplified systems that enable quantifying the handprint. The abiotic resource depletion, minerals and metals results are presented in **Figure 28**.

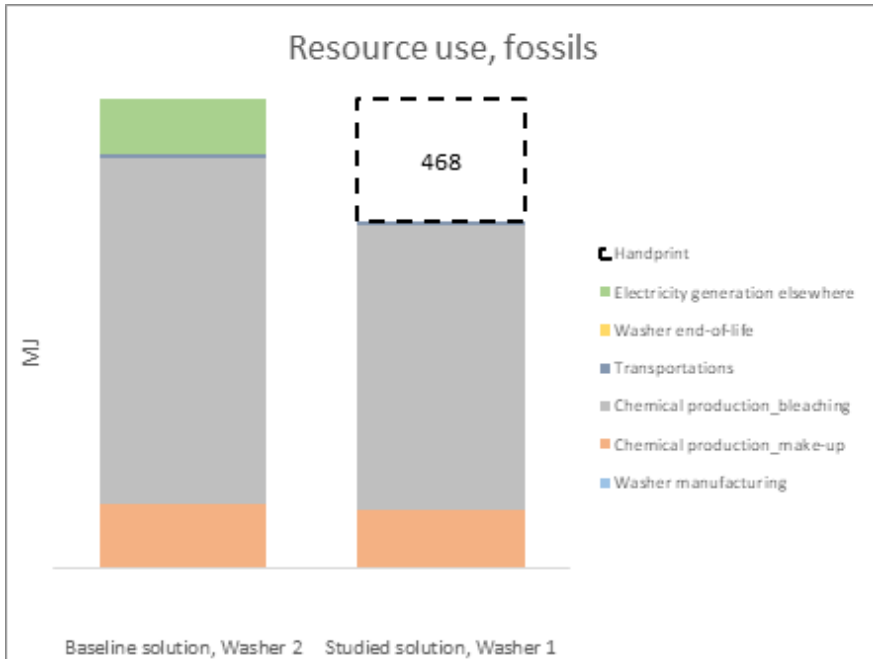
It can be seen that the result for the studied solution is smaller than for the baseline solution, and thus, a handprint is created. This is mainly due to the reduced use of bleaching chemicals, especially chlorine dioxide. The impact from the make-up chemical production decreases slightly in the studied solution, but it has only a minor contribution to the overall results. The equipment-related life cycle stages are negligible. Even though the impact caused by the washer manufacturing is somewhat higher for Washer 1, the effect is insignificant due to the one-off nature and long operating life of the machine. The same applies to the transportation where the

chemical transports dominate, despite the multifold distance of the Washer 1 machines that are transported from Finland to China.



**Figure 28.** Abiotic resource depletion, minerals, and metals.

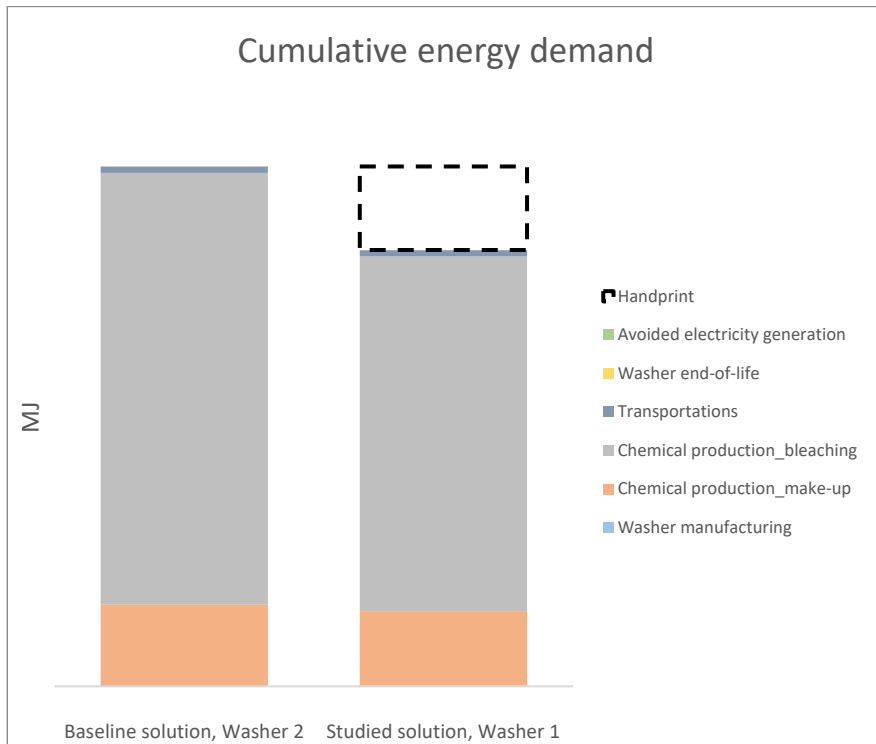
The abiotic resource depletion results for fossil fuels are presented in **Figure 29**. The results show that the studied solution performs better, consuming less fossil fuels than the baseline solution. The chemicals' production accounts for the largest contribution, but also the electricity generation avoided has a significant effect on the results. In the studied solution, less energy is used to run the processes at the mill and more energy can be sold out. The amount of sold electricity in the studied solution is considered as a part of the functional unit (yearly production of the pulp mill), and the additional energy needed to be produced elsewhere in the baseline solution is described in the figures as "Electricity production elsewhere". This is assumed to be the average grid mix of the Guangdong province, consisting of coal power (76%), nuclear power (13%), hydro power (9%), and others (2%). Transportation has a clearly higher impact on the fossil fuel depletion compared to minerals and metals depletion, but it is still of low importance with an approximately 1% share of the total impacts.



**Figure 29.** Abiotic resource depletion, fossil fuels.

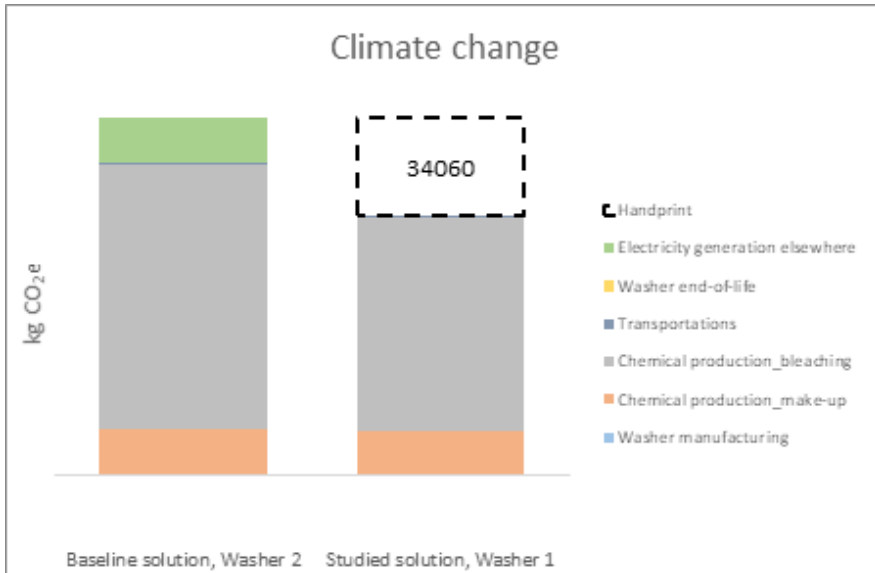
The cumulative energy demand (CED) results are presented in **Figure 30**. The results follow the same principles as the resource depletion results, chemical production contributing the most. The handprint is smaller than created in the fossil fuel depletion category because the CED considers all the energy forms and focuses on the demand. Therefore, the studied solution does not benefit from the larger amount of excess energy.





**Figure 30.** Cumulative energy demand.

The global warming potential results are presented in **Figure 31**. It can be seen that the results are similar to the fossil fuel depletion results. Chemicals affect the results the most, but the electricity generation elsewhere also has a significant contribution.



**Figure 31.** Global warming potential.

The results of all the four impact categories show that the main contributor to the impacts is the production of process chemicals. Additionally, electricity generation affects things significantly when fossil fuels and greenhouse gas emissions are considered. Thus, the changes in the pulp mill are the most important effect of the washing system, and the production, transportation and disposal of the process equipment do not make a difference between the baseline and studied solution.

The large impact of chemical production derives mainly from the electricity production that is needed for the production processes. Reduced use of chemicals in the studied solution results in lower electricity demand in the value chain, which can be seen in the impact on the fossil fuel depletion, cumulative energy demand, and global warming. A similar impact can also be seen in the depletion of minerals and metals, where the need for minerals as raw materials has decreased in the studied solution.

Identify the relevant indicators to be communicated

The abiotic depletion potential of fossil fuels and elements, cumulative energy demand and climate change should be communicated.

Consider critical review of the handprint

A critical review was not conducted, as this case was done for the purpose of developing the resource handprint approach.

## Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. The abiotic depletion of fossil fuels and cumulative energy demand are reported as MJ values. The abiotic depletion of elements is reported in terms of the kg Sbe, while the climate change is reported in terms of the kg CO<sub>2</sub>e.

### **6.3 Case study: moss-based gardening soil**

This case study for resource handprint development was conducted for the ecological gardening product company Biolan's soil products. The traditional gardening soils in Finland are often based on peat as a growth medium, but nowadays there is a need to use more renewable and recycled materials. The possibility for a resource handprint was thus tested with two possible gardening soil compositions: the conventional peat-based gardening soil acted as a baseline solution, while a renewable, moss-based and waste/by-product-based raw material were used for the studied solution. The framework of the case study is presented in Appendix A.

#### Define the scope of the studied solution

The studied solution is called "Yrttimaa" and is made of sphagnum moss, broiler manure (a waste stream from broiler feedlots including manure and peat bedding used for the birds), light peat, a bark/sand mix (a waste stream from the forest industry), biochar (a waste stream from a birch-based charcoal production plant), and calcium carbonate.

#### Identify potential handprint contributors

Biolan reduces the consumption of (primary) peat and synthetic fertilizers by using moss and bio-based by-products from secondary sources. Additionally, the fossil CO<sub>2</sub> emissions from the use stage peat degradation are reduced, when using bio-based products.

#### Identify the environmental impacts in question and their potential indicators

The study considers the cumulative energy demand, abiotic depletion of fossil fuels (especially peat in this study), and the carbon footprint.

#### Identify the users and beneficiaries of the studied solution

Biolan's gardening soils are used by private consumers and gardening companies. The products selected for the resource handprint study could be used by private consumers in their own gardens.

## Define the baseline

The baseline “peat-based gardening soil” is a typical peat-based gardening soil, which consists mainly of peat with minor amounts of calcium carbonate, calcium hydroxide and of synthetic nitrogen fertilizer.

## Define the functional unit

The functional unit of the study is 1kg of gardening soil, produced by Biolan from two optional raw materials, and used in the garden in a similar way.

## Define the system boundaries

The system boundaries include the production of the primary raw materials, transportation of all raw materials, gardening soil production at Biolan’s site, production of packaging materials (plastic bag for the product and EUR-pallet for transportation), and the use of the soil. The secondary, waste-based raw materials are treated as cut-off, i.e. only transportation to Biolan is considered. The end-of-life of the soil is neglected since it is expected that the soil will slowly “disappear/degrade” in the use stage and no end-of-life treatment is needed.

## Define data needs and sources

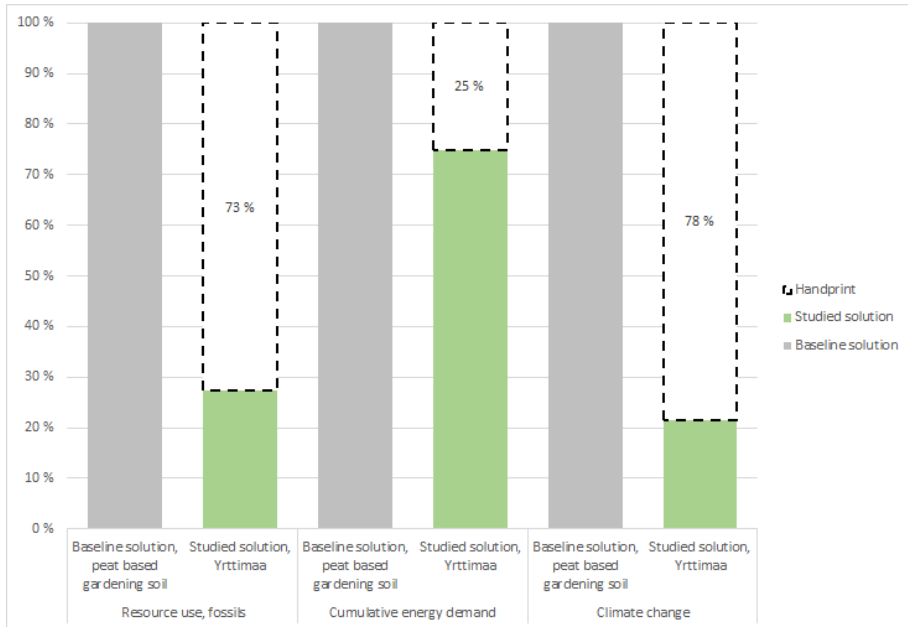
A life cycle assessment was done for both solutions. This required data on the raw material production, transportation distances for each raw material, the production process data at Biolan’s facilities, and information on the packaging of the soils. In addition, the use stage of the soils was modelled. Since peat is used as a raw material, it was expected to decompose during the use stage. The cellulose and hemicellulose of the peat were expected to release fossil CO<sub>2</sub> emissions. The share of peat in used broiler manure in the studied solution was also considered. Additional emissions from the use stage were expected from added lime, of which 12% of the carbon content was expected to be released as fossil CO<sub>2</sub>.

The biogenic CO<sub>2</sub> was assumed to be removed and released to the atmosphere with equal quantities and was thus not studied in the calculations.

The LCA calculations were done using the SULCA software, using PEF-recommended impact assessment factors and the total cumulative energy demand as indicators. Primary data was used for the raw material compositions of both solutions, Biolan’s processes (which were similar for both products), fuel consumption for the sphagnum moss collection and transport distances. Secondary data from the Ecoinvent 3.5 database with a cut-off approach was used for fuel and energy production, transportation emissions, peat production, lime production, and fertilizer production. The chemical composition of the peat and the share of the peat bedding in the broiler manure were based on the literature (Alakangas et al. 2016 and Luostarinen et al. 2017).

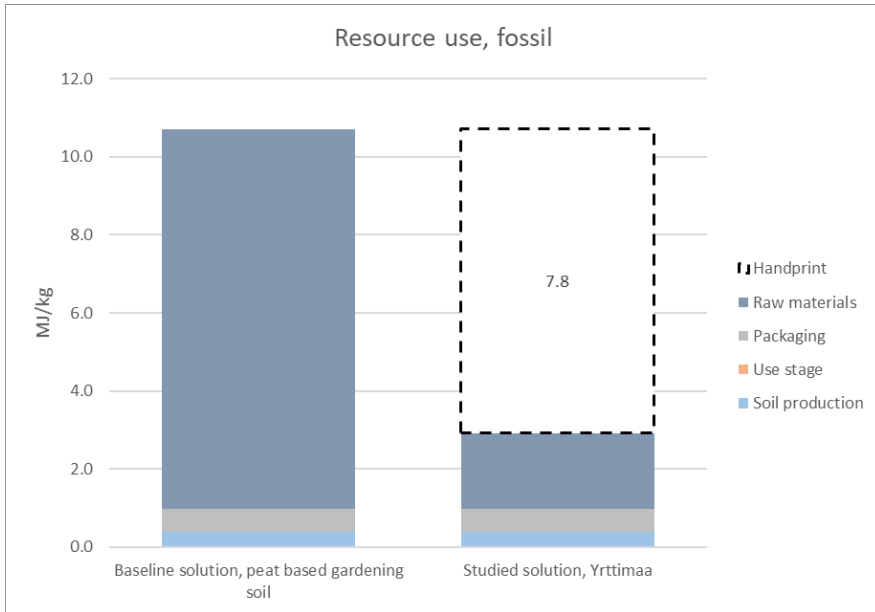
## Quantification: Calculate the footprints and the handprint

The results of the baseline solution and studied Yrttimaa solution and the handprint created are shown in **Figure 32**, where the baseline is marked as 100% and the studied solution is compared to it. All indicators show that a resource handprint is created with the Yrttimaa product.



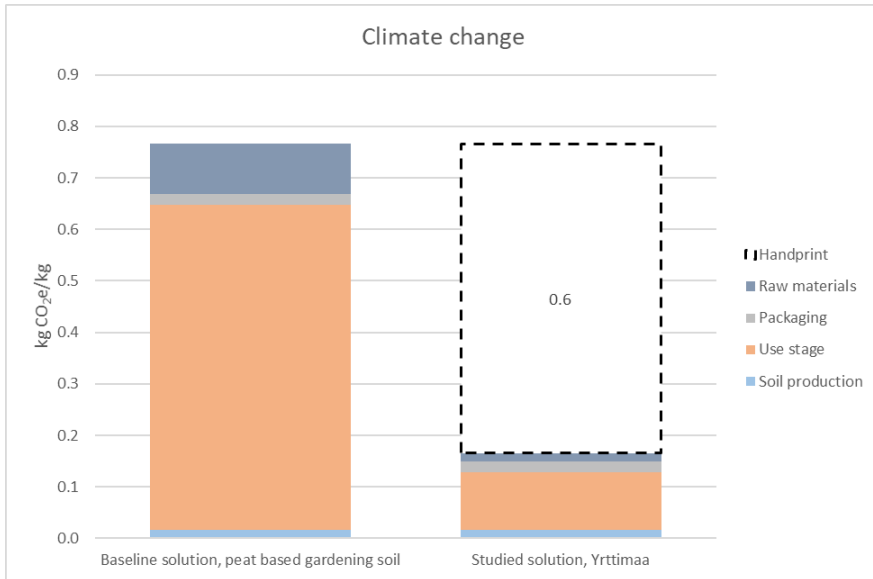
**Figure 32.** The resource handprint results of the Biolan case study.

