UPPSALA
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UPTEC W 14 002
Examensarbete 30 hp
Mars 2014

Water footprint calculation for truck production

Beräkning av vattenfotavtryck vid produktion av lastbilar

Lina Danielsson

ABSTRACT

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Water is an irreplaceable resource, covering around two thirds of Earth´s surface, although only one percent is available for use. Except from households, other human activities such as agriculture and industries use water. Water use and pollution can make water unavailable to some users and places already exposed for water scarcity are especially vulnerable for such changes. Increased water use and factors such as climate change make water scarcity to a global concern and to protect the environment and humans it will be necessary to manage this problem.

The concept of water footprint was introduced in 2002 as a tool to assess impact from freshwater use. Since then, many methods concerning water use and degradation have been developed and today there are several studies made on water footprint. Still, the majority of these studies only include water use. The aim of this study was to evaluate three different methods due to their ability to calculate water footprint for the production of trucks, with the qualification that the methods should consider both water use and emissions.

Three methods were applied on two Volvo factories in Sweden, located in Umeå and Gothenburg. Investigations of water flows in background processes were made as a life cycle assessment in Gabi software. The water flows were thereafter assessed with the *H_2Oe*, the *Water Footprint Network* and the *Ecological scarcity method.* The results showed that for the factory in Umeå the water footprint values were 2.62 Mm^3 H_2Oe, 43.08 Mm^3 and 354.7 MEP per 30,000 cabins. The variation in units and values indicates that it is complicated to compare water footprints for products calculated with different methods. The study also showed that the *H_2Oe* and the *Ecological scarcity* method account for the water scarcity situation. A review of the concordance with the new ISO standard for water footprint was made but none of the methods satisfies all criteria for elementary flows.

Comparison between processes at the factories showed that a flocculation chemical gives a larger water footprint for the *H_2Oe* and the *Ecological scarcity* method, while the water footprint for the *WFN* method and carbon footprint is larger for electricity. This indicates that environmental impact is considered different depending on method and that a process favorable regarding to climate change not necessarily is beneficial for environmental impact in the perspective of water use.

Keywords: Impact assessment methods, life cycle assessment, water consumption, water degradation, water footprint.

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ISSN 1401-5765

REFERAT

Beräkning av vattenfotavtryck vid produktion av lastbilar

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Vatten är en ovärderlig resurs som täcker cirka två tredjedelar av jordens yta men där endast en procent är tillgänglig för användning. Människan använder vatten till olika ändamål, förutom i hushåll används vatten bland annat inom jordbruk och industrier. Vattenanvändning och utsläpp av föroreningar kan göra vatten otillgängligt, vilket kan vara extra känsligt i de områden där människor redan lider av vattenbrist. Den ökade vattenanvändningen tillsammans med exempelvis klimatförändringar bidrar till att göra vattenbrist till en global angelägenhet och det kommer att krävas åtgärder för att skydda människor och miljö.

År 2002 introducerades begreppet vattenfotavtryck som ett verktyg för att bedöma miljöpåverkan från vattenanvändning. Sedan dess har begreppet utvecklats till att inkludera många olika beräkningsmetoder men många av de befintliga studierna har uteslutit föroreningar och bara fokuserat på vattenkonsumtion. Syftet med denna rapport var att utvärdera tre olika metoder med avseende på deras förmåga att beräkna vattenfotavtryck vid produktion av lastbilar, med villkoret att metoderna ska inkludera både vattenkonsumtion och föroreningar.

I studien användes tre metoder för att beräkna vattenfotavtrycket för två Volvo fabriker placerade i Umeå och Göteborg. En livscykelanalys utfördes i livscykelanalysverktyget Gabi, för att kartlägga vattenflöden från bakgrundsprocesser. Därefter värderades vattenflödena med metoderna; *H_2Oe, WFN* och *Ecological scarcity*. Resultatet för fabriken i Umeå gav för respektive metod ett vattenfotavtryck motsvarande 2,62 Mm^3 H_2Oe, 43,08 Mm^3 respektive 354,7 MEP per 30 000 lastbilshytter. Variationen i enheter och storlek tyder på att det kan vara svårt att jämföra vattenfotavtryck för produkter som beräknats med olika metoder. Studien visade att *H_2Oe* och *Ecological scarcity* tar hänsyn till vattentillgängligheten i området. En granskning av metodernas överensstämmelse med den nya ISO standarden för vattenfotavtryck gjordes men ingen av metoderna i studien uppfyllde alla kriterier.

Av de processer som ingår i fabrikerna visade det sig att vattenfotavtrycket för *H_2Oe* och *Ecological scarcity* metoden var störst för en fällningskemikalie. För den tredje metoden och koldioxid var avtrycket störst för elektriciteten. Detta tyder på att olika metoder värderar miljöpåverkan olika samt att de processer som anses bättre ur miljösynpunkt för klimatförändringar inte nödvändigtvis behöver vara bäst vid vattenanvändning.

Nyckelord: Konsekvensanalys, livscykelanalys, vattenanvändning, vattenfotavtryck, vattenkvalitet.

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ISSN 1401-5765

PREFACE

This report was made as a degree project on 30 credits, the final stage in my Master´s degree in Environmental and Water engineering at Uppsala University. The study has been performed in cooperation with the project EcoWater at IVL Swedish Environmental Research Institute. Supervisor was Tomas Rydberg from Organizations, Products and Processes at IVL Swedish Environmental Research Institute in Stockholm and subject reviewer was Sven Halldin from Department of Earth Sciences, Program for Air, Water and Landscape Sciences at Uppsala University in Uppsala.

I would like to thank Åsa Nilsson for your permission to reproduce figure 2 in my report and to let me use data from EcoWater. Further, thanks to Elin Eriksson at IVL Swedish Environmental Institute for her permission to use the ISO 14046 draft.

I also want to thank a number of people for their participation that helped me complete this study. First of all, Jonatan Wranne, Tomas Rydberg and Mikael Olshammar at IVL Swedish Environment Research Institute deserve thanks for their help as supervisors. Other staff at IVL that have helped me with different things and made my time enjoyable throughout the project were Åsa Nilsson, Elin Erisson, Filipé Oliveira, Johanna Freden, Sara Alongi Skenhall, Lena Dahlgren and Anja Karlsson. Secondly, a special thanks to my subject reviewer Sven Halldin for his advice and involvement. Finally, my family and friends earn many thanks for their support, advice, listening and for comments about my work.

Lina Danielsson

Stockholm, January 2014

POPULÄRVETENSKAPLIG SAMMANFATTNING

Beräkning av vattenfotavtryck vid produktion av lastbilar

Lina Danielsson

Koldioxidavtryck är ett begrepp som används av många för att utrycka huruvida en produkt eller livsstil är miljövänlig. Uttrycket beskriver utsläpp av växthusgaser i en motsvarande mängd koldioxid och är en indikator på den globala uppvärmningen. En produkts koldioxidutsläpp kan beräknas för hela dess livscykel, det vill säga från att råmaterialet utvinns till att produkten används och återvinns samt alla processer däremellan. En liknande analys kan göras för att bedöma miljöpåverkan från vattenanvändning och kallas för vattenfotavtryck. Vattenfotavtryck är ett nyare begrepp som vuxit fram i takt med att vattenbrist blivit en global angelägenhet. Den här studien visade att processer som är miljövänliga ur en koldioxidaspekt inte behöver vara gynnsamma ur ett vattenanvändningsperspektiv.

Vatten är en naturlig resurs som allt levande på jorden är beroende av och som inte kan ersättas av något annat. Människan är beroende av att ha tillgång till vatten av god kvalitet. I många delar av värden lider människor av vattenbrist men även på ställen där vattentillgången anses god ses vattenbrist som ett kommande problem. Förutom personlig konsumtion av vatten kräver många av våra aktiviteter stora mängder vatten, som till exempel jordbruk och industrier. Problemet uppstår inte enbart av att vi tar bort vatten från dess naturliga plats, vi släpper även ut stora mängder föroreningar till vatten. Den här studien har undersökt hur tre olika metoder värderar miljöpåverkan från vattenanvändning.

Tidigare har framförallt den mängd vatten som används undersökts, men detta mått kan vara missvisande. Jämför till exempel en fabrik som konsumerar stora mängder vatten i ett vattenrikt område med en fabrik belägen i en region som lider av vattenbrist, ska dessa fabriker anses ha samma miljöpåverkan? Den här studien visar att två av de tre metoderna ger ett högre vattenfotavtryck för en fabrik belägen i ett område med minskad tillgång på vatten. Det visas också att metoderna lägger olika stor vikt vid de föroreningar som släpps ut i samband med produktion. En av metoderna värderar att det är utsläppen som står för den största miljöpåverkan medan en annan metod ser vattenanvändningen som den dominerande faktorn. Det här visar vikten av att klargöra vilken metod som har använts för beräkning av vattenfotavtryck och att det inte är möjligt att jämföra vattenfotavtryck beräknat med olika metoder.

Till skillnad från växthusgasutsläpp har vattenkvalitet en mycket lokal miljöpåverkan och effekterna är beroende av de lokala förhållandena. Detta gör det mycket komplext, om inte omöjligt, att bedöma konsekvenserna av vattenanvändning. Trots dessa osäkerheter är det viktigt att kunna identifiera vilka processer och var det största vattenfotavtrycket sker, så att vi på ett hållbart sätt ska kunna använda vattenresurserna.