The sources for the handprint are described further in the figures below. Peat is considered as a fossil resource in the Product Environmental Footprint Guide and it creates 92% of the fossil consumption in the raw materials stage. Thus the use of renewable raw materials in Yrttimaa's raw materials reduces the consumption of fossil resources remarkably, by 73%. In addition, with the cut off approach the renewable by-products consume only minor amounts of fossil fuels in the transportation stage. The production, packaging and use stage of both products are equal, as shown in **Figure 33**.



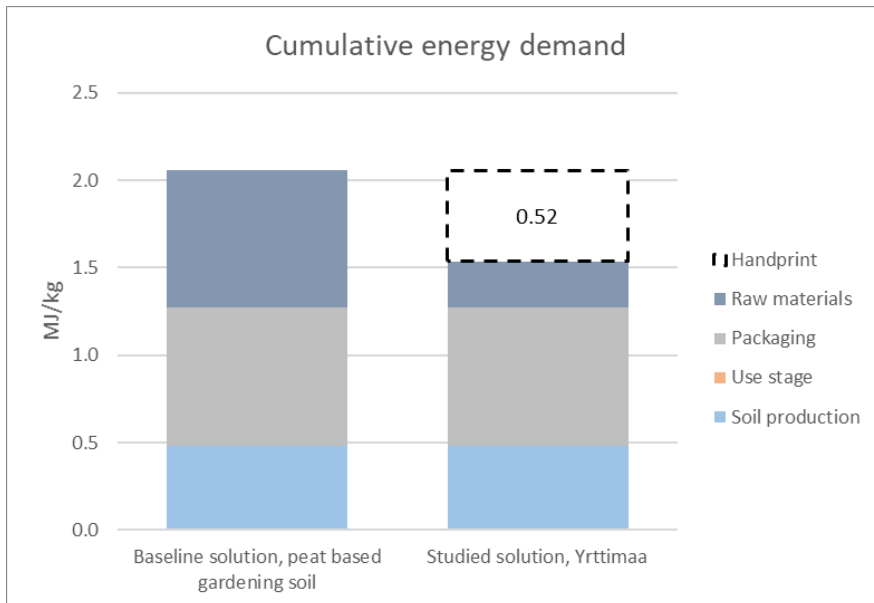
**Figure 33.** Sources of consumption of fossil fuel resources in the baseline and studied solutions of the Biolan case.

Peat is also the main source of greenhouse gas emissions, described in **Figure 34**. The decomposition of cellulose and hemicellulose in the use stage create most of the carbon footprint of both products, but for the studied solution, Yrttimaa, the emissions are 78% lower.



**Figure 34.** Carbon footprints of the baseline and studied solutions of Biolan case.

For the cumulative energy demand, a smaller handprint is created, but still 25% energy can be saved with the Yrttimaa product when compared to the baseline product. The savings again relate to the raw materials production as shown in **Figure 35**, where the waste/by-product-based raw materials are produced without a burden. The main consumer of energy in the raw materials for the peat-based gardening soil is the synthetic nitrogen fertilizer, causing 68% of the raw materials' CED. The second important consumer of energy is the peat production process.



**Figure 35.** Cumulative energy demand in baseline and studied solutions of Biolan case.

This case study showed that the use of waste/by-product-based streams as raw materials is beneficial from the resource perspective. Additionally, the renewability of raw materials is shown in the decreased consumption of fossil resources.

From the LCA calculation perspective, peat can be a challenging topic, since most of the impact assessment methodologies consider it as an energy source. If peat is used as a raw material, however, it must be considered separately, and its energy content should not be considered in the CED calculation.

#### Identify the relevant indicators to be communicated

The abiotic depletion potential of fossil fuels, cumulative energy demand and climate change should be communicated.

#### Consider critical review of the handprint

A critical review was not conducted, as this case was done for the purpose of developing the resource handprint approach.

#### Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. The abiotic depletion of fossil fuels and cumulative energy demand are reported as MJ values, while the climate change is reported in terms of the kg CO<sub>2</sub>e.



## 6.4 Case study: recycled plastic

In this case study, polyethylene (PE) film production was studied to determine the effect of recycled raw materials. The studied solution was a PE film produced partly from secondary PE granulates, and it was compared to a baseline solution that was entirely based on primary PE. A handprint was considered because less primary resources would be needed for the production. The framework of the case study is presented in Appendix A.

### Define the scope of the studied solution

The study considers a packaging film made partly from recycled polyethylene.

### Identify potential handprint contributors

The baseline and studied solutions differ in their raw material sources. Half of the polyethylene used in the studied solution is recycled PE that is collected and processed into new granulates. These secondary granulates do not need oil as a raw material, whereas the main raw material in the primary PE production is oil. Thus, the reduced demand for the raw materials for the primary PE production creates a potential resource handprint.

### Identify the environmental impacts in question and their potential indicators

The study considers the cumulative energy demand, abiotic depletion of fossil fuels, and the carbon footprint.

### Identify the users and beneficiaries of the studied solution

PE films can be used in multiple applications, e.g. in the packaging industry. The customer could be a packaging producer that utilizes the film as a barrier layer in paperboard packaging, or a company that uses the film as such to pack its products.

### Define the baseline

The baseline solution is the conventional PE film production using primary raw materials.

### Define the functional unit

The functional unit of the study is 1 kg of PE film delivered to a customer. The secondary PE was assumed to have the same properties as the primary PE, and thus, equal amounts were needed to fulfil the same functionality.

## Define the system boundaries

The system boundaries cover the life cycle from raw material extraction to the delivery to a customer. The value chain includes the granulate production and its upstream processes, granulate transportation, film production, product transportation to a customer, and end-of-life treatment. The use stage was excluded due to the assumption that the film does not affect resource use when used.

Geographical boundaries were set to cover the production and product delivery in Finland. Secondary PE granulate production was located in Austria, from where the granulates were transported to Finland to be used in the film production.

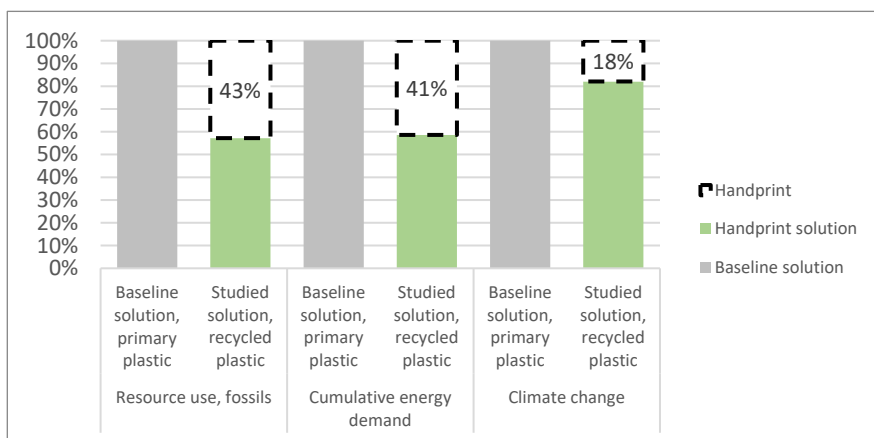
## Define the data needs and sources

Life-cycle models were created for the baseline and studied solutions, which required data on the raw material production, film production, transportation, and end-of-life treatment. The models were created in the GaBi LCA software and the GaBi database was utilized as the main data source.

The GaBi Professional database was used for the raw material production processes, film production, energy production, transportation, and end-of-life treatment. The shares of different end-of-life treatment were based on data from Statistics Finland (Official Statistics Finland 2020).

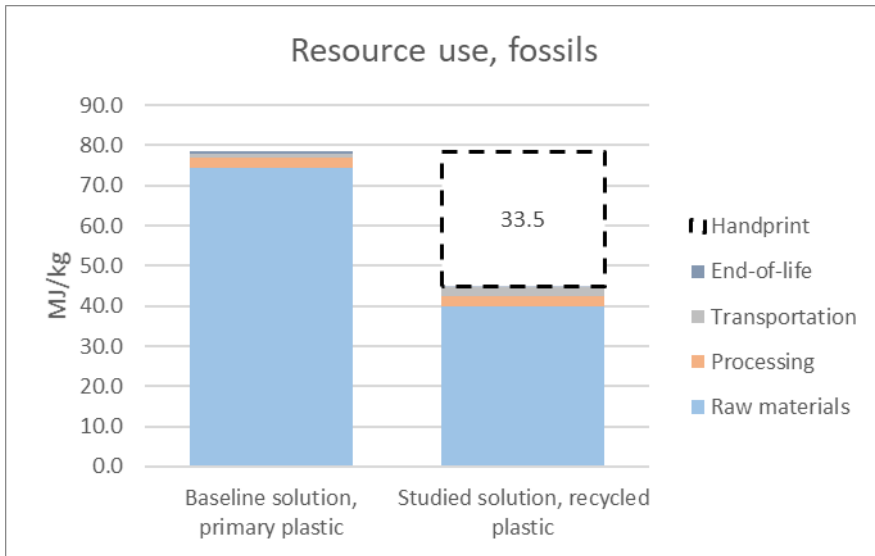
## Quantification: Calculate the footprints and the handprint

The relative results of all three impact categories are presented in **Figure 36**. The results for the baseline solution represent 100% and the results for the studied solution are proportioned accordingly. The results for the studied solution are approximately 60–80% of the baseline solution results, meaning that the potential environmental impacts are smaller, and a handprint is created.



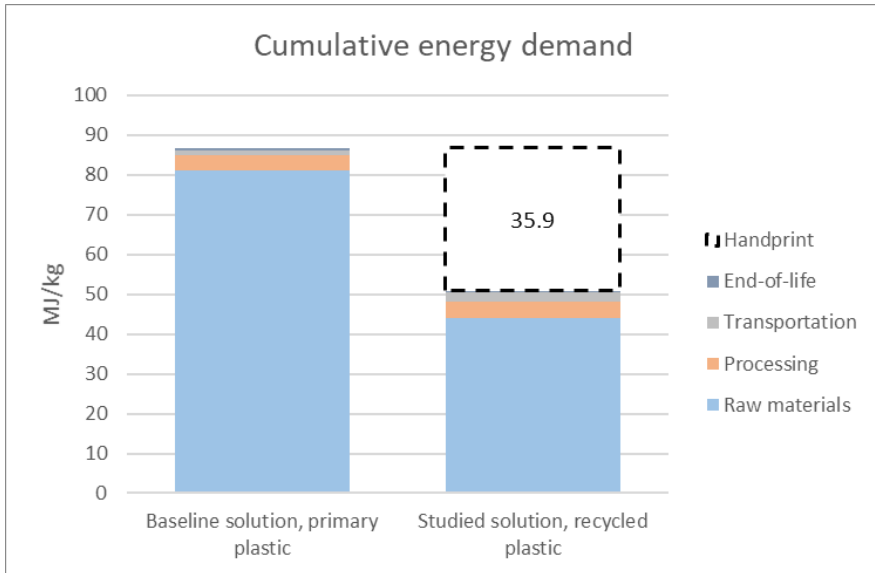
**Figure 36.** Relative results of the studied impact categories.

The fossil resource use and results are presented in **Figure 37**. The results show that raw material production is the main contributor to the use of fossil resources, and the rest of the value chain has only a minor effect. This was expected because crude oil is the main raw material in plastic production. The effect of using secondary plastic as a raw material in the studied solution can clearly be seen in the result that is remarkably lower than that of the baseline solution. The longer transportation distance of the recycled granulates affects things twice as much as the transportation in the baseline case, but the effect on the overall result is rather small.



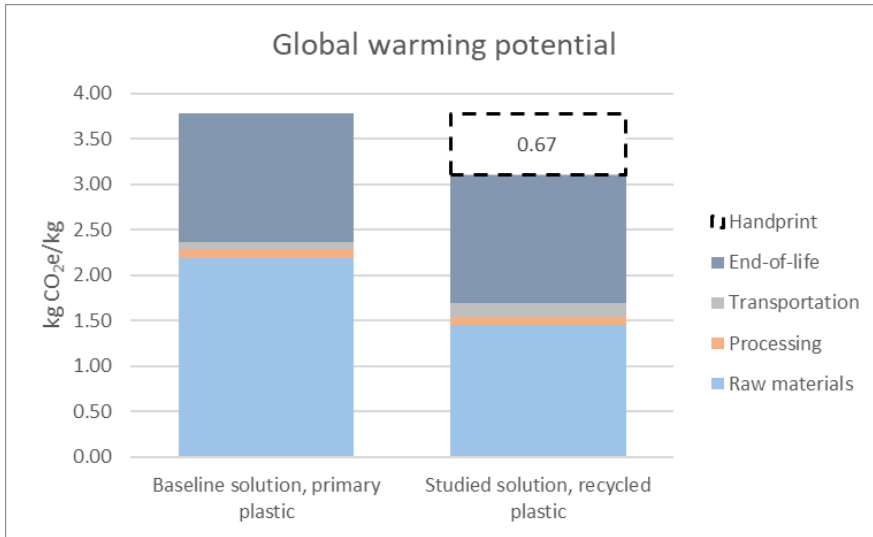
**Figure 37.** Results of the fossil resource use for the Borealis case.

The cumulative energy demand results, reported as the primary energy demand in GaBi, are presented in **Figure 38**. In addition to the use of fossil resources, the results consider the whole energy demand, despite the source. Thus, the absolute results are somewhat larger than for the fossil resource use, but the studied solution performs significantly better than the baseline solution. The raw material processing into film has a larger contribution, but the raw material production is dominant, as it is for the fossil resource use.



**Figure 38.** Cumulative energy demand results for the Borealis case.

The global warming potential results are presented in **Figure 39**. In addition to the raw material production, the end-of-life treatment has a large impact. This is due to plastic incineration where the oil-based material is burned causing carbon dioxide emissions. The longer transportation of the secondary granulates can also be seen as a larger impact in the studied solution than in the baseline solution, but it has only a minor contribution.



**Figure 39.** Global warming potential results for the Borealis case.

The results show that a handprint is created in all the three impact categories. This is mainly due to the reduced need for oil as the main raw material, as recycled plastic is used instead in the studied solution. When considering climate change, a smaller handprint is created because relatively large emissions are caused in the end-of-life phase. The processing of PE granulates into film and the transportation have only a minor contribution to the impacts overall.

An even larger handprint could be created if more primary plastic could be replaced with secondary raw material. This could be improved by increasing the recycling capacity, which could also enhance the carbon handprint as more plastic would be recycled instead of undergoing incineration.

#### Identify the relevant indicators to be communicated

The abiotic depletion potential of fossil fuels, cumulative energy demand and climate change should be communicated.

#### Consider critical review of the handprint

A critical review was not conducted, as this case was done for the purpose of developing the resource handprint approach.

#### Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. The abiotic depletion of fossil fuels and cumulative energy demand are reported as M values, while the climate change is reported in terms of the kg CO<sub>2</sub>e.

## 6.5 Case study: computer remanufacturing

This case study focuses on the possibility to achieve a resource handprint in remanufacturing. Ekox Finland Oy produces laptops from used laptops and can reuse c. 70% of the incoming material (computers) in their products. Only minor amounts of new materials are added to the remanufactured laptops. Thus, in this case study the life cycle of the remanufactured laptops is compared to the life cycle of new laptops. The framework of the case is presented in Appendix A.

### Define the scope of the studied solution

The study considers a remanufactured laptop by Ekox.

### Identify potential handprint contributors

The remanufacturing of laptops by Ekox reduces the need for primary raw material extraction and the energy needed in the laptop production chain. Since Ekox can utilize c.70% of the incoming computers in their remanufactured laptops, one remanufactured laptop replaces 0.7 primary laptops. This means that 0.3 primary laptops are still needed per one remanufactured laptop if it is assumed that the number of laptops in use is kept constant. The energy consumption in different operation modes differ slightly between the two laptops, so the energy consumption in the use stage depends on the operation profile.

### Identify the environmental impacts in question and their potential indicators

The study considers the cumulative energy demand, abiotic depletion of fossil fuels and elements, and the carbon footprint.

### Identify the users and beneficiaries of the studied solution

Both individual consumers and companies can buy remanufactured laptops from Ekox. In the case study example, the laptop operation profile was modelled for typical office usage.

### Define the baseline

The baseline is a typical laptop made from primary materials. The packaging materials, i.e., plastic films, polystyrene covering and packaging board box of the laptop are included in the study.

The laptop is assumed to be used for three years. It is assumed that the usage takes place in an office 5 days/week, the laptop is turned off at night (16h per day) and at weekends (2 days/week), and put into sleep mode during lunch breaks (1h per day). The active office hours (7 hours per day) are divided into 3 h of normal operation in a short idle mode, 4h in normal operation in a long idle mode. Holidays

or other additional free days were not considered in the study. The division between the different operation modes is shown in **Table 1**.