I den här studien har vattenfotavtrycket beräknats för lastbilshytter och lastbilar, producerade i varsin Volvofabrik belägna i Sverige. Vattenflödena som ingår i dessa fabriker kartlades med en så kallad livscykelanalys, så att även flöden kopplade till produkter som används i produktionen inkluderas. De flöden som utvärderades i den här studien var använda vattenvolymer och utsläpp av föroreningar till vatten. Det visar sig att metoderna endast värderar en begränsad mängd av föroreningarna och de utsläpp som inte analyseras anses därför inte påverka vattenkvaliteten. Av detta kan man dra slutsatsen att mycket information går förlorad och att det krävs en utveckling av befintliga metoder eller att det tas fram tydligare kriterier om vilka ämnen som bör ingå i beräkning av vattenfotavtryck.

Delar man in produktionen i olika processer kan man identifiera de olika processernas bidrag till det totala vattenfotavtrycket. När man har hittat processen med störst vattenfotavtryck kan man börja arbeta för att minska miljöpåverkan. I den här studien visade det sig att en fällningskemikalie och elektricitet är de processer som ger det största vattenfotavtrycket. För att minska vattenfotavtrycket för Volvos produktion av lastbilshytter och lastbilar bör man alltså minska användningen av dessa processer, eller hitta ett substitut med ett mindre vattenfotavtryck.

Resultatet från den här studien kan användas för att uppmärksamma att det inte är mängden vatten som är intressant, utan att vissa metoder värderar att det är utsläppen som ger den största miljöpåverkan. Studien kan också öka medvetenheten om att en produkt som säljs i Sverige kan ha gett större vattenfotavtryck om produktionen sker i andra delar av världen där vattenbrist är ett större problem.

Det finns delade meningar om hur vattenfotavtryck ska beräknas och den här studien visar på tre olika beräkningssätt samt att det krävs enighet i beräkningarna av vattenfotavtryck, för att man ska kunna jämföra produkter och använda begreppet på en global skala. Det är enbart en av metoderna som relaterar vattenanvändning och utsläpp till globala förhållanden och detta kan ses som ett sätt att globalisera uttrycket.

Information om dagens vattensituation visar också att det krävs åtgärder för att vi ska kunna använda vatten på ett hållbart sätt. Vattenfotavtryck är ett bra alternativ, men det finns fortfarande en mängd oklarheter i beräkningssättet för vattenfotavtryck som behöver lösas. Dessutom har arbetet resulterat i åsikten att det är viktigt att se till att vattenfotavtryck som ett globalt handelsverktyg inte är en nackdel för länder som naturligt lider av vattenbrist. Slutligen kan det konstateras att det är möjligt att utnyttja jordens vattenresurser på ett hållbart sätt men det krävs vissa åtgärder och vi bör inse att god vattenkvalitet är en begränsad resurs.

CONTENT

1 INTRODUCTION

Water is a unique natural resource and one of the most important for human existence (Yan, et al., 2013). People around the world use water for agricultural, domestic and industrial purposes (Hoekstra, et al., 2011). Due to displacement or degradation of freshwater, water can become unavailable to some users (Boulay, et al., 2011). Furthermore, population growth and climate changes are other factors that together with the expansion of freshwater use make the availability of freshwater to a growing global concern (Ridoutt & Pfister, 2009).

Until recently, even though it is known that water quality changes cause environmental impact, most of the studies on the impact of freshwater use have been focused on quantity of water use (Pfister, et al., 2009). Today, research of water use management and assessment is focused on creating an analytical tool that can assess the impact of freshwater use comprehensively. This research area, the concept of water footprints, can be used to evaluate the sustainability of freshwater resources due to human activity and products (Yan, et al., 2013).

Water footprint (WF) studies have been calculated for a number of products, for example cotton, tea and coffee (Ridoutt & Pfister, 2009). Because of the complexity of data collection and the limitation in calculation methods there are just a small number of studies that have been conducted on industrial products. Nonetheless, industrial activity is a huge contributor to the pollution and the unstable situations of water resources (Yan, et al., 2013). Therefore, awareness of environmental impact related to freshwater use in industries can be a motive to calculate WFs from industry processes.

This thesis aims to investigate the applicability of water footprint calculation methods on industrial processes, in this case for a part of the automotive industry of the Volvo Trucks. The case study is part of a larger research project, EcoWater (EcoWater, 2013), and data about the production of trucks were received from their study. Furthermore, the data were used in life cycle assessment (LCA) to consider water use in background processes.

The objective of this study was to evaluate how different impact assessment methods assess water use in LCA. The methods used in this study were the H_2Oe method, the Water Footprint Network method and the Ecological scarcity method. To reach the goal of this study the following research questions have been formulated:

- Can the methods be used to calculate water footprint for the two industrial processes in the case study of the Volvo Trucks?
- Do the methods result in different water footprint?
- Is the geographical location for water use considered in the methods?
- Are there differences between water and carbon footprint for the processes?
- Do any of the methods appear to satisfy the requirements of elementary flows in the international standard for water footprint (ISO 14046)?

2 BACKGROUND

A glossary over water footprint terms and a number of abbreviations are available in appendix I. An understanding of the differences between water withdrawal, water use and water consumption is relevant before reading this report. Withdrawal is the total amount of water abstracted from a basin. Water use refers to the total input of water volumes into a system while water consumption is the volumes that not are transferred back of to the same basin as the abstracted water. A number of water footprint methods consider water use and other methods consider water consumption. Therefore, those terms are mixed in this report and in a general context of water footprint, depending on calculation method; those terms can replace each other. Moreover, water use can sometimes refers to both used or consumed water volumes and pollutions.

2.1 EVOLUTION OF THE WATER FOOTPRINT CONCEPT

Water is covering around two-thirds of Earth surface, but only three percent of the volume is freshwater and barely one percent is available for use (Berger & Finkbeiner, 2012). Due to removal or quality degradation freshwater can be unavailable for some users (Boulay, et al., 2011). Furthermore, water is unevenly distributed around the globe and in many places water is overexploited due to economic development (Jeswani & Azapagic, 2011).

Scarcity is the major cause of global water problems (Jefferies, et al., 2012). More than 780 million people do not have access to safe drinking water and 2.5 billion people do not have enough water for sanitation (The world bank, 2013). Despite the fact that many people already have water related problems, an increased scarcity is expected in the future (Jefferies, et al., 2012).

Today the actual water use is under the estimated sustainable limit (Kounina, et al., 2012), but human activities can be a threat to ecosystem and to our own well-being, if they cause changes in the global water cycle (Pfister, et al., 2009). Still, industries are one of the most important reasons for the global water crisis, due to pollution and water depletion (Yan, et al., 2013). Some other factors that increase the pressure on freshwater resources are population growth, climate change, economic development (Ridoutt & Pfister, 2009) and intensive agriculture (Chapagain & Orr, 2008).

Current and future water demand can be satisfied if water use is correctly managed. Misuse of water, resulting in degradation of ecosystem, occurs mainly when economic and political reasons underpin the decision instead of hydrological motive. For that reason, many water systems are forced over their sustainable limit (Chapagain & Orr, 2008). Due to water scarcity and overexploitation at several places, it has become a social and environmental concern (Ridoutt & Pfister, 2009).

Visual water use is easier to understand then the hidden, but envisioning of unseen water is important for management of global fresh water resources. Unseen water like process can come from any global water resource, as a consequence of international trade, for example steps in the production can be located at other places than the final

consumption. Therefore, by using a product, consumers contribute to environmental impact and effect water resources at global scale. By using visual and unseen water, players such as consumers, industries and traders can be reported as direct and indirect water users (Hoekstra, et al., 2011). Hence, companies can inform customers about measured and identified environmental impact raised from their products due to water use, as a manner to express their good approach for the community (Ridoutt & Pfister, 2009).

There are two main approaches to evaluate impact on water consumption from products (Jefferies, et al., 2012). The first one is by LCA (Boulay, et al., 2011), a tool to assess environmental impact associated to a product during its entire life time (Goedkoop, et al., 2009). Still, this method provides tiny attention to the different types of consumed water and even smaller considerations are made for the environmental impact developed from water use and emissions. Consequently, most of the studies on impact from freshwater use are so far explained quantitatively (Pfister, et al., 2009). The second approach, the concept of water footprint, is now the focus for water use management and assessment research. This new analytical tool intends to comprehensively describe the impact from freshwater use (Yan, et al., 2013) and some methods are developed to evaluate impact from water use in LCA (Hoekstra, et al., 2011).

LCA is used as a methodological tool to quantitatively analyze the environmental impact during a life cycle of a product or activity (Goedkoop, et al., 2009).

2.2 WATER FOOTPRINT CALCULATION

Water footprint, introduced by Hoekstra in 2002 (Jefferies, et al., 2012), is a comprehensive indicator for freshwater use, that accounts for both consumption and pollution of freshwater. It is used to calculate the volume of freshwater consumed for a product during its entire production chain, including both direct and indirect water use (Hoekstra, et al., 2011). It is possible to calculate a water footprint for a nation, a business, a community, an individual and for products (Jefferies, et al., 2012). Furthermore, the concept accounts for both the sources of consumed volumes and the pollution type in polluted volumes. In the total water footprint, all components are geographically and temporally specified. In other words, it is a volumetric measure for freshwater consumption and pollution in time and space for a process. Still, water footprint measures water use and pollution in volumes, but do not describe the severity of the impact from water consumption. The severity depends on the local systems vulnerability and the number of consumers for this system. Therefore, water footprint cannot, even with the extended concept, be used as a measurement for environmental impact, only for volumetric consumption and pollution (Hoekstra, et al., 2011).

There is a need for a comprehensible indicator for impact related to water use. However, results from methods based on LCA, including both consumptive and degradative water use, are due to all mechanisms in the environment often reported as a profile of indicators. A single value would facilitate communication with the general public and attain a wider knowledge in the community, similar to the carbon footprint (Ridoutt &

Pfister, 2012). Though, there are studies generating single values for the amount of water consumed per produced product, the development of water footprints is required to receive a uniform and useful concept for consumers and producers (Ridoutt & Pfister, 2009). Today, the international organization of standardization (ISO) is developing a standard to assess water use in LCA (Berger & Finkbeiner, 2010).