**Table 1.** Assumptions for the operation mode profile of a laptop.

	Normal operation, short idle	Normal operation, long idle	Sleep	Off
Time per day, h/workday	3	4	1	16
Time per day, h/weekend day	0	0	0	24
Total operation time in each mode in 3 years, h	2340	3120	780	19968

### Define the functional unit

The functional unit of this study is one laptop computer, produced either from primary raw materials (baseline solution) or remanufacturing (studied solution) but used in a similar way.

### Define the system boundaries

The system boundaries include the production of the primary raw materials used in the laptop, production of the packaging materials for the laptop and the energy production for all energy consumed in the life cycle (raw material processing, computer manufacturing and the use stage). Transportation of the laptops was excluded. Additionally, the end-of-life treatment of discarded laptop was excluded from the study due to two reasons: 1) the EOL treatment for both laptops would be similar, i.e., there would only be minimal impact on the possible handprint, and 2) according to publications, EOL treatment only has a minor influence on the environmental impacts of electronic waste in the first place (e.g. Manhart et al. 2016). Thus, it was considered that the study would be acceptable also without the EOL.

### Define the data needs and sources

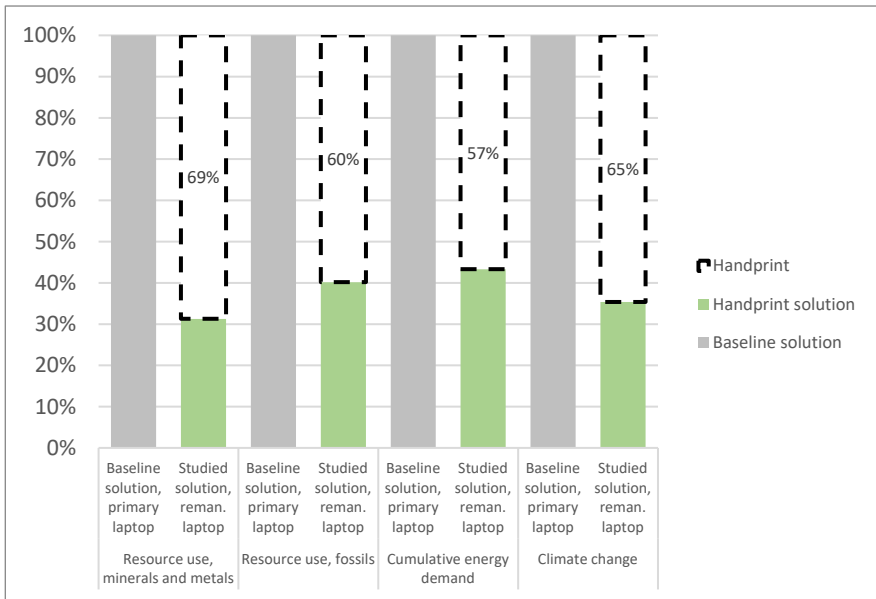
A life cycle assessment was done for both laptops. This required data on the raw material composition and packaging materials used for the laptop, production of the raw materials and energy, and the energy consumption data in each operation mode at the use stage.

The LCA calculations were done using the SULCA software, using PEF-recommended impact assessment factors and the total cumulative energy demand as indicators. Data from the Ecoinvent 3.5 database was used for the baseline laptop production, its packaging and energy production for the value chain. Primary data from Ekox was used for the laptop remanufacturing process, i.e., the utilization rate of the incoming laptops, and for the energy consumption in each operation mode for both solutions. Since Ekox typically adds an SSD-card in the remanufacturing process, the typical composition of an SSD card was collected from the literature

(Seagate technology LLC 2011) and combined with the material production data from the Ecoinvent database. It was assumed that the remanufactured laptop would not consume any packaging materials.

Quantification: Calculate the footprints and the handprint

The results of the baseline solution (primary laptop) and studied solution (remanufactured laptop) and the created handprint are shown in **Figure 40**, where the baseline result is marked as 1.00 and the studied solution is compared to it. All the indicators show that a resource handprint is created with the remanufactured laptop. As was explained earlier, one remanufactured laptop replaces 0.7 primary laptops, and 0.3 primary laptops must still be produced per one remanufactured laptop in order to keep the number of laptops in use constant. The share of 0.7 of raw materials (i.e., the utilized share of incoming laptops) is considered burden-free. The SSD card weighs less than 80 grams, so the impact on the elementary resource consumption is only minor compared to the weight of the computer.

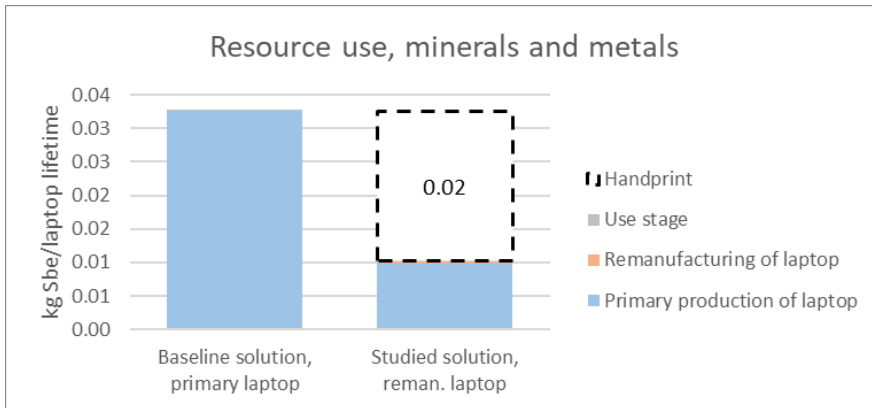


**Figure 40.** The resource handprint results of the Ekox case study.

With the typical office use operation mode profile, the remanufactured laptop consumed c. 2% more electricity than the baseline laptop within the 3 years of usage. The energy consumption has a larger impact on the fossil resource consumption, carbon footprint and CED than on the abiotic elementary consumption, which is visible in the smaller handprints for those three indicators. However, the handprint remains remarkable also for the CED which has the smallest handprint of 57%.

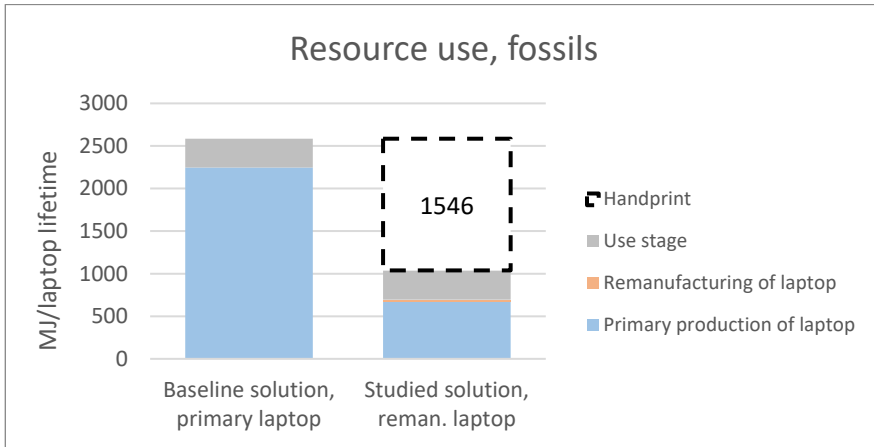


The elementary resource consumption is shown in more detail in **Figure 41**. The division into the life cycle stages confirms that the primary production is the main consumer of resources while the use stage and remanufacturing consume only minor amounts of elements. The primary production in the studied solution relates to the 0.3 share of primary products needed to keep the number of laptops in use constant, when 70% of the laptops can be utilized in the remanufacturing process. Despite their light weight, circuit boards are the main reason (>80%) for the elementary consumption since they include rare metals which have higher impact factors than more common raw materials.



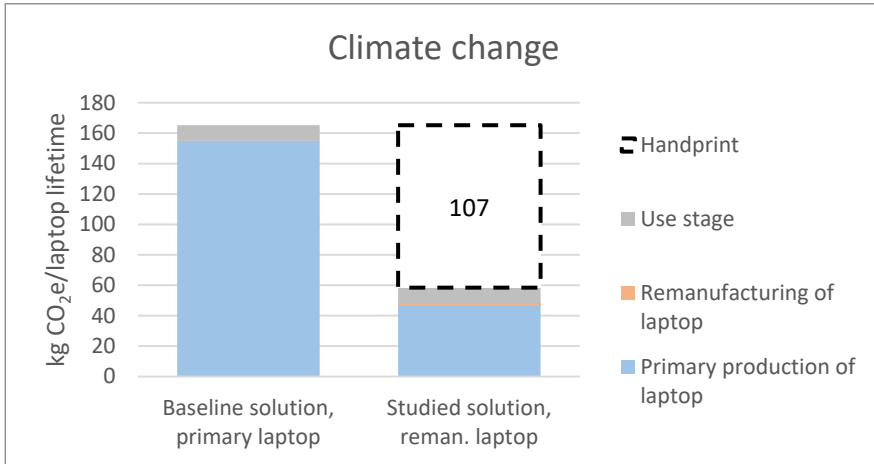
**Figure 41.** Elementary resource consumption in different life cycle stages in the Ekox case study.

Most of the fossil resources are mostly consumed during primary production, but also the electricity consumption in the use stage plays a role in this indicator, as shown in **Figure 42**. In the studied solution, the use stage consumes a third of the fossil resources, while in the baseline case the share from the use stage is only 13%. The remanufacturing consumes less than 2% of the fossil resources.



**Figure 42.** Fossil resource consumption in different life cycle stages in the Ekox case study.

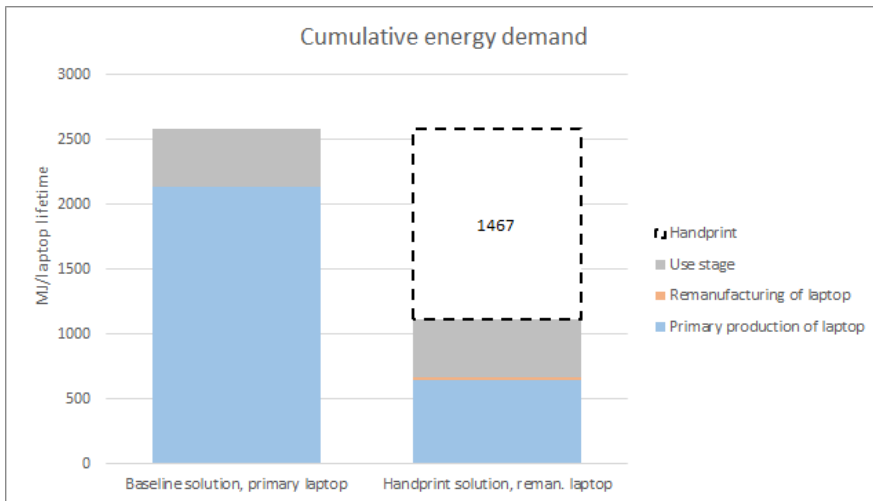
**Figure 43** shows the carbon footprint results from the different life cycle stages. The contributors are very similar to the previous results, i.e., the largest share of emissions comes from primary production (c. 93% in the baseline solution and c.79% in the studied solution), while the use stage is the second important source. Again, the remanufacturing has a minor role in the results.



**Figure 43.** The carbon footprint in different life cycle stages in the Ekox case study.

The cumulative energy demand is shown in **Figure 44** in more detail. 83% and 58% of the energy is consumed in primary production in the baseline and studied solution, respectively. The use stage is responsible for 17% in the baseline solution and

41% in the studied solution, while the remanufacturing consumes less than 2% of the CED in the studied solution.



**Figure 44.** Cumulative energy demand in different life cycle stages in Ekox case study.

This case study showed that remanufacturing can save both material and energy resources and create a smaller carbon footprint than primary production. However, the utilization rate of incoming and burden-free raw materials must be carefully considered.

#### Identify the relevant indicators to be communicated

The abiotic depletion potential of fossil fuels and elements, cumulative energy demand and climate change should be communicated.

#### Consider critical review of the handprint

A critical review was not conducted, as this case was done for the purpose of developing the resource handprint approach.

#### Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. The abiotic depletion of fossil fuels and cumulative energy demand are reported as MJ values, the abiotic depletion of elements is reported in terms of the kg Sbe, while the climate change is reported in terms of the kg CO<sub>2e</sub>.

## 7. Handprint in organizations

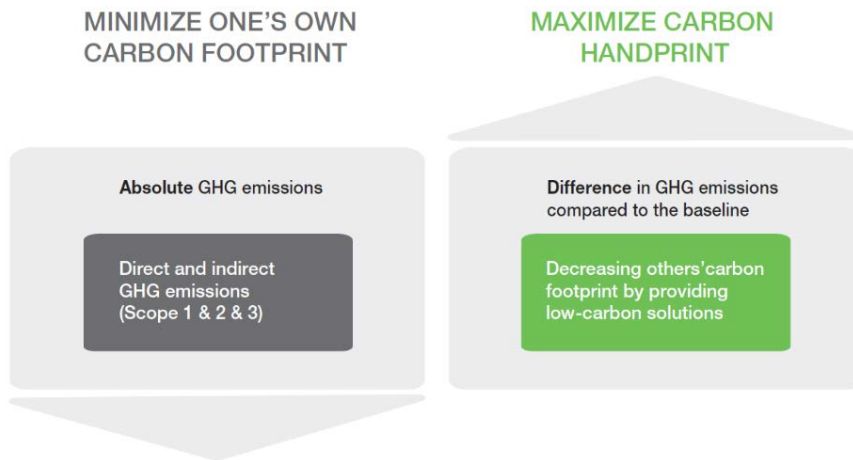
Organizations can have positive impacts on the environment. While the carbon handprint approach was originally developed for products, the benefits of the life cycle approach may be extended to the broader prospect of organizational assessments. The assessment for an organization is often more complex than that of a single product. There is more than one product life cycle to follow since most organizations are engaged in many product life cycles, many departments and business divisions are involved, and a large part of the environmental impacts may reside outside the organization's gate.

ISO/TS 14072 states that organizational LCA shall not be used for comparative assertions between organizations intended to be disclosed to the public (e.g., ranking among organizations), but rather it should be used to drive improvements in the given organization. Product LCAs (as well as the footprint and handprint approaches) are meant for comparing products providing the same function. Different organizations have variable product portfolios, numbers of employees, locations, overall business models etc. and therefore comparison between organizations is not realistic.

Like an organizational LCA, handprint in organizations is not intended for comparison between organizations but should be used as an internal tool to gain knowledge on the organizations' performance, potential positive environmental impacts, and spots where actions could be further improved. Handprint calculations of organizations show the environmental hotspots in the value chain and pinpoint where there could be impact reduction potential. From the handprint calculations an organization can gain insight into internal operations and see how impacts in the value chain may differ in different markets. It can also show the environmental potential of different product categories and therefore be used to support strategic decision making.

In this project, companies were interviewed and asked what they considered the most important use of an organizational handprint to be. Most answers stated communication as the most important use of the handprint from an organizational point of view. Companies stated that the handprint would be useful for comparing different years of the organization's own operations. Handprints could be used to show environmental benefits with marketing purposes also.

Especially, at the organizational level, it is important to aim for improvements in both trying to enlarge the handprint while minimizing the footprint. **Figure 45** shows the setting of separate targets for the handprint and footprint related to climate impacts.



**Figure 45.** It is important to set separate targets for both: aiming to enlarge the handprint while minimizing the footprint. The example relates to climate impacts.

In this report, the carbon handprint of organizations is considered, but the methodology applies to other environmental impacts as well.

## 7.1 Steps in the organizational handprint calculation

### Define the scope of the studied solution

The scope of the study should represent the product/service portfolio of the company to be studied.

### Identify potential handprint contributors

The corporate handprint contributors come from the product/service portfolio of the company. Products or services that have the possibility to help others mitigate their emissions contribute to the corporate handprint.

### Identify the environmental impacts in question and their potential indicators

All relevant environmental impacts in the studied corporate case should be specified and, after that, relevant indicators can be identified. In some cases, several impact categories and indicators may need to be considered. After identifying the relevant environmental impacts and indicators, guidelines given for each environmental impact category in the general handprint framework can be followed.

## Identify the users and beneficiaries of the studied solution

Guidelines for identifying the customers as specified in the general guidelines apply. The customers are those who benefit from changes in the product/service portfolio. There may be also additional parties that benefit from the studied solution.

## Define the baseline

Guidelines for defining the baseline as specified in the general guidelines apply.

## Define the functional unit

Guidelines for defining the functional unit as specified in the general guidelines apply.

## Define the system boundaries

Guidelines for defining the system boundaries as specified in the general guidelines apply.

## Define data needs and sources

Guidelines for defining data needs as specified in the general guidelines apply.

## Calculate the footprints

Using equal functional units, the indicators over the life cycle of the two systems are calculated.

## Calculate the handprint

By comparing the footprints of the studied and baseline solutions indicator by indicator, it can be found whether the studied solution reduces the amount of emissions. If multiple indicators are studied, controversial results, i.e., both positive and negative changes, may occur. In case a reduction is achieved in one indicator but there is an increase in another, the results must be communicated transparently.

## Identify the relevant indicators to be communicated

The general guidelines apply.

## Consider critical review of the handprint

The general guidelines apply.

## Communicate the results

The general guidelines apply.

## 7.2 Case study: second-hand items

Helsinki Metropolitan Area Reuse Centre, Kierrätyskeskus, provides usable second-hand items and provides education on environmentally friendly choices. Kierrätyskeskus has several stores in the metropolitan area: in Vantaa, Espoo, and Helsinki. They offer useful second-hand items at reasonable prices, as well as information about sustainable consumption. Kierrätyskeskus sells items that are donated by the public or various companies.