After its introduction, water footprint calculations methods have expanded, both in numbers and content, through several different studies. The first methods included the term blue water (BW) (Chapagain & Orr, 2008), hereafter the consumption has been further divided into green water (GrW) and grey water (GW) (Hoekstra, et al., 2011).The first term, BW footprint, refers to the consumption of BW resources, such as surface and groundwater, which do not return to the original water catchment. The second term, GrW footprint, is often used for cultivation of crops or forestry industry. However, GrW refers to the use of evaporated flows from land, found in soil and vegetation. The last term, GW footprint, is an indicator for the degree of freshwater pollution and is defined as the amount of freshwater needed to dilute wastewater (WW) to harmless concentrations or to an approved load compared to natural concentrations (Hoekstra, et al., 2011). One problem with the GW concept is that the term is used with another meaning in industries (Ridoutt & Pfister, 2012). The benefit in having the contaminations expressed in one term is that it is possible to compare all pollutions with water consumptions (Hoekstra, et al., 2011). Normally, BW resources have a higher scarcity and opportunity costs than GrW resources, and this is one reason why BW often gets more attention in water footprint calculations (Hoekstra, et al., 2011).

2.2.1 Water footprint assessment

In water footprint calculations data are provided to express how much of the available freshwater that is used by humans, basically conveyed in volume terms, while a water footprint assessment covers the entire activity. In addition to quantifying and localizing the water footprint or to quantifying it in time and space, a water footprint assessment also evaluates the environmental, social and economic sustainability of this footprint and invents a response strategy, which means it brings up the entire scope of the activities (Hoekstra, et al., 2011).

In a water viewpoint, the goal of water footprint assessment is to create more sustainable activities by creating better understanding among people about what can be done. Hence, depending on interest for making a water footprint assessment, it can appear different (Hoekstra, et al., 2011). However, a water footprint assessment can be useful to reduce impact and make water use more effective in the way of evaluating, identifying and informing about the possibly impact associated to water use (ISO, 2013b).

2.2.2 Water footprint of a product

Water footprint is basically calculated for one step in a process and by combining water footprints for each step it makes it possible to calculate footprints for larger processes. Consequently, summation of every process in a supply-chain results in water footprint

for a product, often expressed in volumes per unit of product; for example volume/mass, volume/money or volume/pieces. Estimation of the total water footprint for a product is therefore made on the knowledge about consumption and pollution in every step in the product-chain (Hoekstra, et al., 2011).

To receive manageable information in water footprint calculation it is necessary to identify the product system and its process steps and thereafter limits the processes to reasonable amounts of processes. Depending on where and when the processes are performed, the water footprint gets different size and colour. However, schematization of the processes makes the calculations easier, but induces quite a bit of uncertainties, from assumptions and simplifications. Another problem in water footprint calculation is double counting, for example, adding water footprints for intermediated products can cause double counting (Hoekstra, et al., 2011).

2.2.3 Environmental relevance

If water was fully recycled and returned to the same water body and if pollution was completely reduced, it would almost be possible to reduce water footprint from industries to zero, excluding water incorporation and thermal pollution. However, there are at least two ways to reduce water footprint, firstly by replacing old technology with new and secondly by eliminating specific components or final products. Even consumers, countries and businesses can reduce their water footprint, for example if water footprint becomes a global tool consumers can change to products with smaller water footprint as well as they can reduce their direct water use (Hoekstra, et al., 2011).

Water footprint is a useful indicator for freshwater limitation, but it needs to be pointed out that it is just an indicator for the sustainability of and improvement to reduce water footprint. Therefore water footprint needs to be complemented to receive a better understanding for the environmental impact (Hoekstra, et al., 2011).

2.3 PREVIOUS STUDIES

Since 2002 there have been a number of studies made on water footprint. Water footprints have for example been calculated for cotton, coffee, meat products (Ridoutt & Pfister, 2009), tea and margarine (Jefferies, et al., 2012). A study of water footprint has been made by Berger et al (2012) for water use related to car production. In that study they compared water footprint calculated with different methods and one conclusion was that impact assessment methods require lots of inventory data. Data for spatial differentiation of water flows and temporal information, especially for background systems, are mentioned as hard to get. There is also a study performed were different methods are compared regarding to their suitability for assessing environmental impact from water use during cultivation of corn. GW is not included in this study due to lack of reliable and consistent data, but the study illustrates that a volumetric water footprint is not enough to assess environmental impacts from water consumption (Jeswani & Azapagic, 2011).

Another study, where volumetric water footprint is evaluated, is made by Ridoutt and Pfister (2009) and they compare volumetric and stress-weighted water footprint between

different products. The result shows that the different types of footprint vary between products. For one product volumetric footprint was larger than for the second product while the latter product had a larger stress-weighted footprint. However, there are also a number of studies made for water footprint concerning degradative use. One example of that is a study for an industrial sector in China, where the calculations show that the GW footprint was slightly higher than the BW footprint (Yan, et al., 2013).

In a study of Kounina et al. (2012) a number of methods have been theoretically evaluated for their potential to describe impact related to freshwater use. The result shows that none of the methods can be used to describe the full impacts but some methods can give an indicator for all the areas of protection (AoP), and some methods give an indicator for one of those areas (Boulay, et al., 2011).

2.4 ECOWATER

EcoWater is a research project supported by the 7th Framework Programme of the European Commission and the purpose of the project is to *develop meso-level eco-efficiency indicators for technology assessment* (EcoWater, 2011b). The project looks into three different sectors and aims to understand what happens, in both an economic and environmental perspective, as changes are made in technologies of the water service system (EcoWater, 2011c). There are eight case studies in EcoWater and one of those, included in the industry sector, is the case study of Volvo Trucks, representing Swedish automotive industry (EcoWater, 2011a).

Processes in the industry that consume water affect both economic and environmental interests and implementation of correct eco-efficient technology may result in savings for both interests. The case study of Volvo Trucks intends to investigate water use for all significant steps in the production chain and looks into the environmental and economic impact associated to relevant technology (EcoWater, 2011a).

Systemic Environmental Analysis Tool (SEAT) is developed by EcoWater as a tool for environmental analysis. SEAT is together with a tool for economic analysis, EVAT included in the web-based EcoWater toolbox, where eco-efficiency indicators can be estimated for different technology scenarios. SEAT´s main functionalities are the opportunity to make an own model/illustration of the system, to show the steps and processes included in the value chain, to analyze the resource flow and to calculate emissions and waste produced (Kourentzis, 2012). SEAT is available as a free service for users creating an account on their website (EcoWater, 2011d).

3 THEORY

3.1 LIFE CYCLE ASSESSMENT

LCA is used as a methodological tool to quantitatively analyze the environmental impact during a life cycle of a product or activity (Goedkoop, et al., 2009). A total LCA includes all related stages of a product such as extraction of resources, processing of resources, manufacturing of products, use of the products, transports and disposals or recycling processes (Frischknecht, et al., 2009). A cradle-to-gate LCA covers the entire life cycle of a product (Finnveden, et al., 2009), while a gate-to-gate LCA covers for example manufacturing processes (Hoekstra, et al., 2011).

LCA consist of four phases; Goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation (Figure 1) (Hoekstra, et al., 2011), those phases should be included according to one of the international standards for LCA (ISO 14044) (Frischknecht, et al., 2009). The first phase clarifies the reason to carry out the study and the system boundaries, the inventory phase results in the input and output flows, the impact assessment evaluates the environmental impact related to the flows and the last phase, interpretation, the results are evaluated regarding to the goal and scope of the study (Finnveden, et al., 2009). A more comprehending explanation of the phases is available in following chapters.

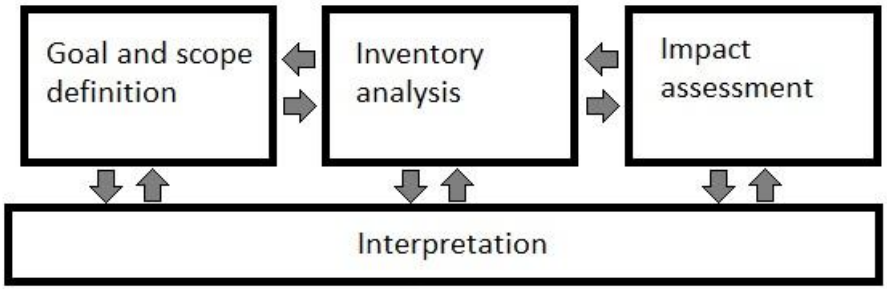

Figure 1. *Illustration of the interaction between the four phases in the framework of life cycle assessment (Carvalho, et al., 2013).*

By different methods or indicators it is possible to assess freshwater use in a life cycle perspective. In LCA it needs to be considered about the methods used for LCI and LCIA (Kounina, et al., 2012). Freshwater use was earlier not considered in most LCA studies and generally LCI databases did only account for input of freshwater use while outputs were excluded. Consequentially, focus in LCIA methods were amount of water used (Hoekstra, et al., 2011). Impact proceeded from water use is both time and location dependent and probably because LCA is independent, water has been neglected (Jeswani & Azapagic, 2011).

Now there are methods developed to evaluate freshwater use in LCA (Hoekstra, et al., 2011). Water footprint methods related to LCA can vary from simple water inventories to complex impact assessment methods. Inventory methods list and make difference

between input and output water flows, midpoint impact assessment methods assess effects from water use and consumption while endpoint methods assess potential damages from water use or consumption in the end of the cause-effect chain (Berger & Finkbeiner, 2012). Midpoint indicator is often located as a half way point on that environmental mechanism chain between man-made intervention and the endpoint indicator (Goedkoop, et al., 2013). However, midpoint and endpoint assessment methods can give relevant indicators for different or all AoP (Hoekstra, et al., 2011).The impact categorizes at midpoint level can be acidification, ecotoxicity or climate change while damages to ecosystem or human health are examples of categories at endpoint level (Goedkoop, et al., 2013).