### Define the scope of the studied system

The study considers the carbon footprint of Kierrätyskeskus.

### Identify potential handprint contributors

Three carbon handprint contributors were identified:

1. Products are reused (54%) and the production of primary materials and the manufacture of products are avoided.
2. The rest of the products end up being recycled more efficiently than they would be when disposed directly from households. Especially furniture and books are recycled more efficiently than in households.
3. Environmental education: raising awareness.

This study focused on the first two, as the third is difficult to quantify. However, it is obvious that the third contributor also provides a carbon handprint as Kierrätyskeskus increases environmental awareness among people, companies, and organizations throughout the Helsinki metropolitan area. They provide environmental education and consulting services to 60,000 children, adolescents, adults, and educators each year. Kierrätyskeskus also organizes environmental awareness events and provides educational materials.

Kierrätyskeskus also has a social handprint, as it offers work for people in different life situations: for disabled people, the long-term unemployed, students of the Finnish language, on-the-job trainees, and people performing community service.

### Identify the environmental impacts in question and their potential indicators

The study focuses on carbon emissions and therefore climate change is considered a relevant environmental impact. This is measured as the global warming potential. Other environmental impacts are not considered.

### Identify the users and beneficiaries of the studied solution

Customers can reduce the carbon footprint of their consumption by purchasing used products. Customers can dispose of their used products by donating them to Kierrätyskeskus instead of disposing of them in conventional ways such as putting them into mixed waste bins.

## Define the baseline

The baseline is the situation if Kierrätyskeskus did not exist. For the first handprint contributor the same products as in the studied solution are produced using primary raw materials in the baseline solution. I.e., 54% of products are produced either from primary raw materials (baseline solution) or reused (studied solution). For the second contributor, books are incinerated (baseline solution) or recycled (studied solution). 50% of the recycled paper in the studied solution is assumed to be used for tissue paper production and 50% used for the production of fluting medium, which are both made from primary materials in the baseline solution. The recycling of furniture is assumed to utilize only the steel parts while the other materials of the furniture are incinerated in both solutions. The steel material production is assumed to be steel plate for both the baseline and studied solution.

## Define the functional unit

The functional unit of this study is the Kierrätyskeskus (Helsinki Metropolitan Area Reuse Centre) in 2019.

## Define the system boundaries

The system boundaries cover the life cycle of the products, starting with the arrival at Kierrätyskeskus and ending at the end-of-life treatment or secondary production. The value chain includes the transportation from the donors to Kierrätyskeskus and the internal logistics of Kierrätyskeskus. The transportation from Kierrätyskeskus or primary production to customers is excluded as it is assumed to be the same in both studied and baseline solutions. The use phase of the products was excluded as it is the same in the studied and baseline solutions.

## Define data needs and sources

The emissions avoided due to reuse of products were calculated using an Excel tool provided by Kierrätyskeskus. Fuel consumption data was provided by Kierrätyskeskus. Transportation emissions were calculated using emission factors from the VTT LIPASTO database. Emissions from average energy production were calculated using emission factors from the sustainable development company Motiva. The Ecoinvent database was used to calculate emissions from the tissue paper and fluting medium production. Steel production emissions were calculated with emission factors from the World Steel Association.

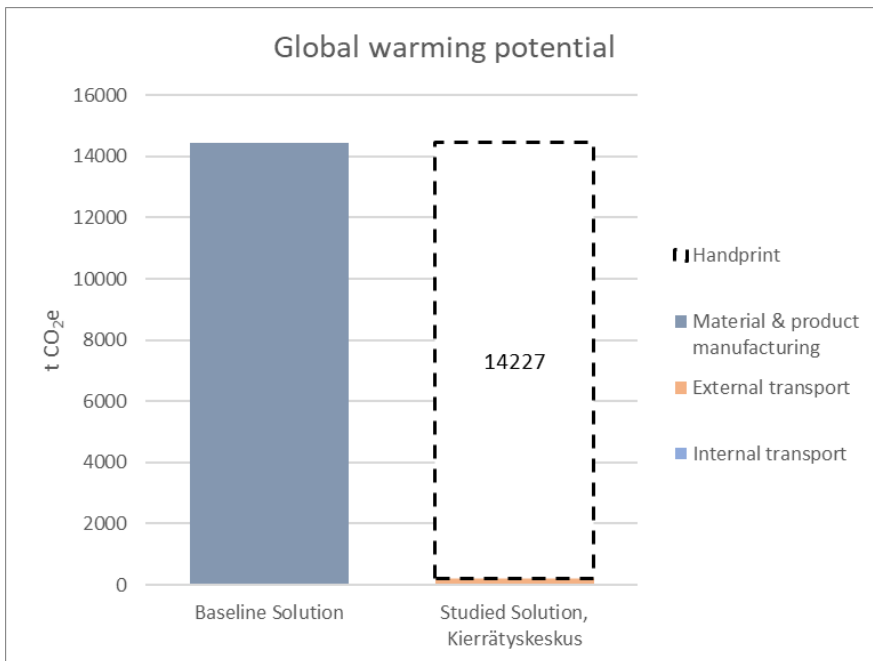
## Quantification: Calculate the footprints and the handprint

In the baseline solution, Kierrätyskeskus would not exist, the products are manufactured using virgin materials, and energy is produced from products that would be reused if Kierrätyskeskus was operational.

The results of the baseline and studied solution and the created handprint of the first handprint contributor (i.e., product reuse) are shown in **Figure 46**. The internal

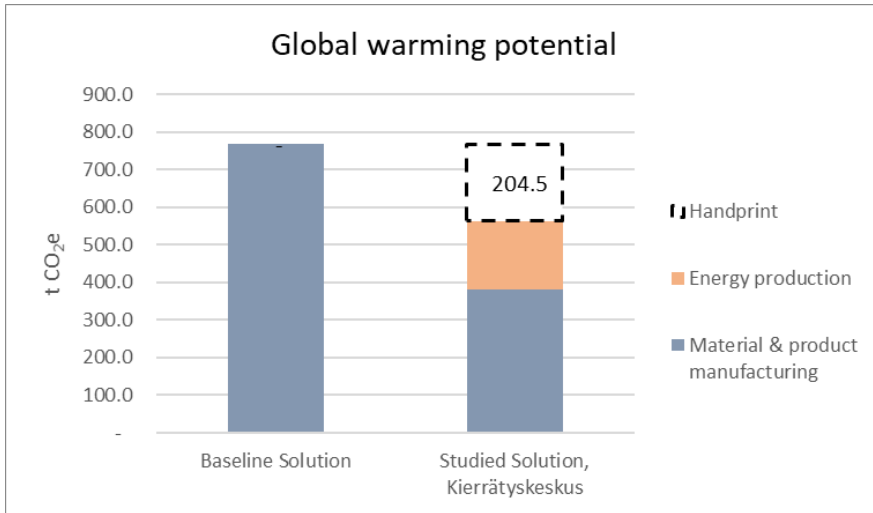


and external transport that include combustion emissions and fuel production emissions in the studied solution are insignificant compared to the emissions from primary material and product manufacturing emissions in the baseline solution. Internal transport encompasses all internal logistics of Kierrätyskeskus. External transport includes the transportation of the product by the donor to Kierrätyskeskus. No material or product manufacturing emissions are present in the studied solution as the products are reused.



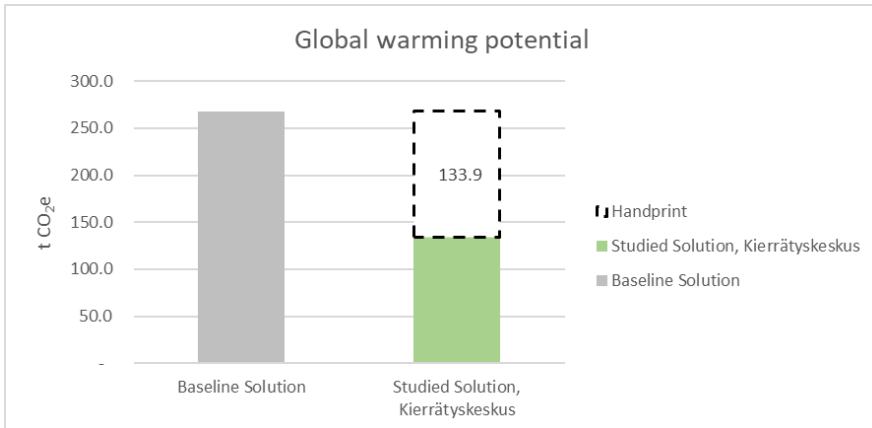
**Figure 46.** Climate change results of the first handprint contributor, product reuse.

The results of the baseline solution and the studied solution and the created handprint for the second handprint contributor (the recycling of books ) are shown in **Figure 47**. Books are incinerated in the baseline solution, but due to the paper in the books containing 100% biogenic carbon it is not included in the carbon footprint. Other materials in books are not considered as paper makes up most of the material in books. A handprint is still created due to secondary production of tissue paper with a lower carbon footprint than primary production, even though the primary fluting medium production has a lower carbon footprint than fluting production from recycled materials. Since the incineration of books create energy in the baseline solution, a similar amount of energy is produced in the studied solution with an average Finnish CHP plant.



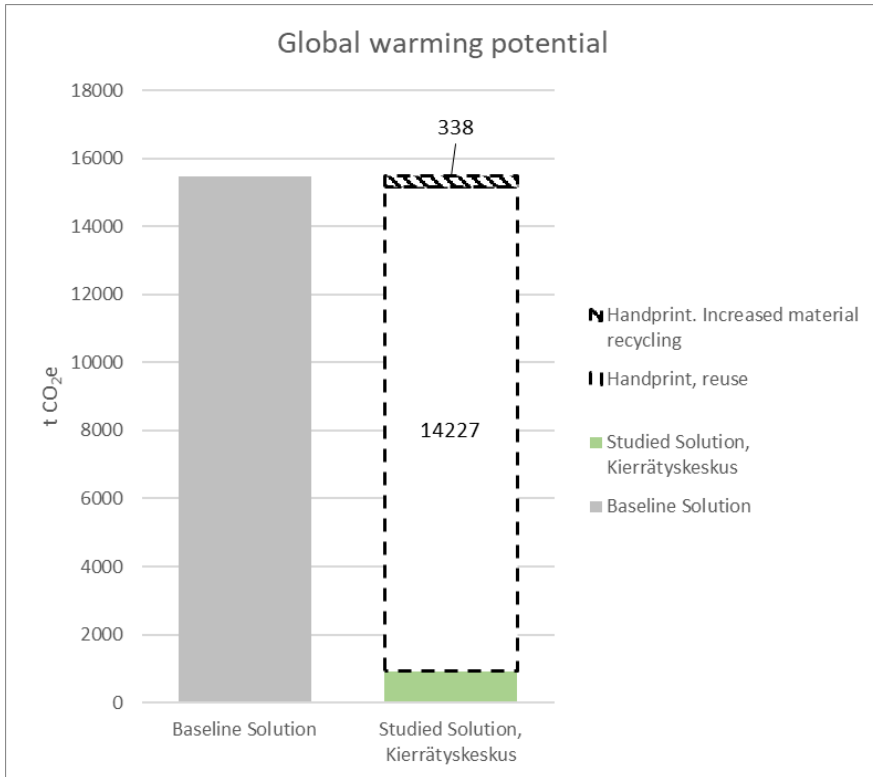
**Figure 47.** Climate change results of the second handprint contributor, more efficient recycling of books.

The results of the baseline and studied solution and the created handprint of the second handprint contributor, the more efficient recycling of furniture, is presented in **Figure 48**. It is assumed that about one third of the furniture mass is steel. Only steel production is considered for this handprint contributor as the rest of the furniture materials are considered to be incinerated in both solutions. It is assumed that emissions from incineration both in the baseline and in the studied solution would be equal, and steel would be the only material which would be more efficiently recycled in the studied solution. A handprint was created as the secondary steel production had lower emissions than the primary production of steel.



**Figure 48.** Climate change results of the second handprint contributor, more efficient recycling of furniture.

The results of the baseline solution and studied solution and the created handprint of Kierrätyskeskus in 2019 are presented in **Figure 49**. A significant handprint is created mainly due to the reuse of products.



**Figure 49.** Global warming potential results of Kierrätyskeskus in 2019.

In the case of Kierrätyskeskus, a large handprint is created with a relatively small footprint. Most of the handprint is created thanks to the emissions avoided from material and product manufacturing due to reuse. The second handprint contributor with the increased recycling of books and furniture also creates a handprint, but to a much lesser degree than the reuse of products.

Identify the relevant indicators to be communicated

Climate change in terms of the global warming potential should be communicated.

Consider critical review of the handprint

A critical review was not conducted, as this case was done for the purposes of developing the corporate handprint approach.

## Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. The carbon handprint results should be communicated in terms of the kg CO<sub>2</sub>e.

### **7.3 Case study: packaging from renewable materials**

This case study focused on the carton board materials of Stora Enso Packaging Materials division. Their biggest product categories: liquid packaging board, folding carton board, food service and food packaging board, containerboard and cigarette packaging board were compared to relevant fossil-based plastic solutions and other carton solutions from different producers with the same end use. The potential for a handprint was tested when fossil plastic-based products and carton products not produced by Stora Enso are replaced with Stora Enso's carton board products.

#### Define the scope of the studied system

The study considers the carbon footprint of carton board materials from the Stora Enso Packaging Materials division.

#### Identify potential handprint contributors

The main contributor to carbon handprint is that Stora Enso's products are made from renewable paperboard and thus the use of fossil materials is avoided.

#### Identify the environmental impacts in question and their potential indicators

The study focuses on carbon emissions and therefore climate change is considered a relevant environmental impact. It is measured as the global warming potential. Other environmental impacts are not considered.

#### Identify the users and beneficiaries of the studied solution

Stora Enso's products fulfil the same function as the products in the baseline solution. Customers of Stora Enso benefit from the studied solution as they will be able to use renewable packaging instead of alternatives made from non-renewable materials and therefore reduce the carbon footprint of their consumption. In addition to this, other companies in the supply chain benefit from the studied solution as their business is increased.

#### Define the baseline

The baseline solution is defined as where Stora Enso products would not be on the market, and all demand would be met by fossil-based products and other carton products from different producers. The shares of different alternative products in the

baseline are based on estimates from Stora Enso. For product categories which have carton-based alternatives, the share of Stora Enso's production is removed from the baseline solution.

### Define the functional unit

The functional unit of this study is the production of Stora Enso Packaging Materials Division in 2019. Only the production of products is considered, not support activities, for example. All products are made from fossil raw materials (baseline solution) or carton materials (studied solution) but used in a similar way. The baseline solution contains the products that are present on the market with the same use case as Stora Enso products.

### Define the system boundaries

The production of raw materials, manufacturing of the packaging products, transportation, and end of life treatment (cradle to grave) are included in the system boundaries. Recycling at the end-of-life phase is treated as cut-off i.e., only transportation to the recycling center is included. Incineration on the other hand is considered fully, meaning the whole process is included within the system boundaries from transportation to the incineration plant and the incineration process itself. Emission credits from possible heat and electricity production were not considered. The use phase of the product is not included. Six major product categories of Stora Enso Packaging Materials division are included in the scope of this study. These six product categories amount to roughly 90% of the total production volume. The remaining product categories were excluded as no baseline products could be specified.

### Define data needs and sources

Primary life cycle inventory data for the products, annual production volumes and baseline market share estimates for the major geographical regions were provided by Stora Enso. Secondary data for the baseline solution's raw material production, processing, transportation processes, and end of life treatment processes were gathered from databases. The weights of the substitute products were calculated using mass replacement factors. The production process of the substitute products was simplified to include 1–2 raw materials and 1 manufacturing process.

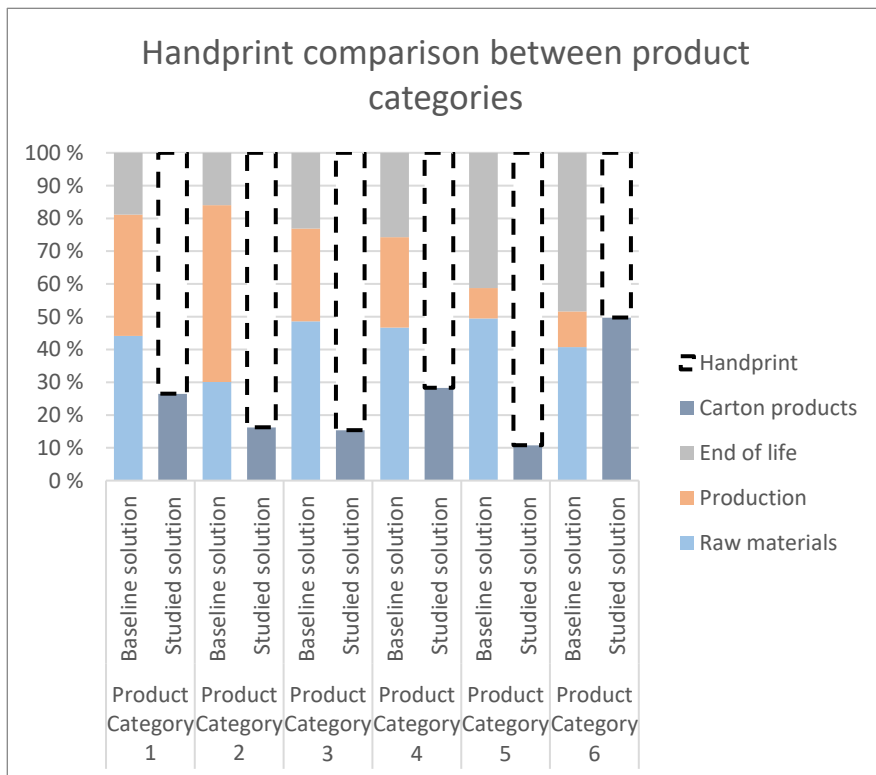
The LCA calculations were done using the SULCA software, using PEF Climate Change indicators. Secondary data from the Ecoinvent 3.7 database with the cut-off approach was used for fuel and energy production, transportation emissions, raw material production, and processing.

The end-of-life treatment methods considered were incineration and recycling. Recycling rates for the various products were gathered from databases and the literature. The recycling and incineration emissions for the products in the studied solution were provided by Stora Enso.

## Quantification: Calculate the footprints and the handprint

In the baseline solution, Stora Enso's products are not on the market and all demand is met by fossil plastic-based products and other carton solutions. The quantity of baseline products in each product category was calculated based on the estimated market shares.

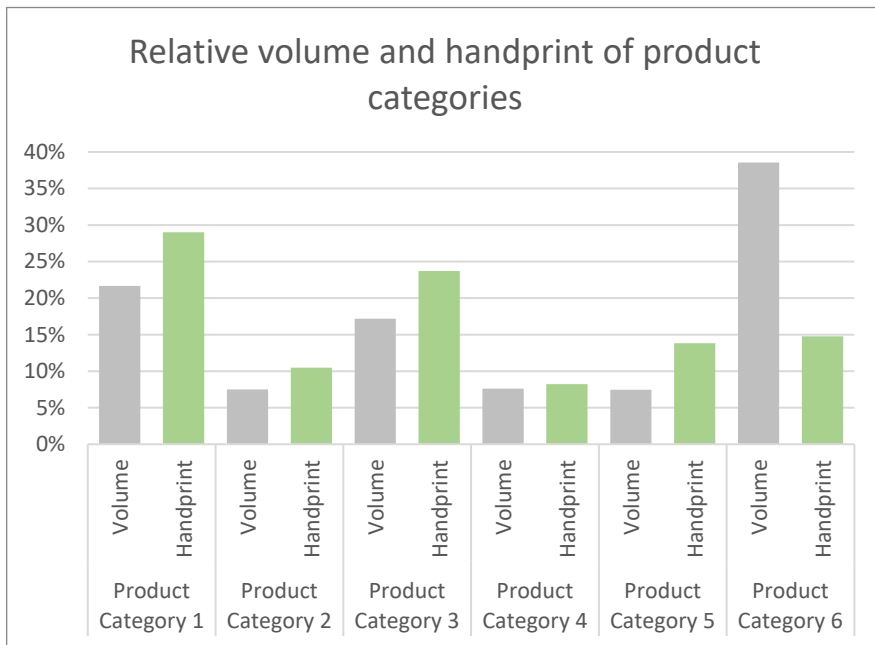
The results of the baseline solution and studied solution and the created handprint per product category are presented in **Figure 50**. Handprints are created in each product category. The baseline solution carbon footprint is divided into raw materials, production, and end-of-life stages.



**Figure 50.** Handprint results per product category.

**Figure 51** shows the relationship between production volumes and the handprint as shares of the total volume and handprint. Product categories with a high or low handprint compared to the production volume can be identified. For five of the product categories the handprint share is larger than the volume share. These products have good handprint potential. Product category 6 with 39% of the production volume only contributes 13% to the handprint. This shows that there is little handprint

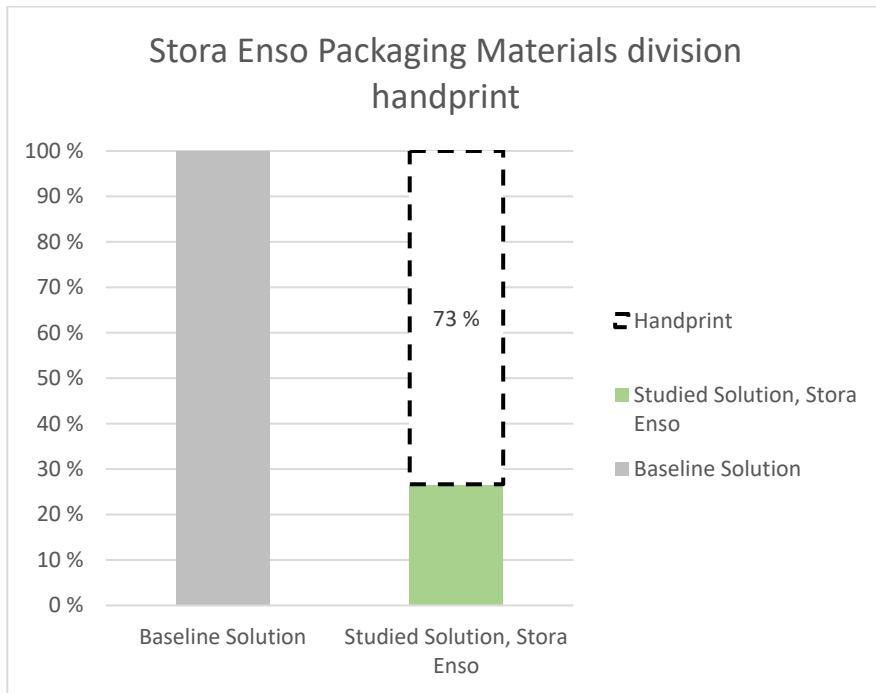
potential compared to the production volume in that product category. In comparison, product categories 3 and 5 show a lot of handprint potential even though they comprise a relatively small part of the total production volume.



**Figure 51.** Volume and handprint comparison of product categories.

The total handprint of Stora Enso Packaging Materials division is presented in **Figure 52**. The carbon footprint of Stora Enso products is only 27% of the footprint of the products in the baseline solution so a significant handprint is created.





**Figure 52.** Handprint result for the Stora Enso Packaging Materials division.

Identify the relevant indicators to be communicated

Climate change as global warming potential should be communicated.

Consider critical review of the handprint

A critical review was not conducted, as this case was done for the purposes of developing the corporate handprint approach.

Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. The carbon handprint results are communicated in terms of the kg CO<sub>2</sub>e.

## 8. Project handprint

Determining the beneficial environmental impacts of projects is important in many cases, e.g., when evaluating investment decisions or verifying the results of a project. Previously, guidelines for quantifying and reporting greenhouse gas emissions reductions from climate change mitigation projects have been introduced (ISO 14064-2:2019, GHG Protocol 2003). However, in this report, general guidelines for the project handprint are also given for other environmental impacts than only climate change. The same environmental impacts and indicators can be used for the project handprint as the handprint framework presents with slight modifications presented below.

The project handprint can be assessed beforehand or after a project, referred to as the pre- or post-project perspective. The assessment of the project handprint before implementing a project might be important for example, when evaluating investment decisions. However, sometimes a project's environmental benefits cannot be assessed until the end of a project. In any case, monitoring of the project is an essential part of the project for verifying results and for determining how set goals have been met. Monitoring is regarded as a best practice also in the International Organization for Standardization (ISO) management standards (ISO 14064-2:2019) and is required by most investors.

### 8.1 Steps in the project handprint calculation

#### Define the scope of the studied solution

A project can be defined as a non-recurrent activity to achieve the preferred outcome in a defined time frame. Project activities should be identified and defined accurately to understand potential mechanisms that would create a handprint. All the activities that would bring improvements in some environmental sectors are determined.

#### Identify potential project handprint contributors

After defining the scope of the studied project, potential handprint contributors can be identified. The aim is to identify the hypothetical benefits of the project and mechanisms behind them. A handprint contributor could, for example, be a new technology or product producing fewer emissions, an improvement on an existing technology or process, or a new service. However, a project handprint should be separated from a product's or service's handprint. For a project it is characteristic that it has the beginning and an end, a project plan, clear goals, and the aim to create something new that will bring benefits also after the project. Additionally, usually there are external investors financing a project, and a finalized budget.

## Identify the environmental impacts in question and their potential indicators

It should be specified, which environmental impacts are relevant in the studied project and after that the relevant indicators can be identified. The relevancy of the environmental indicators is closely linked to the mechanism identified which may contribute to the creation of the handprint in the previous step. In some cases, it may be necessary to examine several impact categories and indicators. After identifying the relevant environmental impacts and indicators, guidelines given for each environmental impact category in the general handprint framework can be followed.

## Identify the users and beneficiaries of the studied solution

Identify parties that will benefit from the project. In some cases, the project brings benefits to many parties, or the users may not be identified. In these cases, an examination can be done at the system level. For example, in climate change mitigation projects the beneficiary might be society as a whole. However, all the parties related to the studied project should be identified.

## Defining the baseline

The baseline for the studied project in the handprint calculation should be the situation without the project. In other words, the baseline solution should represent the conditions that would have occurred in the absence of the studied project. In some cases, it might be relevant to choose an alternative or similar project to the studied solution as a baseline project. Temporally, the baseline solution should cover the same period as the project.

## Defining the functional unit

Guidelines for defining the functional unit as specified in the general guidelines apply. Additionally, the period of time under examination should be representative over the entire project. This means that the time period under examination should be long enough to make sure that variability in operating patterns are accounted for in the assessment.

## Defining the system boundaries

The system boundaries of a project handprint calculation include all the activities associated with the studied and the baseline project that have an effect on the environmental impact under examination. The same system boundaries should be applied to both the studied and the baseline solutions. Otherwise, the same guidelines for defining the functional unit as specified in the general guidelines apply.

## Defining data needs and sources

The same guidelines for defining the system boundaries as specified in the general guidelines apply. Additionally, in the case of projects, the data accuracy strongly

depends on the time of the handprint assessment. In a pre-project assessment the data is mostly based on the literature, or on earlier projects, and more assumptions must be made. In post-project assessments the data will more likely be verified and based on real project data. Data accuracy, verifiability and reliability have a substantial impact on the results, which have to be kept in mind when evaluating or monitoring a project.

## 8.2 Case study: leaching plant in a copper smelter

In this case, the Nordic Investment Bank (NIB) is investing in a project, in which the Swedish mining and smelting company Boliden is building and launching a new leaching plant at their copper smelting facilities in Rönnskär, Sweden. The leaching plant can extract metal from residual material from the copper smelter and thus improve the resource efficiency of the operations. This case supports the methodological development for the project handprint definition. Therefore, the calculations and the results provided are estimations based on generally available data and are subject to change if more detailed analysis are conducted. The framework of the study is described in Appendix A.

### Define the scope of the studied solution

The scope of the solution is the leaching plant project at the Boliden facilities in Rönnskär financed by NIB and Boliden.

### Identify potential project handprint contributors

The resource efficiency of the facility is assumed to be improved with the leaching process via the following mechanisms:

- recovering metals as much as possible (from the residual material)
- reducing the amount of waste and hazardous waste
- reducing the land use needs, as waste will no longer be stored on site
- reducing the wastewater treatment needs, as waste is no longer stored on site
- reducing energy use while avoiding traditional means such as mining in the metal production

### Identify the environmental impacts in question and their potential indicators

Given the handprint mechanisms above, the relevant environmental impact categories were selected from the ones suggested for the resource handprint: the use of materials (minerals and metals) as well as energy. In addition, the carbon handprint was considered interesting to calculate. As residual material or in other words waste is utilized as a raw material in this project, it is also relevant to include the waste

amount reduction as an indicator in the study. Land use and water use were left out of the assessment due to lack of data.

### Identify the users and beneficiaries of the studied solution

From the environmental impacts point of view, there are several users or beneficiaries in this study. Through resource efficiency improvements Boliden can increase their productivity and reduce various environmental impacts. A local pulp mill can gain a utilization possibility for their side streams (green liquor and lye) and side streams from Boliden's own operations (sulfuric acid) can be used in the leaching plant. Boliden will have less waste to be treated, as the waste amounts will be significantly reduced through utilization in the leaching plant. Additionally, the end customers are assumed to be able to use metals with a lower environmental burden, as the metal will be derived from residual material rather than from virgin sources.

### Defining the baseline

The baseline is defined as the situation without the project: The copper and the lead is produced by traditional means (mostly mining from virgin sources and partly from recycled sources using scrap metal). In addition, the waste from the copper smelter is treated by traditional means, meaning storing it on site.

### Defining the functional unit

The functional unit of the study represents the annual amount of copper and lead produced through the leaching plant or the equal amount through the baseline route. In the study, it is assumed that annual production of copper is 27.4 ktonnes and for lead it is 24.75 ktonnes.

### Defining the system boundaries

The system boundaries of the study represent the unit processes in the copper and lead value chain from cradle to grave. However, there are some limitations to the calculations in terms of whether all the relevant unit processes are included. Nevertheless, as this calculation is to support the methodological development only, the limitations are regarded as acceptable.

In the baseline case, the copper and lead are produced by mining and metal recycling via electrolysis. All relevant unit processes from the cradle to grave are included. In the studied solution, the copper and lead are produced only through the leaching plant route. The residual material entering the leaching plant is considered waste, therefore it is considered to have no burden. Other inputs needed in the leaching plant as indicated by Boliden (chemicals, water, heat, electricity) are taken into account. The outputs of the leaching plant are copper sulphate and copper/zinc sulphate. The processes needed to convert these sulphates into copper, and lead is not included in the study, which causes some error.

## Defining data needs and sources

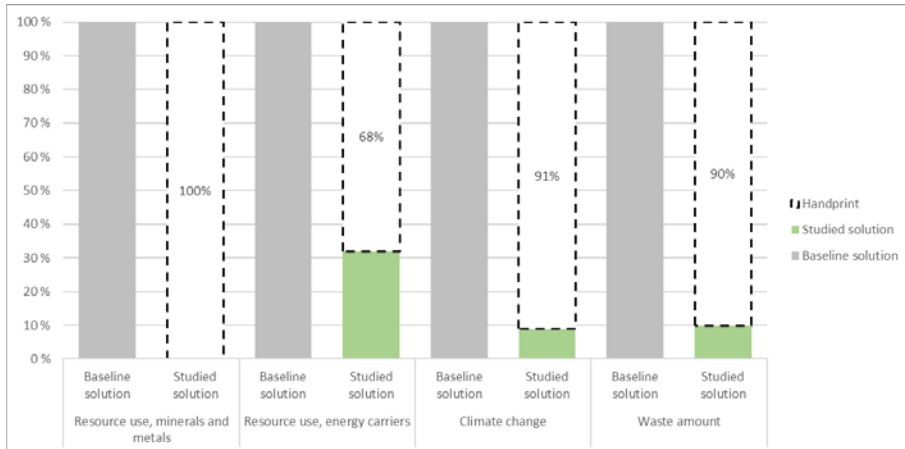
Primary data was preferred for all operations at Boliden, while secondary data was used concerning the supply chain processes. Primary data was used for the Rönnskär facility operations reported in the GaBi database for the baseline processes (lead and copper production from cradle to gate). The reference year for this data is 2019 and it is estimated that the data is valid until 2022. For the leaching plant, Boliden has provided primary data on the inputs and outputs of the leaching plant. Secondary complementary data was used for the production of the inputs needed in the leaching plant. Whenever possible, the background processes represent Swedish conditions.

## Quantification: Calculate the footprints and the handprint

**Figure 53** presents the results for the leaching plant project. The impact assessment method used is the Environmental Footprint version 3.0 (Fazio et al. 2018) and the calculations were made using the GaBi software version 10.0.0.71. As can be seen from these results a handprint was created for all the assessed indicators for the studied solution (the leaching plant project). The major reason behind the handprint creation is the use of the residual material, i.e., waste, as a raw material, which enters the system burden free. Processing the residual material in the leaching plant naturally requires energy and material inputs, but not to the same extent that it is required in the baseline route. The percentual handprint result is highest in the category resource use of mineral and metals, where the studied solution has under a 1% impact compared to the baseline solution. This is explained by the relatively high impact of the mining in the baseline solution compared to the burden free material entering the leaching plant in the studied solution.

From the energy carrier and climate change point of view, the studied solution seems to be a better solution. In the studied solution the major contributors to these environmental impact categories was the energy needed in the leaching process: i.e., electricity assumed to be derived from the Swedish grid mix, and the thermal energy assumed to be derived from the biomass. The production of sodium hydroxide has the highest global warming potential of the inputs needed in the leaching plant. However, in the modelling, the production process used for mixing the sodium hydroxide (50%) took place in the EU and various production locations. At Boliden, the sodium hydroxide is derived from close to the pulp mill, and thus there could be an overestimation at least of the greenhouse gas emission caused by transportation. In the baseline situation the production of copper causes a greater environmental burden than the production of lead. Due to the nature of the data used in the baseline situation (aggregated database data) it is not possible to very comprehensively analyze the reasons behind the baseline results.

The waste amount was also seen as a relevant indicator and thus analyzed here alongside the resource and carbon handprint. Even though there are some uncertainties in the estimations of Boliden about the actual waste flows around the leaching plant, it can be seen that the waste amount can be significantly reduced via the leaching plant route.