Development of LCA tools has been necessary; partly to get information about the environmental aspect as well as to unify different parts in common decisions. Results from LCA were often criticized and therefore an international standard for LCA, complemented with a number of guidelines has been produced (Finnveden, et al., 2009).

The four phases in LCA comprise different information and in the first phase a goal of the study should be defined. In this phase it is also important to define functional unit and system boundaries, as a scope description (Frischknecht, et al., 2009). Functional unit refers to a quantitative measure for the provided function from the system (Finnveden, et al., 2009). The three other phases are described in the following sections.

3.1.1 Life cycle inventory

In the second phase of LCA, inventory analysis, the inputs and emissions from the system are described related to the functional unit. This phase requires lots of data and is often challenging due to absence of appropriate data (Finnveden, et al., 2009). The required environment and product data can often be received by life cycle inventory databases (Frischknecht, et al., 2009), often combined with LCA software tools (Finnveden, et al., 2009). However, quantity of used water is often reported in LCI, but ideally documentation would include source of water, type of use and geographical location. Another recommendation is to separate consumptive and degradative use (Pfister, et al., 2009). Outcomes from LCI, the inventory data, represent flows for example extraction of natural resources or emission of hazardous substances (Goedkoop, et al., 2013).

Gabi software, a widely used inventory database, can be used for every stage in LCA and tracks all material, energy and emissions flow as well as the program account for several environmental impact categories. Gabi software is complemented with databases containing more than 4,500 LCA datasets (PE International, 2011). However, Gabi includes elementary flows for freshwater withdrawals, with potential to name water input depending on water type. Further, Gabi also includes water inputs and outputs for fore- and background processes (Kounina, et al., 2012) as well as electricity production (Berger & Finkbeiner, 2012). The database makes differences between withdrawal and release and degradative use is measured by emissions to water (Kounina, et al., 2012).

3.1.2 Life cycle impact assessment

In the third phase, LCIA, the inventory data are assessed into terms of environmental impact (Hanafiah, et al., 2011). The assessment can be done in different steps and the results can be represented as single or profile indicator. Classification, characterization and sometimes normalization and weighting can be used to obtain an indicator. During classification, flows from LCI are classified concerning different environmental impact. Further, a characterisation factor expresses the relation between the magnitude of an impact and the inventory data. Normalization relates the environmental load from a system to the total load occurring in an area, as a region, country or worldwide and that impact is further aggregated using a weighting factor (Frischknecht, et al., 2009).

There exists a wide range of methods developed to calculate WF (Berger & Finkbeiner, 2010). The H_2Oe method, the ecological scarcity methods and the Water Footprint Network (WFN) method are midpoint impact assessment methods giving a single index for all AoP. Those methods are a selection of methods in this study and the motivation to the selection is available in the methodological chapter. Indices for the first two methods are based on a withdrawal-to-availably ratio, while the WFN method is based on a consumption-to-availably ratio. The H_2Oe method and the ecological scarcity method have different characterization factors depending on country while the WFN method has characterization factors depending on watersheds (Hoekstra, et al., 2011). More comprehending explanations of the methods are available in chapter 3.2, 3.3 and 3.4.

3.1.3 Interpretation

During the last phase, interpretation, the result from LCIA is evaluated related to the goal and scope of the study (Finnveden, et al., 2009). For example, the interpretation can be carried out by comparison between products or processes and/or by recommendations for optimization of processes. In this phase it is also relevant to carry out a sensitivity analysis (Frischknecht, et al., 2009).

3.2 METHOD 1 – H_2Oe METHOD

Ridoutt and Pfister (2012) recently presented a method for water footprint calculation, counting for both consumptive (CWU) and degradative (DWU) water use, see glossary. This LCA-based method calculates a single value for water footprint, expressed in a reference unit of water equivalent (H_2Oe), why this method is called the H_2Oe method in this report. The idea with this method is to summarize all water use, in terms of local water stress index and water consumption, with a critical dilution volume (equation 1).

$$Water\ footprint\ (H_2Oe) = CWU(H_2Oe) + DWU(H_2Oe) \quad (1)$$

CWU concerns consumptive water use and DWU describes the degradative water use caused by pollutions in a theoretical water volume, analogous to GW. CWU includes terms for local consumptive water use (CWU_i), the local water stress index (WSI_i) and a global water stress index (WSI_{global}) (equation 2). The global water stress index for this method is assumed to be 0.602 (Ridoutt & Pfister, 2012). DWU is expressed in terms of ReCipe points (equation 3) and this impact assessment methodology models the pollutions ($ReCipe_{points}$). A value for a global ReCipe point ($ReCipe_{points,global}$) is calculated to 1.86 x 10^{-6} ReCipe points, established as an average value for 1 L of CWU.

$$CWU(H_2O) = \sum_i \frac{CWU_i \times WSI_i}{WSI_{global}} \quad (2)$$

$$DWU(H_2Oe) = \frac{ReCipe\ points\ (emission\ to\ water\ for\ product\ system)}{ReCipe\ points\ global\ (average\ for\ 1L\ consumptive\ water\ use)} \quad (3)$$

(Ridoutt & Pfister, 2012).

The method developed by Ridoutt and Pfister does not consider a special AoP and is a single indicator. The method considers surface water and groundwater (Kounina, et al., 2012).

Water Stress Index – WSI

In general, water stress is calculated as a ratio of total annual freshwater withdrawals and hydrological availability (equation 4).

$$WTA_i = \frac{\sum_j WU_{ij}}{WA_i} \quad (4)$$

where WU_{ij} are withdrawals from different users j and WA_i is annual freshwater availability, for each watershed i. When this ratio is above 20 respective 40 percent a moderate and severe water stress occurs. Pfister et al. (2009) advance this concept into a characterization factor for "water deprivation" for midpoint level in LCIA. This factor, water stress index (WSI), ranging from 0 to 1 and includes an advanced WTA (equation 5). The modification of WTA (WTA*) includes a variation factor to consider periods of water stress for watersheds with strongly regulated flows. Therefore, WSI allows assessing increased impact in specific periods for strongly regulated flows.

$$WSI = \frac{1}{1+e^{-6.4 \cdot WTA^* (\frac{1}{0.01}-1)}} \quad (5)$$

Minimal water stress for WSI is 0.01 and at the border between moderate and severe stress, where WTA is 0.4, WSI is 0.5. The expanded WSI can be used as an indicator or characterization factor for water consumption in LCIA (Pfister, et al., 2009).

Recipe points

The report (Goedkoop, et al., 2013) provides useful material for how to calculate life cycle impact category indicators, in other words a structure for LCIA. The name of this LCIA method, ReCipe, is an acronym consisting of the initials of the main institute contributors to the project. The method can model results for both midpoint and endpoint levels and as a LCIA method it can convert LCI results into impact category indicators results with characterization factors. However, the formula for characterization at midpoint level (equation 6) consists of a characterization factor (Q_{mi}) that connects the magnitude of inventory flow (m_i) with the midpoint category m. The result, I_m, is an indicator for midpoint impact category m.

$$I_m = \sum_i Q_{mi} m_i \quad (6)$$

Characterization factors are available in a work sheet on the ReCiPe website. At midpoint level there are eighteen addressed impact categories (Table II:1) (Goedkoop, et al., 2013).

Environmental mechanisms such as eutrophication are based on European models and are generalized towards developed countries. Therefore, this method has limited validity to countries not counted to well-developed in temperate regions. However, there is an amount of uncertainties included in characterization models, since there is an incomplete and uncertain understanding in the environmental mechanism involved in different impact categories (Goedkoop, et al., 2013).

The midpoint indicator for freshwater ecotoxicity uses the chemical 1, 4-dichlorobenzene (14DCB) as a reference substance. The characterization factor for ecotoxicity includes the environmental persistence and toxicity of a chemical. Nutrient enrichment in inland waters can be seen as one of the major factors for the ecological quality. Inland waters in temperate and sub-tropical regions of Europe are generally limited by phosphorus. Therefore, the midpoint indicator for eutrophication in ReCipe uses phosphorus loads into freshwater as reference substance (Goedkoop, et al., 2013).

3.3 METHOD 2 – WATER FOOTPRINT NETWORK METHOD

Water footprint of a product is the sum of all processes included to produce the product and one general method to calculate water footprint of a product ($WF_{prod}[p]$) is the stepwise accumulative approach (equation 7). This approach considers the process water footprint for each outgoing product ($WF_{proc}[p]$) and distributes the total water footprint from input products ($WF_{prod}[i]$) on each outgoing product by a *product fraction* parameter.

$$WF_{prod}[p] = (WF_{proc}[p] + \sum_{i=1}^{y} \frac{WF_{prod}[i]}{f_p[p,i]}) \times f_v[p] \quad \text{[volume/mass]} \quad (7)$$

where p is the output product, i are the different input products from 1 to y, $f_v[p]$ is a *value fraction* and $f_p[p,i]$ is the *product fraction*.

The *product fraction* is defined as the number of output products ($w[p]$) produced from a number of input products ($w[i]$) and can be available for specific product processes in literature (equation 8).

$$f_p[p,i] = \frac{w[p]}{w[i]} \quad [-] \quad (8)$$

The *value fraction* is defined as

$$f_v[p] = \frac{price[p] \times w[p]}{\sum_{p=1}^{z}(price[p] \times w[p])} \quad [-] \quad (9)$$

where $price[p]$ refers to the price of product p and the summation in the denominator is made over the z outgoing products produced from the input products. The components in this water footprint calculation approach are green, blue and grey water footprint (Hoekstra, et al., 2011).

Blue water footprint

Consumptive use of fresh surface or groundwater, BW, results in a blue water footprint. BW footprint for a process step ($WF_{proc,blue}$) is calculated as

$$WF_{proc,blue} = BWEvap. + BWIncorp. + LostReturnFlow \quad [\text{volume/time}] \quad (10)$$

where $BWEvap.$ refers to losses from evaporation, during processes such as storage, transport, processing and disposal, $BWIncorp.$ refers to the volumes included in products and $LostReturnFlow$ refers to the water flow that no longer is available for reuse, due to return to another aquifer or return in another period of time (Hoekstra, et al., 2011).

BW consumptive use for an industrial process can often be measured, direct or indirect, if water input and output are accessible. Differences in input and output water volumes indicate losses during the production. Normally, the volumes included in the products are known and the remained part can be specified as other evaporative losses. Depending on where water is returned, parts of the output volumes are assumed to be lost return flow. Collection of BW consumption data in water footprint calculations are suggested from the producer themselves, but can also be obtained from databases, though those are often limited or miss necessary information (Hoekstra, et al., 2011).

Unclear decisions about water footprint calculations can occur when water is recycled or reused. Recycling occurs when water is captured, from evaporated water or WW, and used for the same purpose again, while reuse means water transfer from one process to another and water is used there as well. However, those uses are not accounted into consumptive water use, but it can be used to reduce a water footprint from a process. A second unclearness proceeds from lost return flow, when water is moved from one basin to another. The replacement to the second basin can be thought of as a compensate act for the lost in the first basin, as a negative water footprint. Still, this inter-basin water transfer should not be seen as compensation and is supposed to be included as lost return flow in BW footprint (Hoekstra, et al., 2011).

Green water footprint

GrW footprints are primarily calculated for products based on plants or wood, where water is incorporated in the products ($GrWIncorp.$). Furthermore, GrW footprint does also include the total evapotranspiration from rainwater ($GrWEvapor.$) and for a process step the GrW footprint ($WF_{proc,green}$) is calculated as

$$WF_{proc,green} = GrWEvapor. + GrWIncorp. \text{ [volume/time]} \quad (11)$$

(Hoekstra, et al., 2011).

Grey water footprint

To receive a harmless concentration in WW with high concentrations of pollutant it can be necessary to dilute the outgoing water with freshwater. This volume of freshwater, not actually used, is expressed as GW footprint ($WF_{proc,grey}$) and can be calculated as

$$WF_{proc,grey} = \frac{L}{c_{max} - c_{nat}} \quad \text{[volume/time]} \quad (12)$$

where L is the pollutant load [mass/time], c_{max} the maximum acceptable concentration and c_{nat} the natural concentration, without human influences, in the recipient body [mass/volume] (Hoekstra, et al., 2011).

Maximum concentrations can be based on different local environmental quality standards for water, also called ambient water quality standards, and the central point is to specify which standard and natural background concentration that are used. It can be an idea to divide GW footprint calculations into two parts, since groundwater and surface water quality have different allowed concentrations; the first refers to drinking water quality while the latter concerns ecological circumstances. Groundwater, on the other hand, normally ends up as surface water and therefore it can be a better idea to take the values from the most critical water body (Hoekstra, et al., 2011).

For chemicals in WW that are released directly into surface water body the pollutant load (L) can be calculated as

$$L = Effl \times c_{effl} - Abstr \times c_{act} \qquad \text{[mass/time]} \qquad (13)$$

where $Effl$ is the effluent volume, c_{effl} is the concentration of pollutant in effluent volume, $Abstr$ is the abstracted volume and c_{act} is the actual concentration of pollutant in intake water. For transport between water catchments, when water is abstracted in one and released in another, the GW footprint in the receiving catchment does not have any abstracted water, therefore, $Abstr$ is equal to zero for the second one. In contrast to point sources, diffuse sources of water pollutions, such as fertilizer or pesticides, are treated differently using various models (Hoekstra, et al., 2011). Evaporation is another water degradation factor, where loss of water volumes causes higher concentrations with remaining amount pollutions (Hoekstra, et al., 2011).

Similar to pollutant concentration, thermal pollution can also be included in GW footprint. Thus, the different pollution concentrations are exchanged against maximum, natural, effluent and actual temperatures (equation 14). If no local guidelines exist for T_{max} and T_{nat} a default value for $T_{max} - T_{nat}$ are 3°C.

$$WF_{proc,grey} = \frac{Effl \times T_{effl} - Abstr \times T_{act}}{T_{max} - T_{nat}} \qquad (14)$$

The degree of GW footprint depends on the pollutant concentration that reaches the environment and therefore it is possibly to decrease its value by reducing the pollutant with different treatments before water is released (Hoekstra, et al., 2011).

3.4 METHOD 3 – ECOLOGICAL SCARCITY METHOD

The Ecological scarcity method is a LCIA method used to support LCI in LCA and it generates an indicator for environmental impact (Berger & Finkbeiner, 2010). Environmental impact from products, processes or whole organizations in a life cycle perspective, can be assessed with the ecological scarcity method where environmental impact is converted into points. However, the method is also used with other names as "ecoscarcity method" or "eco-points method" (Frischknecht, et al., 2009). The Ecological scarcity method is used as a single indicator, not an indicator for any specific AoP. The method focuses on water scarcity quantification in the way of availability and considers surface water and groundwater (Kounina, et al., 2012).

This method was developed in 1990 as a private initiative, but has later been advanced to satisfy ISO requirements and to wide its scope of use. Currently, in order to follow

ISO requirements elements for characterization, normalization and weighting are included. However, the growing relevance for LCA and the use of this method in decision making have pushed the Swiss Federal Office for the Environment (FEON) to complement the earlier report by FEON with updated and new information. The latest version is from 2006 and one important update for water footprint is a new indicator for regional freshwater use. The method is originally produced with Switzerland as system boundary, but indicators for environmental impact from water use have also been established for countries as Sweden and Norway (Frischknecht, et al., 2009).

The method provides ecofactors (EF) for a range of substances and resource use, used to express the total environmental impact from the outcomes in LCI. Provided ecofactors are used as an indicator for the specific environmental impact from each substance and the outcomes from LCI represent the elementary flows ($Load_i$). Thus, the elementary flows are multiplied with corresponding EF and the results are expressed in ecopoints (EP) (Berger & Finkbeiner, 2010). Furthermore, summation of these EF supplies a total ecofactor (EF_{TOT}) for the product, process or organization (equation 15).

$$EF_{TOT} = \sum_i EF_i * Load_i \tag{15}$$

where $EF_i$is the EF for substance i at a specific location and $Load_i$ is the product-specific emission (Baumann & Rydberg, 1993). Further, to avoid double counting in LCA every emission is scored once and that is the first time a substance crosses the line between the anthropotechnosphere and the natural environment (Frischknecht, et al., 2009).

EFs for substances are results from political goals or environmental laws (equation 16). Ecofactors are expressed in the unit EPs per unit of environmental pressure, where the pressure can be pollutant emission or resource extraction. A higher value indicates that the emissions or consumption of resources are higher related to the environmental protection targets.

$$EF = K \cdot \frac{1 \cdot EP}{F_n} \cdot \left(\frac{F}{F_k}\right)^2 \cdot c \tag{16}$$

where the first term K is the characterizations factor of a pollutant or resource. The second term is used for normalization, with F_n as the normalization flow representing the current actual flow with Switzerland as system boundary. The third term is a weighting factor consisting of F as the current flow in the reference area and F_k as the critical flow. Finally, c is a constant (10^{12}/year) that is used for a more convenient

magnitude. Flow is used to express the quantity of a resource, the load of a pollutant or the intensity of an environmental impact (Frischknecht, et al., 2009).

The same pollution can have different ecofactors, depending on where the emission is released or which environmental impact it generates. Pollutants can be released in water, soil or air where the emissions have diverse influence and therefore give different values. The other differences, depending on environmental impact, arise from variations in political targets and here should the assessment be based on the highest ecofactor, to follow the strictest political target (Frischknecht, et al., 2009).

Weighting factors can also be expressed in terms of water stress, similar to WTA, for a region (equation 17).

$$Weighting = \left(\frac{F}{F_k}\right)^2 = \left(\frac{W}{A \cdot 20\%}\right)^2 = (WTA)^2 \cdot \left(\frac{1}{20\ \%}\right)^2 \quad (17)$$

where WTA is the withdrawal-to-availablity ratio in a specific region and works as an index for local water scarity (Berger & Finkbeiner, 2010)

Ecofactor for water use refers to the total input of freshwater into a product system, but there is no characterization done for water quality or type of water source (Berger & Finkbeiner, 2010). Ecofactors for freshwater resource are weighted depending on water available in a country or depending on different water scarcity situation. So far, country specific ecofactors for water use exist for members of the Organization for Economic Co-operation and Development (OECD). For countries not included in the OECD there are ecofactors available for six different water scarcity situations. This makes it possible to account for the actually observed water scarcity in a region when a LCA is performed (Frischknecht, et al., 2009).

Ecofactors for emission are weighted regarding to the condition in Switzerland and this must be considered if the method is used outside the boundary of Switzerland for production processes. Ecofactors can be regionalized and then regional circumstances need to be accounted for, as for example the size of a water body or if the emissions are released into surface or groundwater. This can be required for some pollutants that have a high variability depending on location, as for example phosphorus released to surface waters. Similar, temporal differentiations can be represented in ecofactors, where the formula includes a periodic dependence weighting. However, the amount of weighted substances is limited due to the priorities of their ecological as well as their political relevance and in 2006 it was seventeen emissions to surface water listed with an ecofactor (Table III:1). Anyway, toxicity of organic substances is not accounted for in the ecological scarcity method and natural background concentration is also outside the system boundaries (Frischknecht, et al., 2009).