**Figure 53.** Handprint results for the leaching plant project.

While analyzing these results, it must be kept in mind that the copper smelter operations feed the residual material to the leaching plant, and the leaching plant could not thus operate without them. However, as indicated by Boliden, after using the stored residual material alongside the Rönnskär smelter waste, the leaching plant could receive and treat residual material from other sites as well. In that situation transportation needs might play a more relevant role in the study, and therefore they should be analyzed more carefully then. In any case, it would be recommended to repeat the study after some years of operation to confirm whether the leaching plant is functioning as planned and is delivering the environmental benefits that this handprint study indicates.

#### Identify the relevant indicators to be communicated

The resource handprints, carbon handprint, and waste amount reduction should be communicated.

#### Consider critical review of the nutrient handprint

A critical review was not conducted, as this case was done of the purpose of developing the project handprint approach.

#### Communicate the results

The results should be communicated respecting appropriateness, clarity, credibility, and transparency. Resource handprints should be reported in terms of the kg Sb eq. and MJ, the carbon handprint in terms of the kg CO<sub>2e</sub> and the waste amount reduction should be reported in tonnes. The results are here reported in percentual changes due to uncertainties in the data used.

## 9. Handprint communication

This chapter discusses specific aspects related to the communication of environmental handprint results. A review of existing guidelines and standards relevant to handprint communication was presented in the Final Report of the Carbon Handprint Project (Vatanen et al. 2018). An updated checklist for preparing handprint communication is presented. The checklist is compatible with the existing guidelines, standards, and good practices for environmental communication.

The handprint approach is considered particularly beneficial for communication purposes. The potential target groups for handprint communication cover a broad range of both internal and external stakeholders, including customers, employees, investors, consumers, policymakers, and the general public. Depending on the context, the customer may be a consumer, a company, or a public organization, but often the most important target group will be the next actor in the value chain. As with all communication, handprint-related communication must be targeted according to stakeholder needs and interests.

Several guidelines, standards and recommendations for environmental communication and marketing are available. The overall aim of the guidelines and standards is to present good practices, prevent misleading statements and unfair competition and protect consumers. The guidelines are relevant to all environmental marketing and claims but are especially relevant to handprint communication since the aim of the handprint is to communicate positive environmental impacts. It is extremely important therefore to avoid misleading statements that could be interpreted as greenwashing.

European Standard EN ISO 14063 Environmental Communication - Guidelines and Examples (ISO 14063 2020) provides guidance for all organizations regarding general principles, policy, strategy, and activities that may relate to both internal and external environmental communication, and to an organization or its products. The generic principles presented in ISO14063 can be considered comprehensive, overall guidelines for preparing environmental communication and are thus also a valid guideline for handprint communication. According to the standard, the following principles should be applied in all environmental communication:

- Transparency – the processes, procedures, methods, data sources and assumptions related to environmental communication should be made available to all interested parties (but taking into account confidentiality requirements).
- Appropriateness – the information should be relevant and understandable to the stakeholders.
- Credibility – communication should be conducted in an honest and fair manner and the information should be produced using recognized and reproducible methods and indicators. All communication should be open and responsive to the needs of interested parties.
- Clarity – Communication and the language used should be understandable to the interested parties.



- Regionality – Communication should take into consideration the local or regional environmental context relevant to the area where the corresponding environmental impacts occur. (ISO 14063 2020)

Specific guidance regarding communication of the LCA-based footprint-related information is provided in ISO14026 (ISO 14026 2017), which lists both generic principles and examples that are also useful in the case of handprint communication. According to the standard, the main principles that should be followed when communicating footprint results are:

- Credibility and reliability – information should be relevant and reliable in terms of addressing areas of concern.
- Life cycle perspective – relevant life cycle stages should be considered.
- Comparability – comparison is possible only between products in the same product category and with the same functional unit.
- Transparency – access to information on where the footprint communication originated should be provided.
- Regionality – the local or regional context relevant to the area in which the impacts occur should be considered (ISO 14026 2017).

In general, LCA studies include a lot of information and assumptions that would need to be made clear to the receiver in order for them to properly understand the result and its meaning. It is therefore reasonable to assume that similar challenges would apply to the handprint, which is based on the LCA and footprint methodologies. As the handprint is a new concept, the scientific grounding of the approach needs to be emphasized, e.g., by highlighting its compliance with the same standards that are applied to the LCA and footprint. Transparency and clarity are needed, especially regarding the baseline solution and the origin of the handprint. The communication must be targeted according to the audience (own employees, consumers, other companies, policy makers, other stakeholders) taking into account their knowledge of the value chain in question, together with their general environmental awareness.

Also, interested parties should be informed how and where they can get further information. In addition, anyone presenting a handprint result should be prepared to provide additional information and share original calculations, reports, or relevant parts of them, and use critical reviews as a necessary third-party verification.

Due to the novelty of the concept, it is recommended to distinguish between information on the handprint concept and information on case study results (actual handprint results). Targeted communication on both the handprint concept and specific case results will be needed during the introductory phase of the concept.

## 9.1 Checklist for planning and preparing handprint communication

To support the planning phase of environmental handprint communication, we have updated the checklist, which follows the general principles of ISO14063 for environmental communication and the specific questions corresponding to the principles laid out in the standard (ISO14026) on footprint communication. The checklist provides a useful summary of basic principles and expands the scope of the handprint guidance from calculation to communication. It is not exhaustive and cannot be used as the sole guideline for communication planning. The aim of the checklist is to help in preparing environmental claims that are specific and that provide sufficient background information, thus avoiding generalized statements that could be easily viewed as greenwashing.

### Checklist for planning and preparing handprint communication

#### \* Necessary information

##### Appropriateness

- Is the intended audience familiar with the studied product or service and the value chain in question?
- Is the intended audience familiar with the life cycle assessment method or the footprint concept?
- Is the intended audience familiar with the handprint concept?

##### Clarity

- \* **What is the quantity and unit of the calculated handprint?**
- \* **What is the baseline solution?**
- Who are the users or beneficiaries of the studied solution?
- \* **What are the main contributors to the handprint (or mechanisms behind emission or resource use reduction)?**
- \* **What year does the data and/or the most important assumptions apply to?**
- \* **What geographical area does the result directly or potentially apply to?**
- In which parts of the life cycle does the handprint (emission or resource use reduction) take place?
- How significant is the handprint within the studied solution provider's product portfolio?

##### Credibility

- Which methods, guidelines and standards were used for the assessment?
- Who was responsible for conducting the assessment?
- Has the study been critically reviewed?

## Transparency

- Is the original study available to the public?
- Do you have a result report that can be made publicly available or shared with interested stakeholders upon request?
- \* **How can/will additional information be provided to interested parties?**

## 10. Conclusions and discussion

This project was a response to the need of companies to communicate positive impacts that companies, products, and projects may initiate when replacing less sustainable solutions. While footprints should be reduced as much as possible, they can only be mitigated close to zero in the best case, but some negative impact still remains, and the actions are thus limited. However, since positive impacts, handprints, appear in the value chains of other actors, the potential to do good is unlimited.

A water handprint assessment considers the potential positive environmental impacts related to water associated with a product, process, or organization. The assessment is based on ISO-standardized water footprints (ISO 14046) and a comprehensive study should include several water related impacts, e.g., scarcity, availability, eutrophication and toxicity. A water handprint may also be connected to nutrient, resource, and carbon handprints; so a comprehensive LCA may be reasonable to show all the possible environmental benefits created.

A nutrient handprint is a multidimensional indicator applicable to different nutrients. Criteria and preconditions have been established that define which changes in indicator values compared to a baseline solution enable nutrient handprint creation. The nutrient handprint consists of positive changes in the nutrient balance of a system, i.e., input and output nutrient flows. Additionally, the environmental impacts of nutrient emissions, such as the eutrophication potential, are considered. The nutrient handprint may require system expansion to reveal the positive impacts, and thus, become a rather wide area of responsibility for those studied solution providers who wish to create a nutrient handprint.

An air quality handprint considers the reduction in emissions of air pollutants and is assessed separately for different air pollutant compounds such as PM, O<sub>3</sub>, NO<sub>x</sub> and SO<sub>2</sub>. Typically, air pollutant emissions are released and affect the environment locally, but recognizing impacts in different locations including the whole life cycle of the studied product or service in the assessment is important. Assessment of the air quality handprint is always conducted at least at the inventory level, but if possible, taking the calculations further to the mid and end point is desirable.

The resource handprint is suggested to be calculated based on the abiotic depletion potential of elements and fossil fuels, the cumulative energy demand, and the carbon footprint. These indicators show most of the changes in the life cycle, since they consider renewable and fossil energy, and the recycling of materials, and changing from fossil to renewable materials is shown in these values. However, the selected indicators may be insufficient, e.g., when renewable raw materials are the focus of the study. In such cases, land use indicators and a comprehensive LCA should be applied to study the environmental impacts even further.

The handprint in organizations provides information for strategic decision making and steering internal operations by showing the environmental potential of different product categories and how impacts in the value chain may differ in different markets. Similarly to organizational footprints, an organization shall not be compared to

other organizations based on handprints. At the organizational level it is important to try enlarging the handprint while minimizing the footprint, and both perspectives may be communicated but not subtracted from each other.

The project handprint aims to track positive environmental impacts of projects. All environmental impact categories and indicators presented in the general handprint guidelines can be applied in the project handprint calculation. An assessment can be conducted before a project to evaluate the potential outcome or afterwards to monitor and verify the results of a project.

Even though water, nutrients, air quality, and resources were assessed separately in this report, they may be interlinked and connected to each other and to the carbon handprint. It may be reasonable to proceed with a comprehensive LCA to show all the possible environmental benefits created and to make sure that the environmental burdens are not shifted from one life cycle step or one environmental impact category to another.

## References

- Alakangas, E., Hurskainen, M., Jaatikainen-Luntama, J. & Korhonen, J. 2016. Suomessa käytettävien polttoaineiden ominaisuuksia. VTT Technology 258. <https://www.vttresearch.com/sites/default/files/pdf/technology/2016/T258.pdf>
- Aluehallintavirasto. 2014a. Lapland Goldminers Oy:n Pahtavaaran kaivoksen ympäristöluvan ja vesilain mukaisen luvan 68/06/1 lupamääräyksen 2 muuttaminen, Sodankylä. PSAVI/39/04.08/2013. <https://ylupa.avi.fi/fi-FI/asia/891563>
- Aluehallintavirasto. 2014b. Kevitsan kaivoksen tuotannon laajentamisen ympäristö- ja vesitalouslupa sekä töiden ja toiminnanaloittamislupa, Sodankylä. PSAVI/144/04.08/2011. <https://ylupa.avi.fi/fi-FI/asia/891240>
- Aluehallintavirasto. 2020. Sotkamon hopeakaivoksen toiminnan laajentaminen ja muuttaminen. PSAVI/5663/2018. <https://ylupa.avi.fi/fi-FI/asia/1566968>
- Boulay, A-M., Bare, J., Benini, L., Berger, M., Lathuillière, M.J., Manzardo, A., Margni, M., Motoshita, M., Núñez, M., Pastor, A.V., Ridoutt, B., Oki, T., Worbe, S. & Pfister, S. 2018. The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). The International Journal of Life Cycle Assessment 23, 368–378. <https://doi.org/10.1007/s11367-017-1333-8>
- EEA. 2018. Air quality in Europe—2018 report, Report. doi: 10.2800/62459.
- EN 590:2013. 2017. Automotive fuels. Diesel. Requirements and test methods.
- European Commission. No date. Available at: [https://ec.europa.eu/environment/resource\\_efficiency/](https://ec.europa.eu/environment/resource_efficiency/)
- Fazio, S., Biganzioli, F., De Laurentiis, V., Zampori, L., Sala, S. & Diaconu, E. 2018. Supporting information to the characterization factors of recommended EF Life Cycle Impact Assessment methods, version 2, from ILCD to EF 3.0, EUR 29600 EN, European Commission, Ispra, 2018, ISBN 978-92-79-98584-3, PUBSY No. JRC114822. <https://doi.org/10.2760/002447>
- FMI (Finnish meteorological Institute). No date. Otsoni. Available at: <https://www.ilmatiiteenlaitos.fi/otsoni-ilmansaasteena>
- GHG Protocol. 2003. The GHG Protocol for Project Accounting. World Resources Institute (WRI) and World Business Council for Sustainable Development. Available at: <https://ghgprotocol.org/standards/project-protocol>

- Grönman, K., Ypyä, J., Virtanen, Y., Kurppa, S., Soukka, R., Seuri, P., Finér, A. & Linnanen, L. 2016. Nutrient footprint as a tool to evaluate the nutrient balance of a food chain. *Journal of Cleaner Production* 112(4), 2429–2440. <https://dx.doi.org/10.1016/j.jclepro.2015.09.129>
- HSY. 2016. Ilmanlaatu ja siihen vaikuttavat tekijät pääkaupunkiseudulla vuosina 2006–2015. Ilmansuojelusuunnitelman taustaraportti. Helsingin seudun ympäristöpalvelut -kuntayhtymä. Available at: [https://www.hsy.fi/globalasets/ilmanlaatu-ja-ilmasto/tiedostot/9\\_2016-ilmanlaatu2006-2015-taustaraportti.pdf](https://www.hsy.fi/globalasets/ilmanlaatu-ja-ilmasto/tiedostot/9_2016-ilmanlaatu2006-2015-taustaraportti.pdf)
- Huysman, S., Sala, S., Mancini, L. Ardente, F., Alvarenga, R.A.F., De Meester, S. Mathieux, F. & Dewulf, J. 2015. Toward a systematic framework for resource efficiency indicators. *Resources, Conservation and Recycling* 95, 68–76. <https://doi.org/10.1016/j.resconrec.2014.10.014>
- Hänninen, O., Korhonen, A., Lehtomäki, H., Asikainen, A. & Rumrich, I. 2016. Ilmansaasteiden terveysvaikutukset. Ympäristöministeriön raportteja 16/2016.
- Hänninen O., Leino O., Kuusisto E., Komulainen H., Meriläinen P., Haverinen-Shaugnessy U., Miettinen I. & Pekkanen J. 2010. Elinympäristön altisteiden terveysvaikutukset Suomessa. *Ympäristö ja Terveys -lehti* 3/2010, 12–35.
- ISO 14026. 2017. ISO14026:2017 Environmental labels and declarations – Principles, requirements, and guidelines for communication of footprint information
- ISO 14040. 2006. Environmental management. Life cycle assessment. Principles and framework.
- ISO 14044. 2006. Environmental management. Life cycle assessment. Requirements and guidelines.
- ISO 14046. 2014. Environmental management – Water footprint – Principles, requirements, and guidelines.
- ISO 14063. 2020. EN ISO 14063:2010 Environmental management. Environmental Communication. Guidelines and Examples.
- ISO 14067. 2018. Greenhouse gases. Carbon footprint of products. Requirements and guidelines for quantification and communication.
- ISO/TS 14072. 2014. Environmental management – Life cycle assessment – Requirements and guidelines for Organizational Life Cycle Assessment.

- Kilpeläinen, P. 2020. Biologinen typenpoisto kaivosvedestä. Diplomityö, Tampereen yliopisto. <https://trepo.tuni.fi/handle/10024/123066>
- Korhonen, A. 2017. Ilmansaastealtistuksen analyysi Suomessa. Pro Gradu-tutkielma, Itä-Suomen yliopisto. [https://erepo.uef.fi/bitstream/handle/123456789/18698/urn\\_nbn\\_fi\\_uef-20171210.pdf?sequence=-1&isAllowed=y](https://erepo.uef.fi/bitstream/handle/123456789/18698/urn_nbn_fi_uef-20171210.pdf?sequence=-1&isAllowed=y)
- Lakanen, L., Grönman, K., Väisänen, S., Kasurinen, H., Soininen, A. & Soukka, R. 2021. Journal of Cleaner Production 290. <https://doi.org/10.1016/j.jclepro.2021.125786>
- Leach, A.M., Galloway, J.N., Bleeker, A., Erisman, J.W., Kohn, R. & Kitzes, J. 2012. A nitrogen footprint model to help consumers understand their role in nitrogen losses to the environment. Environmental Development 1, 40–66. <https://dx.doi.org/10.1016/j.envdev.2011.12.005>
- Lehtomäki, H., Korhonen, A., Asikainen, A., Karvosenoja, N., Kupiainen, K., Paunu, V.-V., Savolahti, M., Sofiev, M., Palamarkchuk, Y., Karppinen, A., Kukkonen, J. & Hänninen, O. 2018. Health Impacts of Ambient Air Pollution in Finland. International Journal of Environmental Research and Public Health 15(4), 736. <https://doi.org/10.3390/ijerph15040736>
- Luostarinen, S. Grönroos, J. Hellstedt, M. Nousiainen, J. & Munther, J. 2017. Suomen normilanta - laskentajärjestelmän kuvaus ja ensimmäiset tulokset. <http://urn.fi/URN:ISBN:978-952-326-441-0>
- Manhart, A., Blepp, M., Fischer, C., Graulich, K., Prakash, S., Priess, R., Schleicher, T. & Tür, M. 2016. Resource Efficiency in the ICT Sector. Final Report. [https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/20161109\\_oeko\\_resource\\_efficiency\\_final\\_full-report.pdf](https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/20161109_oeko_resource_efficiency_final_full-report.pdf)
- Ministry of Environment Finland. 2019. Air pollution control. Available at <https://ym.fi/en/air-pollution-control>
- Modak, J.M. 2011. Haber Process for Ammonia Synthesis. Resonance 7(9), 69–77.
- Niemi, J.V. 2004. Characterization and source identification of a fine particle episode in Finland. Atmospheric Environment 38(30), 5003–5012. <https://doi.org/10.1016/j.atmosenv.2004.06.023>.
- Official Statistics of Finland (OSF): Waste statistics [e-publication]. ISSN=2323-5314. 2018, Appendix table 2. Waste treatment in 2018, 1,000 tonnes. Helsinki: Statistics Finland [referred: 22.9.2020]. Access method: [http://www.stat.fi/til/jate/2018/jate\\_2018\\_2020-06-17\\_tau\\_002\\_en.html](http://www.stat.fi/til/jate/2018/jate_2018_2020-06-17_tau_002_en.html)



- Pajula, T., Vatanen, S., Behm, K., Grönman, K., Lakanen, L., Kasurinen, H. & Soukka, R. 2021. Carbon Handprint Guide v.2.0. Available at: <https://cris.vtt.fi/en/publications/carbon-handprint-guide-v-20-applicable-for-environmental-handprint>
- Pajula, T., Vatanen, S., Pihkola, H., Grönman, K., Kasurinen, H., & Soukka, R. 2018. Carbon Handprint Guide. Available at: [https://cris.vtt.fi/ws/portalfiles/portal/225085665/Carbon\\_Handprint\\_Guide.pdf](https://cris.vtt.fi/ws/portalfiles/portal/225085665/Carbon_Handprint_Guide.pdf)
- THL 2020. Ilmansaasteet. Available at: <https://thl.fi/fi/web/ymparistoterveys/ilman-saasteet>
- Vatanen, S., Pajula, T., Pihkola, H., Behm, K., Hohenthal, C., Grönman, K., Soukka, R., Kasurinen, H., Sillman, J. & Leino, M. 2018. The Carbon Handprint approach to assessing and communicating the positive climate impact of products: Final Report of the Carbon Handprint project, VTT Technical Research Centre of Finland. VTT Technology 346, 74 p. <https://www.vttresearch.com/sites/default/files/pdf/technology/2018/T346.pdf>
- VTT Technical Research Centre of Finland. Seagate technology LLC 2011. Pulsar 2 SSD Product Life Cycle Analysis Summary. Available at: <https://www.seagate.com/files/www-content/global-citizenship/en-us/docs/final-pulsar-lca-summary-report-10-2-2013-ams-031214.pdf>
- Sutton, M.A., Bleeker, A., Howard, C.M., Bekunda, M., Grizzetti, B., de Vries, W., van Grinsven, H.J.M., Abrol, Y.P., Adhya, T.K., Billen, G., Davidson, E.A., Datta, A., Diaz, R., Erisman, J.W., Liu, X.J., Oenema, O., Palm, C., Raghuram, N., Reis, S., Scholz, R.W., Sims, T., Westhoek, H. & Zhang, F.S., with contributions from Ayyappan, S., Bouwman, A.F., Bustamante, M., Fowler, D., Galloway, J.N., Gavito, M.E., Garnier, J., Greenwood, S., Hellums, D.T., Holland, M., Hoysall, C., Jaramillo, V.J., Klimont, Z., Ometto, J.P., Pathak, H., Ploq Fichelet, V., Powlson, D., Ramakrishna, K., Roy, A., Sanders, K., Sharma, C., Singh, B., Singh, U., Yan, X.Y. & Zhang, Y. 2013. Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.
- Traficom. 2018. Ajoneuvojen avoin data [www Document]. <https://www.trafi.com.fi/fi/ajankohtaista/avoin-data>
- UNEP. 2015. Guidance on Organizational Life Cycle Assessment. Available at: [https://www.lifecycleinitiative.org/wp-content/uploads/2015/04/o-lca\\_24.4.15-web.pdf](https://www.lifecycleinitiative.org/wp-content/uploads/2015/04/o-lca_24.4.15-web.pdf)

- Vallius, M., Lanki, T., Tiittanen, P., Koistinen, K., Ruuskanen, J. & Pekkanen, J. 2003. Source apportionment of urban ambient PM<sub>2.5</sub> in two successive measurement campaigns in Helsinki, Finland. *Atmospheric Environment* 37(5), 615–623. [https://doi.org/10.1016/S1352-2310\(02\)00925-1](https://doi.org/10.1016/S1352-2310(02)00925-1)
- World Health Organization (WHO). 2018. Ambient (outdoor) air quality. Updated 2.5.2018. Available at: [https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health)
- Ypyä, J., Grönman, K., Virtanen, Y., Seuri, P., Soukka, R. & Kurppa, S. 2015. Menetelmäkuvaus ravinnejalanjäljen laskemiseksi – Laskentaesimerkinä elintarvikeketju: NUTS-hankkeen loppuraportti. Luonnonvara- ja biotalouden tutkimus 9/2015. <https://urn.fi/URN:ISBN:978-952-326-008-5>



# Appendix A: The handprint frameworks of case studies

Define the scope of the studied solution	Product Water purification technology	Company (product or service portfolio)	Project (a non-recurrent activity to reach the preferred outcome in a defined time frame)		
Identify potential handprint contributors	Technology removes impurities and nutrients from wastewater and enables reuse of water and smaller emissions to receiving water bodies				
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: e.g. ACP (elements and fossil fuels), cumulative energy demand	Water: scarcity, eutrophication	Nutrients: NPK balance and eutrophication, in addition e.g. toxicity, acidification	Air quality: e.g. PM10, PM2.5, NOx, SO2, VOC, health impacts, POCP <sup>2</sup>
Identify the users and beneficiaries of the studied solution	Mining company Sotkamo Silver				
Define the baseline	Wetlands in the mining area				
Define the functional unit	Yearly amounts of water used and emissions to water				
Define the system boundaries	Operational phase (production of the technology considered negligible and excluded). Primary water intake by the mining company, production of the water treatment chemicals, operation of the water treatment plant, released water to environment. The enrichment process operations and mining products are excluded				
Define data needs and sources	LCI data or water treatment chemicals, water balance of the mining company, water quality parameters before and after the water treatment plant and wetlands				
Calculate the footprints	Water scarcity and water quality as eutrophication potential				
Calculate the handprint	Difference of the footprints calculated				
Identify the relevant indicators to be communicated	Water scarcity and water quality as eutrophication potential				
Consider critical review of the handprint	Critical review is not conducted, as this case was done for developing the air quality handprint approach.				
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Water scarcity is communicated as world m <sup>3</sup> eq/year, and eutrophication potential as kg PO <sub>4</sub> <sup>3-</sup> eq.				

**Figure A1.** The framework for the case study of the water handprint: water treatment technology.

Define the scope of the studied solution	Product Ammonia water	Company (product or service portfolio)	Project (a non-recurrent activity to reach the preferred outcome in a defined time frame)
Identify potential handprint contributors	Gasum reduces the nutrient footprint of pulp and paper mill by offering recycled nitrogen product (ammonia water) for wastewater treatment process. Recycled nitrogen substitutes virgin urea.		
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: e.g. ADP (minerals and fossil fuels), cumulative energy demand	Water: e.g. scarcity, eutrophication, acidification, toxicity  Nutrients: N: balance and eutrophication potential e.g. heavy acidification  Air quality: e.g. PM <sub>10</sub> , PM <sub>2.5</sub> , NO <sub>x</sub> , SO <sub>2</sub> , VOC, health impacts, POPs
Identify the users and beneficiaries of the studied solution	Wastewater treatment plant		
Define the baseline	The use of virgin urea in wastewater treatment process in pulp and paper mill		
Define the functional unit	The functional unit is cubic meters of treated wastewater in UPM pulp and paper mill WWTP per day (94 846 m <sup>3</sup> /d). The unit used in calculations is kgN/d for the nitrogen balance indicators, kg phosphate equivalents/d for eutrophication potential and kgCO <sub>2</sub> e equivalents for carbon handprint.		
Define the system boundaries	Urea production, centrifugation of digestate in biogas plant, evaporator-stripper process in biogas plant, wastewater treatment processes, sludge treatment processes, fate of nitrogen in treated wastewater, fate of nitrogen in treated sludge		
Define data needs and sources	Pulp and paper mill WWWT processes: most recent primary data (2017-2019). Urea production: G&B database (2018-2020). Gasum processes: most recent primary data (2017-2020)		
Calculate the footprints	Nutrient footprints of the baseline and the studied solution consist of the nitrogen footprint profile, i.e., nitrogen balance and eutrophication potential indicator values. In this case also climate change indicator is included.		
Calculate the handprint	Check which nutrient balance handprint criteria are fulfilled and if other nutrient handprint preconditions are fulfilled. Calculate the magnitude of the nutrient handprint from the differences between the baseline and the studied solution in those nutrient balance indicators that fulfill the handprint criteria		
Identify the relevant indicators to be communicated	In addition to the magnitude of the nutrient handprint based on handprint criteria-fulfilling changes in the nutrient balance, include in communications the whole nutrient balance, information about fulfilled preconditions and changes in the eutrophication potential and, if relevant, other environmental impact indicators. In this case also carbon handprint should be communicated.		
Consider critical review of the handprint	Critical review is not conducted, as this case was done for developing the nutrient handprint approach.		
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: Changes in N balance and eutrophication potential in kg <sub>N</sub> /d or kg phosphate equivalents/d, respectively, and in %. Carbon handprint in kgCO <sub>2</sub> e/d and in %.		

**Figure A2.** The framework of the case study for the nutrient handprint: recycled nutrient products.

Define the scope of the studied solution	Product Wastewater treatment service at UPM	Company (product or service portfolio)	Project (a non-recurrent activity to reach the preferred outcome in a defined time frame)
Identify potential handprint contributors	UPM reduces the nitrogen footprint of composting by offering a utilization opportunity of the nitrogen content of composting exhaust gas washer wastewater in the UPM wastewater treatment process. Nitrogen is recycled and does not burden the baseline nitrogen WWTP. Virgin urea consumption is reduced at UPM.		
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: e.g. ADP (minerals and fossil fuels), cumulative energy demand	Water: e.g. scarcity, eutrophication, acidification, toxicity  Nutrients: N: balance and eutrophication potential e.g. heavy acidification  Air quality: e.g. PM <sub>10</sub> , PM <sub>2.5</sub> , NO <sub>x</sub> , SO <sub>2</sub> , VOC, health impacts, POPs
Identify the users and beneficiaries of the studied solution	Composting plant UPM wastewater treatment plant Municipal wastewater treatment plant		
Define the baseline	Composting exhaust gas washer wastewater is treated at the municipal wastewater treatment plant.		
Define the functional unit	The function is to treat 8.64 m <sup>3</sup> of wastewater that contains 155.52 kg <sub>N</sub> , which is the composting exhaust gas washer daily wastewater production volume and N content. The unit used in calculations is kgN/d for the nitrogen balance indicators and kg phosphate equivalents/d for eutrophication potential.		
Define the system boundaries	Unit processes: Composting, Municipal WWTP, UPM WWTP, Combustion (sludge), Urea production, System expansion. Fate of N from composting, in treated wastewater and in sludge. Only N flows from the unit processes into the environment, no further fate and conversion of N in the environment.		
Define data needs and sources	UPM Kaukas processes: most recent primary data (2017-2019) Composting wastewater: most recent primary data (2018) and secondary data Municipal WWTP processes: most recent secondary data (2019-2017)		
Calculate the footprints	Nutrient footprints of the baseline solution and studied solution consist of the nitrogen footprint profile, i.e., nitrogen balance and eutrophication potential indicator values.		
Calculate the handprint	Check which nutrient balance handprint criteria are fulfilled and if other nutrient handprint preconditions are fulfilled. Calculate the magnitude of the nutrient handprint from the differences between the baseline and studied solution in those nutrient balance indicators that fulfill the handprint criteria. (The result is that nutrient handprint equals the reduction in total nutrient inputs and virgin nutrient inputs in the studied solution in comparison to baseline solution, while the ratio of nutrients that continue in the nutrient cycle to nutrients lost from the nutrient cycle is the same and eutrophication potential decreases between the studied and baseline solution.)		
Identify the relevant indicators to be communicated	In addition to the magnitude of the nutrient handprint based on handprint criteria-fulfilling changes in the nutrient balance, include in communications the whole nutrient balance, information about fulfilled preconditions and changes in the eutrophication potential and, if relevant, other environmental impact indicators.		
Consider critical review of the handprint	Critical review is not conducted, as this case was done for developing the nutrient handprint approach.		
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: Changes in N balance and eutrophication potential in kgN/d or kg phosphate equivalents/d, respectively, and in %.		

**Figure A3.** The framework of the case study for the nutrient handprint: a wastewater treatment service.

Define the scope of the studied solution	<b>Product:</b> Renewable diesel made of used cooking oil (hydro-treated vegetable oil, HVO)	<b>Company</b> (product or service portfolio)	<b>Project</b> (a non-recurrent activity to reach the preferred outcome in a defined time frame)		
Identify potential handprint contributors	Reduction of NO <sub>x</sub> and particulate emissions PM <sub>2.5</sub> due cleaner combustion in fuel use phase.				
Identify the environmental impacts in question and their potential indicators	<b>Climate change:</b> GHG emissions	<b>Resources:</b> e.g. ADP (elements and fossil fuels), cumulative energy demand	<b>Water:</b> e.g. scarcity, eutrophication, acidification, toxicity	<b>Nutrients:</b> NPK balance and eutrophication, in addition e.g. toxicity, acidification	<b>Air quality:</b> e.g. PM <sub>2.5</sub> , NO <sub>x</sub> , SO <sub>2</sub> , VOC, health impacts, POPs
Identify the users and beneficiaries of the studied solution	Passenger car owner of EURO 4, 5 and 6 cars The city of Helsinki Inhabitants in the studied area				
Define the baseline	Fossil reference diesel used in Euro 4, 5 and 6 vehicles in 23 and -7 Celsius degrees. Fossil reference diesel used in the defined fleet throughout the year 2018 in Mäkeläntä in observed temperatures.				
Define the functional unit	Kmper vehicle Kms driven with the existing fleet in a certain street (Mäkeläntä) per year				
Define the system boundaries	Well to wheel for both solutions				
Define data needs and sources	Primary data of the fuel production processes complemented with secondary data, measured data on use phase emissions (laboratory measurements). Mileage of the different euro classes for the baseline year in selected area, share of the euro 4, 5 and 6 cars in the certain fleet. Ambient temperatures in the selected area.				
Calculate the footprints	Calculate footprints of the studied and baseline solution based on relevant ISO-standards where applicable				
Calculate the handprint	Difference of the footprints calculated				
Identify the relevant indicators to be communicated	Emissions reductions of NO <sub>x</sub> and PM <sub>2.5</sub>				
Consider critical review of the handprint	Critical review is not conducted, as this case was done for developing the air quality handprint approach.				
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units (for NO <sub>x</sub> & PM <sub>2.5</sub> ) scaled to local mileage. Local change in emissions in kilograms with certain mileage and fleet in a specific region.				

**Figure A4.** The framework of the case study for the air quality handprint: paraffinic renewable diesel, HVO.

Define the scope of the studied solution	<b>Product</b> Washer 1 for pulp washing	<b>Company</b> (product or service portfolio)	<b>Project</b> (a non-recurrent activity to reach the preferred outcome in a defined time frame)		
Identify potential handprint contributors	Improved chemical recovery decreases the chemical consumption at the mill. More efficient washing improves the energy balance of the mill.				
Identify the environmental impacts in question and their potential indicators	<b>Climate change:</b> GHG emissions	<b>Resources:</b> e.g. ADP (elements and fossil fuels), cumulative energy demand	<b>Water:</b> e.g. scarcity, eutrophication, acidification, toxicity	<b>Nutrients:</b> NPK balance and eutrophication, in addition e.g. toxicity, acidification	<b>Air quality:</b> e.g. PM <sub>2.5</sub> , NO <sub>x</sub> , SO <sub>2</sub> , VOC, health impacts, POPs
Identify the users and beneficiaries of the studied solution	Pulp mills				
Define the baseline	Traditional washing system referred as Washer 2				
Define the functional unit	Annual production of a pulp mill				
Define the system boundaries	Washing equipment production, transportation and disposal, pulp mill operations that are affected by the washing process, chemical production, avoided electricity production				
Define data needs and sources	Data for equipment production (Andritz), chemical production (ecoinvent, KnowPulp), pulp mill operations (Andritz), transportations (VTI LIPASTO), energy production (ecoinvent), end-of-life treatments (ecoinvent)				
Calculate the footprints	Resource footprints and carbon footprint of the studied and baseline solutions.				
Calculate the handprint	Difference of the footprints calculated				
Identify the relevant indicators to be communicated	Resource footprints and carbon footprint				
Consider critical review of the handprint	Not conducted, as this case was done for developing the resource handprint approach				
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: kg Sb eq (Resource use, minerals and metals), MJ (Resource use, losses), MJ (CED), kg CO <sub>2</sub> eq (GWP)				

**Figure A5.** The framework of the case study for the resource handprint: a pulp washing system.

Define the scope of the studied solution	Product Moss-based gardening soil	Company (product or service portfolio)	Project (a non-recurrent activity to reach the preferred outcome in a defined time frame)		
Identify potential handprint contributors	Biolan reduces consumption of (primary) peat and synthetic fertilisers by using bio-based by-products from secondary sources. Also the use stage emissions from peat degradation are reduced				
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: ADP (elements and fossil fuels), cumulative energy demand	Water: e.g. scarcity, eutrophication, acidification, toxicity	Nutrients: N/P/K balance and eutrophication, in addition e.g. toxicity, acidification	Air quality: e.g. PM <sub>10</sub> , PM <sub>2.5</sub> , NOx, SO <sub>2</sub> , VOC, health impacts, POCP
Identify the users and beneficiaries of the studied solution	Gardener (consumer or company)				
Define the baseline	Peat-based gardening soil				
Define the functional unit	1 kg gardening soil				
Define the system boundaries	Primary raw material production (secondary raw materials as cut off), gardening soil production, packaging production, use (no end-of-life)				
Define data needs and sources	LCI data or raw materials, share of peat in used by-products (broiler manure), use stage peat decomposing, lime emissions in the use stage				
Calculate the footprints	Resource footprints and carbon footprint of the handprint and baseline solution				
Calculate the handprint	Difference of the footprints calculated				
Identify the relevant indicators to be communicated	ADP (fossil fuels), Cumulative energy demand, Climate change (as GWP)				
Consider critical review of the handprint	Not conducted, as this case was done for developing the resource handprint approach.				
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: MJ (ADP/F), MJ (CED tot), kg CO <sub>2</sub> e.				