3.5 ISO 14046

ISO is a network of national standards bodies which started out from a meeting with 25 countries in 1946 "*to facilitate the international coordination and unification of industrial standards*". Today the organization has members from 163 countries who work together to develop voluntary International standards, which suppose to make the industries more efficiency (ISO, 2013a).

In the middle of 2014 a working group (WG 8) at ISO is planning to publish a standard for water footprint; ISO 14046, *Environmental management – Water footprint – Principles, requirements and guidelines*. Focus for this standard is life-cycle assessments of products, processes and organizations and their water footprint connection (Humbert, et al., 2013).

ISO 14046 intends to work as a tool for a consistent assessment technique, helping to understand the impact related to water and identify water footprints in a worldwide perspective at local, regional and global levels. Results of the impact assessment, a water footprint, should be a single value or a profile indicator. If the assessment agrees with ISO 14046 the results can be used independently, compared to an ordinary impact assessment, to describe the overall potential environmental impact (Humbert, et al., 2013).

To carry out a water footprint assessment, according to ISO 14046, six abstracting points need to be satisfied. A water footprint assessment should:

- Be based on a LCA
- Be modular (summation of life cycle stages should be possible for the total water footprint)
- Identify environmental impact(s) related to water
- Contain significant temporal and geographical dimensions
- Identify changes in water quality and quantity of water use
- Use available hydrological information

(Humbert, et al., 2013)

4 MATERIAL AND METHOD

This study comprehends two automotive industries in Sweden, located in Umeå and Gothenburg. The factories produce cabins and frame beams respectively and the focus for this study was on water use during production. The observed processes were the process steps between water abstraction and release in each industry and the information used was data available in the project EcoWater (EcoWater, 2013). LCA-based methods were used to calculate an industrial water footprint. Gabi was used for inventory of freshwater resources and the H_2Oe method, the WFN method and the Ecological scarcity method were used to assess the related impact. However, the three midpoint impact assessment methods were selected on the basis that they should include both a water use part and a pollution part. All methods were applied to each industry, to enable comparison between differences in water footprint values for the industries and between methods.

4.1 CASE STUDY- VOLVO TRUCKS

Volvo was founded in 1927 and began producing trucks one year later. Today it is one of the world's top producers of trucks and conducts business in more than 140 countries (Volvo, 2013b). Volvo Trucks, one part in the Volvo Group, has 16 plants world-wide (Volvo, 2013a) two of which are used as a case study in EcoWater.

The case study of Volvo trucks focuses on two automotive industries in Sweden and their water supply chain. The final product from the industries is trucks and one manufacturing site is located in Umeå and the other one is located in Gothenburg. The manufactory in Umeå produce cabins and in Gothenburg they produce frame beams. Furthermore, the cabins produced in Umeå are delivered as an intermediate product to Gothenburg. The cabins and the frame beams are together with produced parts from other factories composed into the final trucks (EcoWater, 2012).

The system mapping for the processes in the industries of Volvo Trucks was performed on the same basis as the procedure for other case studies in EcoWater, but with its own complexity. The mapping started with an assessment for the system boundaries, followed by identification and mapping of the water supply chain. One issue occurred in the definition of the system boundaries where the problem was that the industries' water systems were unconnected to each other. This was solved through separation of the industry processes (EcoWater, 2013).

The manufactory sites are divided into four stages: water abstraction, water treatment, water use and WW treatment. Since there are different actors involved in these stages and because of modelling purposes, the stages are further divided into groups of actors. In SEAT this results in a process with eleven stages (Figure 2) (EcoWater, 2013). This thesis focuses on water use and water pollution during the production stages and data were received from the case study of Volvo Trucks (Table IV:1, Table IV:2).

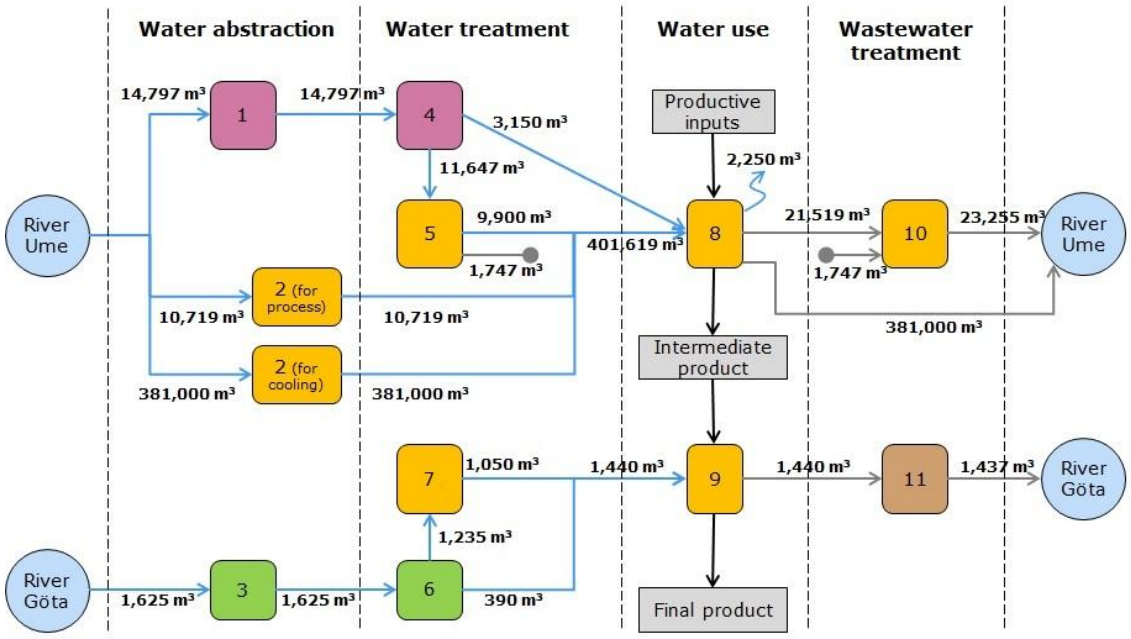

Figure 2. An illustration of the water and WW flows, the four conceptual stages and the actors of the case study of Volvo Trucks. The model is built in SEAT and the stages are here labelled with numbers from 1 to 11. The colours represent different actors and stages are explained in table 1 (EcoWater, 2013).

The different stage numbers for the two sites (Figure 2) are named for Umeå in table 1 and for Gothenburg in table 2.

Table 1. Explanation of the stages at Umeå site showed in figure 2

Stage number	Stage	Abbreviation
1	Municipal water abstraction (UMEVA)	MWA_U
2	Private water abstraction (Volvo Trucks Umeå)	VWA_U
4	Municipal water treatment (UMEVA)	MWT_U
5	Private water purification (Volvo Trucks, Umeå)	VWT_U
8	Water use, (Volvo Trucks, Umeå)	VWU_U
10	Private WW treatment (actor Volvo Trucks, Umeå)	$VWWT_U$

Table 2. Explanation of the stages at Gothenburg site showed in figure 2

Stage number	Stage	Abbreviation
3	Municipal water abstraction (Kretslopp & Vatten)	MWA_G
6	Municipal water treatment (Kretslopp & Vatten)	MWT_G
7	Private water purification (Volvo Trucks, Gbg)	VWT_G
9	Water use (Volvo Trucks, Gbg)	VWU_G
11	Private WW treatment (Stena Recycling)	$SWWT_G$

Umeå

This manufacturing plant is located in the northeast of Sweden and produces truck-cabins. The cabins are delivered both to the manufacturing plant in Gothenburg and distributed outside Sweden to other Volvo facilities. The latter is not further included in this case study. The processes included for water use at the plant in Umeå are de-greasing, phosphating, water recycling, cataphoresis, power washing, painting lines and water for cooling. Water abstraction in Umeå occurs at Volvo Trucks and by municipal water abstraction, both as river and artificial groundwater. WW treatment is carried out by Volvo Trucks and WW is released in River Ume (EcoWater, 2012). The flow of water, electricity and chemicals for Umeå site used in this study is available in table IV:1.

Gothenburg

This manufacturing plant is located in the southwest of Sweden and produces frame beams, in addition to housing a vehicle assembly line. The cabins produced in Umeå are used on the assembly line in Gothenburg and the final product is trucks. Water use at the plant in Gothenburg takes place in the surface treatment of the frame beams, degreasing and phosphating. Water is supplied from the municipality, whilst WW is treated by a private company, Stena Recycling. Both the abstraction and release of water are done in the Göta River (EcoWater, 2012). The flow of water, electricity and chemicals for Gothenburg site used in this study is available in table IV:2.

4.2 STUDY FRAMEWORK

All four phases of LCA were carried out in this study. Goal and scope definition was adapted to satisfy the aim of the project and to suit the investigated case study. In LCI the flows were analyzed with Gabi software with Eco-invent and PE used as databases. Three LCIA methods were selected due to the criteria and later used to assess the environmental impact, from both water consumption and water degradation. Finally, interpretation of the results was performed by comparison of methods results.

The system boundaries were chosen similar to the boundaries in EcoWater and therefore this study includes two industries, one in Umeå and one in Gothenburg, and each water

treatment and WW treatment step. The case study was divided into two LCA systems, one system in Umeå and one system in Gothenburg. As the boundaries were set by water withdrawal and release, this study can be seen as a gate-to-gate LCA.

Flows included in the system were water use, electricity and available chemical data, as well as measured or assumed emissions in WW. The components included were water, electricity, district heating, precipitation chemical, chemical for pH adjustment, dolomite, sand, chlorine and COD, P, Ni, Zn in WW. Because of lack in information, all other inputs and outputs were excluded, such as sludge and input products. Also the intermediate product from Umeå to Gothenburg was excluded from water footprint calculations for the manufactory in Gothenburg. The functional unit for Umeå was the production of 30,000 cabins and for Gothenburg it was frame beams corresponding with 30,000 trucks. Thus the results were calculated and presented as units per 30,000 cabins and frame beams.

4.2.1 Life Cycle Inventory

LCI was performed in two steps; first flows within the system were investigated with data collected by EcoWater and secondly, to include background processes, those flows were used in an inventory database. Data obtained from the case study of the Volvo Trucks were used as raw data in this LCA analysis. Processes in Gabi were selected to match the raw data as closely as possible (Table V:1). Despite this, many assumptions were already made in raw data received from EcoWater.

In Gabi all system stages were modelled as processes and categorized depending on their site. All stages located in Umeå were consolidated into one process chain for cabins (Figure 3) and stages in Gothenburg were combined for production of the final product (Figure 4). The process for the Umeå site was constructed of stages 1, 2, 4, 5, 8 and 10 (Figure 2), while the process in Gothenburg consisted of stages 3, 6, 7, 9 and 11 (Figure 2). Finally, all stages were investigated to track the contribution from each stage to the total water footprint. However, the results from Gabi were used as inventory flows during midpoint impact assessment.

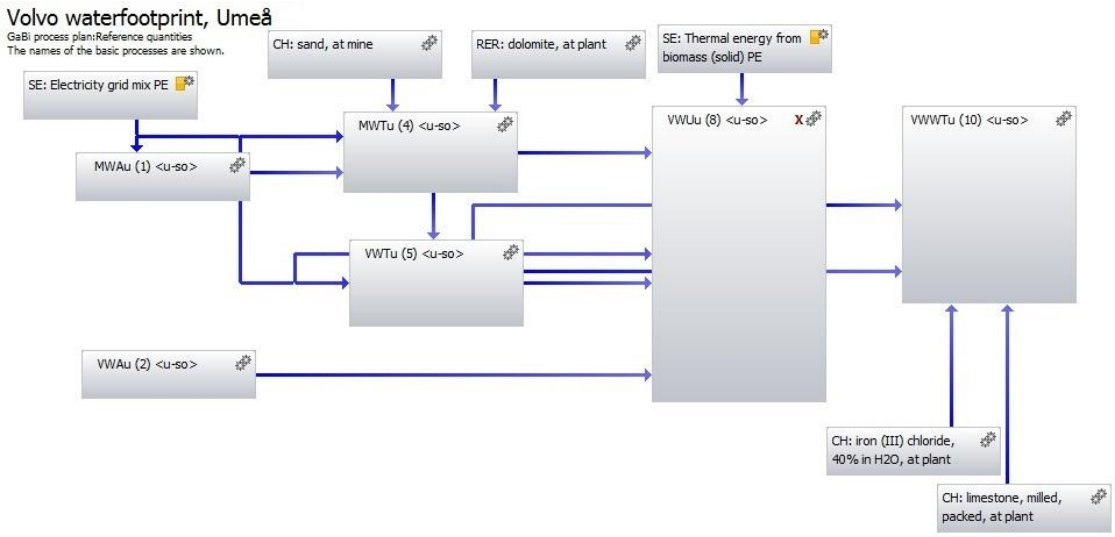

Figure 3. *The processes at Umeå site modelled in Gabi.*

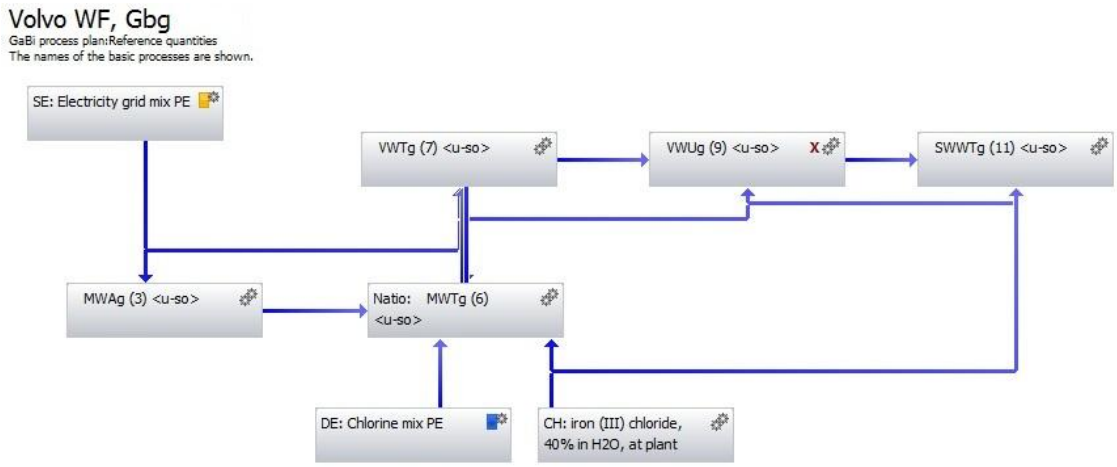

Figure 4. *The processes at Gothenburg site modelled in Gabi*.

4.2.2 Selection of midpoint Impact assessment methods

A comprehensive literature study for water footprint methods was performed in order to select methods useful for impact assessment. Selection of water footprint methods was based on criteria that the method should:

- Consider freshwater use or consumption
- Consider freshwater degradation
- Work as a midpoint impact assessment

A more detailed study was conducted for selected methods and then those were used to assess the flows in LCI. The H_2Oe method, the WFN method and Ecological scarcity method address freshwater use in LCA (Hoekstra, et al., 2011) and were used as impact assessment methods in this study.

4.2.3 Interpretation

The results were investigated depending on processes, so that all contributing steps were calculated and related to the total water footprint value. Another investigation was made to evaluate how different methods consider the local water scarcity situation. Hence, calculations were made for all methods as if the processes had taken place in Switzerland, Spain and Saudi Arabia instead of Sweden, regarding to water use. WSI and EF were adapted to respective country, but the emissions were assumed to be the same as in ordinary calculations. Furthermore, a comparison between the calculated WF result and carbon footprint value generated by Gabi was made. The carbon footprint value generated in Gabi was named as CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.] and is a representative value for carbon footprint (Rydberg, pers. mess.).

Water footprints from the different midpoint impact assessments methods were compared as well as the water footprints for the different manufactory sites.

4.3 METHOD 1 – H_2Oe METHOD

H_2Oe method requires data for:

- Consumptive water use
- Local WSI
- Global WSI
- Degradative water quality expressed in terms of ReCipe points
- Global average ReCipe points

Amount of used water were received from the inventory phase. Local WSI for Sweden, 0.0402, were received from supporting information from Pfister et al. (2009) and a global average WSI, 0.602, were used from Ridoutt and Pfister (2012). With regards to Recipe points, two of the existing eighteen midpoint impact categories were relevant, because they were related to freshwater quality change. Those categories were freshwater eutrophication (FE) and freshwater ecotoxicity (FET). Recipe points for FE and FET were acquired from Gabi results and global Recipe points were used from calculations in Ridoutt and Pfister (2012). Finally, those data were used together with the formula for H_2Oe method and water footprint values were calculated (Appendix XII).

4.4 METHOD 2 – WATER FOOTPRINT NETWORK METHOD

Method 2 requires, for calculation of water footprint for a process, data for:

- Consumed water expressed as blue water
- Maximum concentration for emission
- Natural background concentration for emission
- Load of emission in effluent water

Since this method uses the emission with highest grey WF during calculation of total WF it is desirable to compare grey WF for the emissions released to water. Due to time

constraint and difficulty in collecting data for maximum and natural background concentration this study were restricted in GW footprints. Therefore, this method was limited to three reference values (Table 3). Those emissions were nickel, zinc and total-P, chosen depending on their availability as guidelines in the environmental report from Volvo (2011) as well if they existed in the result from Gabi. The natural concentration for River Ume was assumed to be the same as Lake Remmar located in northern Sweden, in the county of Örnsköldsvik. This lake was used as a reference lake and the values were obtained from a report by Fölster et al. (2012).

Table 3. Reference values for Ni, Zn and tot-P. The maximal concentrations (C_{max}) are set from the environmental report for Volvo (2011)[1)] and the natural background concentrations (C_{nat}) are set as the median values for Lake Remmar (Fölster, et al., 2012)[2)]

Reference values	C_{max} [mg/l]	C_{nat} [mg/l]
Nickel, Ni	0.5[1)]	0.00072[2)]
Zinc, Zn	0.5[1)]	0.0061[2)]
Total-P	1.0[1)]	0.01[2)]

The assumption regarding natural concentration can be seen as representative since this lake has a good or high status and is located in the north of Sweden. Maximum and natural concentrations of those three emissions were compiled and the emission giving the highest GW footprint was used in the final result. Calculations of water footprint for method 2 are available in appendix XII.

Residence time for water in processes, the time between water abstraction and release of water into the same basin, is relevant in the assumption if water should be accounted as consumptive or used. In this study the process cooling water was assumed to be released within a short period of time and was therefore accounted as used water. Since this method considers water consumption, cooling water was not accounted into the BW footprint. The artificial groundwater and process water were accounted as water consumption and therefore included in BW footprint. On the other hand, the result from the Gabi processes shows volumes of used water without knowledge about the residence time. This means that the used water volumes for the processes in Gabi not can be classified as consumed water and therefore all water volumes were included in the footprint calculations of this method.

4.5 METHOD 3 – ECOLOGICAL SCARCITY METHOD

The Ecological scarcity method requires data for:

- Used water
- Emission load in released water
- Ecofactor for water use
- Ecofactors for emissions

Volume of used water and emission load in released water were received from Gabi while EFs for water consumption and emissions were taken from Frischknecht et al. (2009). EFs for emissions are available for Switzerland and those were used for water footprint calculations for Sweden in this method. Regarding water use, there is an EF available for water consumption in Sweden. The available EFs (Appendix III) that fit the result in Gabi were used for calculation of water footprint. An example of calculations for the Ecological scarcity method is given in appendix XII.