**Figure A6.** The framework of the case study for the resource handprint: moss-based gardening soil.

Define the scope of the studied solution	Product Plastic film partly made of recycled polyethylene	Company (product or service portfolio)	Project (a non-recurrent activity to reach the preferred outcome in a defined time frame)		
Identify potential handprint contributors	Less crude oil needed when primary raw material replaced with secondary material, less energy needed in raw material processing				
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: ADP (elements and fossil fuels), cumulative energy demand	Water: e.g. scarcity, eutrophication, acidification, toxicity	Nutrients: N/P/K balance and eutrophication, in addition e.g. toxicity, acidification	Air quality: e.g. PM <sub>10</sub> , PM <sub>2.5</sub> , NOx, SO <sub>2</sub> , VOC, health impacts, POCP
Identify the users and beneficiaries of the studied solution	Packaging industry companies				
Define the baseline	Polyethylene film based on primary raw materials				
Define the functional unit	1 kg polyethylene film				
Define the system boundaries	Primary/secondary raw material production, film production, transports, end-of-life				
Define data needs and sources	LCI data for raw materials, processes, transports and end-of-life treatments (GaBi database), shares for end-of-life treatments (Statistics Finland)				
Calculate the footprints	Resource footprints and carbon footprint of the studied and baseline solutions				
Calculate the handprint	Difference of the footprints calculated				
Identify the relevant indicators to be communicated	ADP (fossil fuels), cumulative energy demand, Climate change as GWP				
Consider critical review of the handprint	Not conducted, as this case was done for developing the resource handprint approach.				
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: MJ (Resource use, fossils), MJ (CED), kg CO <sub>2</sub> eq (GWP)				

**Figure A7.** The framework of the case study for the resource handprint: recycled plastic.

Define the scope of the studied solution	Product Remanufactured laptop	Company (product or service portfolio)	Project (a non-recurrent activity to reach the preferred outcome in a defined time frame)
Identify potential handprint contributors	EkoX remanufactures laptops that can reduce the footprint of consumer/laptop user since the less (abiotic) materials/resources are needed in the laptop (re)manufacturing stage.		
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: ADP (elements and fossil fuels), cumulative energy demand	Water: e.g. scarcity, eutrophication, acidification, toxicity
Identify the users and beneficiaries of the studied solution	Consumer / company		
Define the baseline	Traditional laptop from primary raw materials		
Define the functional unit	Laptop lifetime (3 years) cradle to grave (but EOL excluded)		
Define the system boundaries	Primary/secondary raw material production, use stage of computer in different modes, end-of-life excluded for simplifying reasons (similar to both computers)		
Define data needs and sources	LCI data or raw materials of primary laptop, LCI data of raw materials in the remanufacturing stage, use stage energy consumption of both laptops in different modes		
Calculate the footprints	Resource footprints and carbon footprint of the handprint and baseline solution		
Calculate the handprint	Difference of the footprints calculated		
Identify the relevant indicators to be communicated	ADP (elements and fossil fuels), cumulative energy demand, climate change as GWP		
Consider critical review of the handprint	Not conducted, as this case was done for developing the resource handprint approach		
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: MJ, kg CO <sub>2</sub> eq, kg Sb eq		

**Figure A8.** The framework of the case study for the resource handprint: computer remanufacturing.

Define the scope of the studied solution	Product (goods, service, material, component)	Company Kierrätyskeskus	Project (a non-recurrent activity to reach the preferred outcome in a defined time frame)
Identify potential handprint contributors	Kierrätyskeskus enables increased reuse and material recycling		
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: e.g. ADP (elements and fossil fuels), cumulative energy demand	Water: e.g. scarcity, eutrophication, acidification, toxicity
Identify the users and beneficiaries of the studied solution	People who donate used products People who buy second-hand products		
Define the baseline	Without Kierrätyskeskus, products would be incinerated or otherwise disposed of, and more primary resources would be needed for manufacturing		
Define the functional unit	Volume of donated products in 2019		
Define the system boundaries	From the point of donation until the product is purchased or recycled		
Define data needs and sources	Primary data from Kierrätyskeskus of annual volumes and avoided emissions due to reuse. Secondary data from various databases for calculation of avoided emissions from increased recycling.		
Calculate the footprints	Calculate footprint(s) of the studied and baseline solution based on relevant ISO-standards where applicable		
Calculate the handprint	Difference of the footprints calculated		
Identify the relevant indicators to be communicated	Climate change (ghg-emissions)		
Consider critical review of the handprint	Critical review is not conducted, as this case was done for developing the project handprint approach.		
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: Carbon handprint in kgCO <sub>2</sub> eq, and in %.		

**Figure A9.** The framework of the case study for the handprint for organizations: second-hand items.



Define the scope of the studied solution	Product (goods, service, material, component)	Company (Stora Enso Packaging Materials division)	Project (a non-occurring activity to reach the preferred outcome in a defined time frame)
Identify potential handprint contributors	Stora Enso's packaging products are made from renewable paperboard and the use of fossil materials is avoided		
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: e.g. ADP (elements and fossil fuels), cumulative energy demand	Water: e.g. scarcity, nitrification, acidification, toxicity Nutrients: NPK, balance and nitrification, in addition e.g. toxicity, acidification Air quality: e.g. PM10, PM2.5, NOx, SO2, VOC, health impacts, POPs
Identify the users and beneficiaries of the studied solution	Other companies in the supply chain End users		
Define the baseline	Market of packaging products without Stora Enso		
Define the functional unit	Production of carton board packaging materials in 2019		
Define the system boundaries	Production of raw materials, packaging product manufacturing, transportation, end of life treatment (cradle-to-grave)		
Define data needs and sources	Primary life cycle emissions data for Stora Enso products, secondary data for baseline solution about raw material production, processing, transportation processes and end of life treatment processes from various databases		
Calculate the footprints	Calculate footprint(s) of the studied and baseline solution based on relevant ISO-standards where applicable		
Calculate the handprint	Difference of the footprints calculated		
Identify the relevant indicators to be communicated	Climate change (ghg-emissions)		
Consider critical review of the handprint	Critical review is not conducted, as this case was done for developing the project handprint approach		
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: Carbon handprint in kgCO <sub>2</sub> eq. and in %.		

**Figure A10.** The framework of the case study for the handprint for organizations: packaging from renewable materials.

Define the scope of the studied solution	Product (goods, service, material, component)	Company (product or service portfolio)	Project (Investment to a new leaching plant at Bolden copper smelter)
Identify potential handprint contributors	Resource efficiency is improved with the new leaching process, which recovers as much metals as possible, reduces the amount of hazardous waste and wastewater treatment needs, and reduces land use.		
Identify the environmental impacts in question and their potential indicators	Climate change: GHG emissions	Resources: e.g. ADP (elements and fossil fuels), cumulative energy demand	Water: e.g. scarcity, nitrification, acidification, toxicity Nutrients: NPK, balance and nitrification, in addition e.g. toxicity, acidification Air quality: e.g. PM <sub>10</sub> , PM <sub>2.5</sub> , NO <sub>x</sub> , SO <sub>2</sub> , VOC, health impacts, POPs
Identify the users and beneficiaries of the studied solution	Bolden: Resource efficiency and productivity increases Pulp mill: Utilization for their side streams (resource efficiency) Users of metals: Avoidance of usage of additional virgin metals Waste managers: Bolden, less waste to be treated		
Define the baseline	Situation without the project. The annual amount of copper and lead produced in the leaching plant would be produced with traditional means (mining & scrap metal) & The waste from copper smelter is treated with traditional means		
Define the functional unit	Annual amount of copper and lead produced in through the leaching plant or through baseline route		
Define the system boundaries	Cradle to gate		
Define data needs and sources	Primary data from Rönnskär facility's operations. Secondary database data about inputs needed in the leaching plant		
Calculate the footprints	Calculate footprints of the studied and baseline solution based on relevant ISO-standards where applicable		
Calculate the handprint	Difference of the footprints calculated		
Identify the relevant indicators to be communicated	Resource handprints [kg Sb eq] [MJ], Carbon handprint [kg CO <sub>2</sub> eq.], waste amount reduction [tonnes]		
Consider critical review of the handprint	Recommended in B2C communications, and mandatory if the results are intended for comparative assertions to be disclosed to the public as instructed in the ISO standards 14044 and 14026		
Communicate the results	Communicating the results respecting appropriateness, clarity, credibility, and transparency. Communication units: kg Sb eq (Resource use, minerals and metals), MJ (Resource use, fossils), MJ (CED), kg CO <sub>2</sub> eq (GWP) or percentages		

**Figure A11.** The framework for the case study for a project handprint: a leaching plant in a copper smelter.

Title	<p><b>The environmental handprint approach to assessing and communicating the positive environmental impacts</b></p> <p>Final report of the Environmental Handprint project</p>
Author(s)	<p>Saija Vatanen, Kaisa Grönman, Katri Behm, Tiina Pajula, Laura Lakanen, Heli Kasurinen, Risto Soukka, Lotta Hepo-oja, Kim Lindfors, Matias Alarotu</p>
Abstract	<p>VTT Technical Research Centre of Finland Ltd and LUT University have developed an approach for quantifying the environmental handprint based on standardized methods on life cycle assessment. Since the publication of the carbon handprint approach in 2018, the research work has continued to extend the applicability of the framework to incorporate other positive environmental impacts in addition to greenhouse gas emissions. Examples used in the development of the methodology covered water, nutrient, air quality and resource handprint calculations. Moreover, we have discussed how to address environmental handprints at corporate and project levels. The environmental handprint work was conducted in cooperation with 16 industrial partners representing different business areas, products and services, and has thus benefitted from insider understanding of the varying requirements that arise from diverse operating environments. Similarities between different cases have been identified leading to the creation of a framework that helps to define baselines and take the required calculation steps.</p> <p>The framework for the environmental handprint and case studies of the development work are presented in this final report. A step-by-step guide directs you through the process of assessing and communicating the carbon or other environmental handprint of a product or a service in line with life cycle assessment and footprint methods. In contrast to an environmental footprint, which refers to the negative environmental impacts caused throughout the life cycle of a product or a service, the term handprint represents positive environmental impacts. A footprint and a handprint are separate measurements. It would be necessary to set targets in both: minimizing the footprint and maximizing the handprint.</p> <p>The handprint of a product or a service is achieved by comparing the footprint of the studied solution against the footprint of the baseline solution. The handprint can be used for e.g. environmental strategies based on facts and science, identification of improvement potential, product and production development, comparison of alternative raw materials, technologies, and business solutions, marketing and communication, supporting political decision-making and supporting decision-making of customers and other stakeholders.</p>
ISBN, ISSN, URN	<p>ISBN 978-951-38-8752-0          ISSN-L 2242-1211          ISSN 2242-122X (Online)          DOI: 10.32040/2242-122X.2021.T392</p>
Date	<p>May 2021</p>
Language	<p>English, Finnish abstract</p>
Pages	<p>113 p. + app. 6 p.</p>
Name of the project	<p>Environmental Handprint</p>
Commissioned by	<p>Business Finland, VTT, LUT, companies</p>
Keywords	<p>handprint, footprint, environmental handprint, carbon handprint, carbon footprint, positive environmental im-pact, life cycle assessment, LCA</p>
Publisher	<p>VTT Technical Research Centre of Finland Ltd          P.O. Box 1000, FI-02044 VTT, Finland, Tel. 020 722 111,  <a href="https://www.vttresearch.com">https://www.vttresearch.com</a></p>

Nimeke	<b>Ympäristökädenjälki positiivisten ympäristövaikutusten arviointiin ja viestintään</b> Ympäristökädenjälki-projektin loppuraportti
Tekijä(t)	Saija Vatanen, Kaisa Grönman, Katri Behm, Tiina Pajula, Laura Lakanen, Heli Kasurinen, Risto Soukka, Lotta Hepo-oja, Kim Lindfors, Matias Alarotu
Tiivistelmä	<p>VTT ja LUT-yliopisto ovat kehittäneet ympäristökädenjälki-lähestymistavan, joka perustuu standardoituihin elinkaariarvioinnin menetelmiin. Hiilikädenjälkimenetelmä julkaistiin vuonna 2018 ja sitä on nyt laajennettu positiivisten ilmastovaikutusten lisäksi myös muihin positiivisiin ympäristövaikutuksiin. Menetelmäkehitystyössä käytetyt esimerkit sisälsivät vesi-, ravinne-, ilmanlaatu- ja resurssikädenjälkilaskelmia. Lisäksi kädenjälki-lähestymistapaa sovellettiin organisaatio- ja hanketasoilla. Ympäristökädenjälkiä kehitettiin yhteistyössä 16 yrityksen kanssa, jotka edustivat useita eri aloja, tuotteita ja palveluita, ja siten toivat tietoa erilaisista toimintaympäristöistä johtuvista vaatimuksista. Eri tapaustutkimusten välillä havaitut yhtäläisyydet auttoivat laskentakehyksen luomisessa.</p> <p>Tämä hankkeen loppuraportti kuvaa ympäristökädenjälkimenetelmät sekä kehitystyössä tehdyt tapaustutkimukset. Yksityiskohtainen askel askeleelta ohjeistus neuvoo ympäristökädenjäljen määrittämisessä ja viestimässä. Ohjeistus on linjassa elinkaariarviointi- ja jalanjälkistandardien kanssa. Päävastoin kuin ympäristöjalanjälki, joka kuvaa tuotteen tai palvelun negatiivisia ympäristövaikutuksia elinkaaren aikana, termi kädenjälki viittaa positiivisiin ympäristövaikutuksiin. Jalanjälki ja kädenjälki ovat erillisiä mittareita ja on tärkeää asettaa erilliset tavoitteet molemmille: jalanjäljen minimoinnille ja kädenjäljen maksimoinnille.</p> <p>Tuotteen tai palvelun kädenjälki lasketaan vertaamalla tarjottua ratkaisua vaihtoehtoiseen ratkaisuun. Kädenjälkeä voidaan käyttää esimerkiksi tukemaan faktapohjaista ja tieteeseen perustuvaa ympäristöstrategiaa, parantamispotentiaalien tunnistamiseen, tuotteiden ja tuotannon kehittämiseen, vaihtoehtoisten raaka-aineiden, tekniikoiden ja liiketoimintaratkaisujen vertailuun, markkinointiin ja viestintään, poliittisen päätöksenteon tukemiseen sekä asiakkaiden ja muiden sidosryhmien päätöksenteon tukemiseen.</p>
ISBN, ISSN, URN	ISBN 978-951-38-8752-0 ISSN-L 2242-1211 ISSN 2242-122X (Verkkojulkaisu) DOI: 10.32040/2242-122X.2021.T392
Julkaisuaika	Toukokuu 2021
Kieli	Englanti, suomenkielinen tiivistelmä
Sivumäärä	113 s. + liitt. 6 s.
Projektin nimi	Ympäristökädenjäljet yritysten kansainvälisen liiketoiminnan tukemiseksi
Rahoittajat	Business Finland, VTT, LUT, yritykset
Avainsanat	kädenjälki, jalanjälki, ympäristökädenjälki, hiilikädenjälki, hiilijalanjälki, positiivinen ympäristövaikutus, elinkaariarviointi, LCA
Julkaisija	Teknologian tutkimuskeskus VTT Oy PL 1000, 02044 VTT, puh. 020 722 111, <a href="https://www.vtt.fi/">https://www.vtt.fi/</a>

# **The environmental handprint approach to assessing and communicating the positive environmental impacts**

## **Final report of the Environmental Handprint project**

VTT Technical Research Centre of Finland Ltd and LUT University have developed an approach for quantifying the environmental handprint based on standardized methods. Since the publication of the carbon handprint approach in 2018, the research work has continued to extend the applicability of the framework to incorporate other positive environmental impacts in addition to greenhouse gas emissions. Examples used in the development of the methodology covered water, nutrient, air quality and resource handprint calculations. Moreover, we have discussed how to address environmental handprints at corporate and project levels. The framework for the environmental handprint and case studies of the development work are presented in this final report. A step-by-step guide directs you through the process of assessing and communicating the carbon or other environmental handprint of a product or a service in line with life cycle assessment and footprint methods. In contrast to an environmental footprint, which refers to the negative environmental impacts caused throughout the life cycle of a product or a service, the term handprint represents positive environmental impacts. A footprint and a handprint are separate measurements. It would be necessary to set targets in both: minimizing the footprint and maximizing the handprint.

ISBN 978-951-38-8752-0  
ISSN-L 2242-1211  
ISSN 2242-122X (Online)  
DOI: 10.32040/2242-122X.2021.T392