4.6 COMPAIRSON BETWEEN METHODS AND LOCATIONS

Water footprint calculated for water use in Sweden is compared between the three methods. BW footprint calculated with the WFN method does not consider the scarcity situation in the surrounding. Furthermore, water footprint for the three methods is compared between Sweden and three other countries. Those countries were selected on the criterion that they would have an available WSI and ecofactor. Sweden, Switzerland and Spain had specific values for both WSI and ecofactors. Saudi Arabia only had one available WSI, but was named as a severe overexploited country by Frischknecht et al. (2009). Therefore, Saudi Arabia was placed into the category for extreme scarcity for ecofactors, but could possibly suit in with severe scarcity as well. WSI and EF for the four countries are available in table 4.

Table 4. WSI and EF for Sweden, Switzerland, Spain and Saudi Arabia

Country	WSI	EF
Sweden	0.0402	2.8
Switzerland	0.0923	222
Spain	0.715	990
Saudi Arabia	0.995	6200

Another comparison was made between WF and carbon footprint. A carbon footprint is available in the LCI result as CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.].

4.7 CONCORDANCE WITH ISO 14046

Since the standard first will be available in spring 2014 this report just includes a limited amount of information about its content. However, there were many steps for water footprint assessment that referred to or were identical to earlier standards for LCA, but which focused on impact related to water. Some water related criteria in this draft were selected and used to decide if the methods satisfy parts of this standard.

This thesis focused on the elementary flows that are concerned in ISO 14046. According to ISO 14046 data collection in water footprint assessment should consider specific data connected to water. Most of this data are relevant for water footprint inventory analysis and focus has been on data related to those elementary flows. However, the main purpose of this study was to evaluate if the three midpoint impact

assessment methods could assess potential environmental impact from the elementary flows in ISO 14046 (Table 5). Still, there are more criteria in the complete standard and some changes will probably be made in this draft.

Table 5. Criteria of elementary flows in ISO 14046

Data	Examples of data
Quantity of water used	Water input and output in mass or volume
Resource type of water used	Precipitation, surface water, seawater, brackish water, groundwater, fossil water
Water quality parameters and/or characteristics	Physical (thermal), chemical, and biological characteristics or functional water quality descriptors
Forms of water used	Different forms of water consumption, displacement of water and other forms of water use such as evaporation, product integration and in-stream use.
Geographical location of water withdrawals and/or discharge	Information of the location , as site specific as possible
Temporal aspects of water use	Time of use and release
Emission to air, water and soil with impact on water quality	

5 RESULTS

The results in this chapter are calculated for production of cabins and frame beams representative for 30.000 trucks.

5.1 LIFE CYCLE INVENTORY

The output flow results in Gabi consist of more than 200 different flows, but only 15 were used for calculations, since there only were 15 available EF that suits the result. Gabi results provided Recipe points for around 18 midpoint indicators and two of these were used in the calculations. Table 6 shows the output flow results for Umeå and Gothenburg site that were used for calculations. A table for a more comprehended inventory result from Umeå is available as an example in table VI:1.

Table 6. The output flows from Gabi, used during calculation of water footprint for Umeå and Gothenburg site

Flow	Umeå [kg]	Gothenburg [kg]
Water	13 404 000 000	1 163 000 000
Absorbable organic halogen compounds (AOX)	1.4	0.1
Chemical oxygen demand (COD)	13 500	65
Nitrogenous Matter (unspecified, as N)	0.1	0.01
Arsenic (+V)	1.0	0.1
Cadmium (+II)	0.4	0.05
Chromium	0.3	0.02
Copper (+II)	0.07	0.006
Lead (+II)	0.6	0.05
Mercury (+II)	0.04	0.005
Nickel (+II)	15.0	1.8
Zinc (+II)	1.7	0.2
Phosphorus	3.7	0.4
Polycyclic aromatic hydrocarbons (PAH, unspec.)	0.002	0.0002
Radioactive emissions to fresh water	460 000 000	41 000 000
Recipe Midpoint - Freshwater ecotoxicity [kg 1,4-DB eq]	3 000	370
Recipe Midpoint - Freshwater eutrophication [kg P eq]	130	15

5.2 SELECTION OF METHODS

Nine different methods were compared against the criteria for a water footprint method and four of the methods satisfied the criteria (Table 7). The criterion that the methods should consider freshwater use or consumption, freshwater degradation and that it would be possible to use the method as a midpoint impact assessment method were satisfied by the H_2Oe method, WFN, Bouley et al. (2011) method and the Ecological scarcity method. Both H_2Oe method and the Bouley et al. (2011) method contained WSI and therefore were only one of those methods selected, without any motivations the H_2Oe method was chosen. Consequently, H_2Oe method, WFN and the Ecological scarcity method were further studied.

Table 7. Four of the nine methods consider all three criteria that a method should include freshwater use and degradation and that it would be possible to use the method as a midpoint impact assessment method. A cross (X) means that the method contains the criterion, a hyphen (-) means it does not and an empty cell indicates loss of information, a star (*) means that the midpoint characterization factor is WSI, 1) means that the method considers freshwater fish species loss and 2) that the method considers species richness of terrestrial vegetation related to groundwater use

Method	Freshwater use	Freshwater degradation	Midpoint impact assessment
Chapagain & Orr (2008)	X	X	
H_2Oe method	X	X	X
Milà I Canals et al. (2008)	X	-	
WFN	X	X	X
Pfister et al. (2009)	X	-	
Boulay et al. (2011)	X	X	X*
Hanafiah (2011)	X	-	1)
Zelm et al. (2011)	X	-	2)
Ecological scarcity method	X	X	X

5.3 METHOD 1 – H_2Oe METHOD

H_2Oe method calculates water footprint depending on WSI and Recipe points. Total water footprint for 30,000 cabins is 2.62 Mm^3 H_2Oe and 0.28 Mm^3 H_2Oe for frame beams. So, the total water footprint for Umeå is around nine times the water footprint for Gothenburg. However, the degradative water use contributes with the main part to the total water footprint, 66 percent for Umeå and 73 for Gothenburg. 63 percent of water footprint in Umeå comes from ecotoxicity, 3 from the eutrophication part and consumptive water use contributes with 34 percent (Table 8). Processes with a water footprint between 0.0001 and 0 percent are visualized in the tables as a hyphen (-).

Table 8. Water footprint for Umeå and Gothenburg calculated with the H_2Oe method

WF	Umeå [m^3 H2Oe]	Umeå [%]	Gothenburg [m^3 H_2Oe]	Gothenburg [%]
CWU	895 000	34.1	78 000	27.5
DWU ecotoxicity	1 700 000	63.3	197 000	69.6
DWU eutrophication	69 000	2.6	8 000	2.9
Total DWU	1 700 000	65.9	205 000	72.5
Total	**2 600 000**	**100**	**283 000**	**100**

The distributions of water footprint for the different processes in Gabi and stages for Gothenburg is similar to Umeå and the result for Gothenburg is therefore available in appendix VII (Table VII:3 and Table VII:4).The precipitation chemical contributes with around 46 percent of the total water footprint for Umeå, where almost all contribution comes from the degradative part. Electricity contributes with around 43 percent and the other chemicals contribute with less than 2 percent (Figure 5). Compared to the case study of EcoWater activated carbon, chemical for de-greasing, chemical for phosphating, coagulation agent, chemical for flocculation and sludge are excluded in this study.

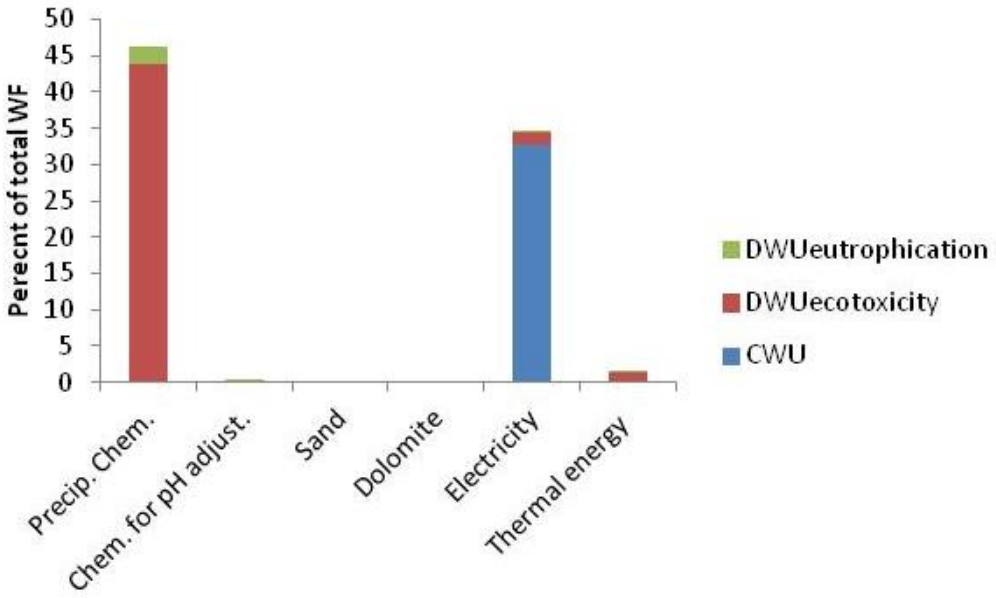

Figure 5. *Consumptive and degradative WF in percent of total WF for the processes in Umeå.*

Volvo WW treatment plant in Umeå contributes with 63 percent of the total water footprint, the water use stage contributes with 33 percent and the remaining stages just stand for less than 1 percent each (Figure 6).

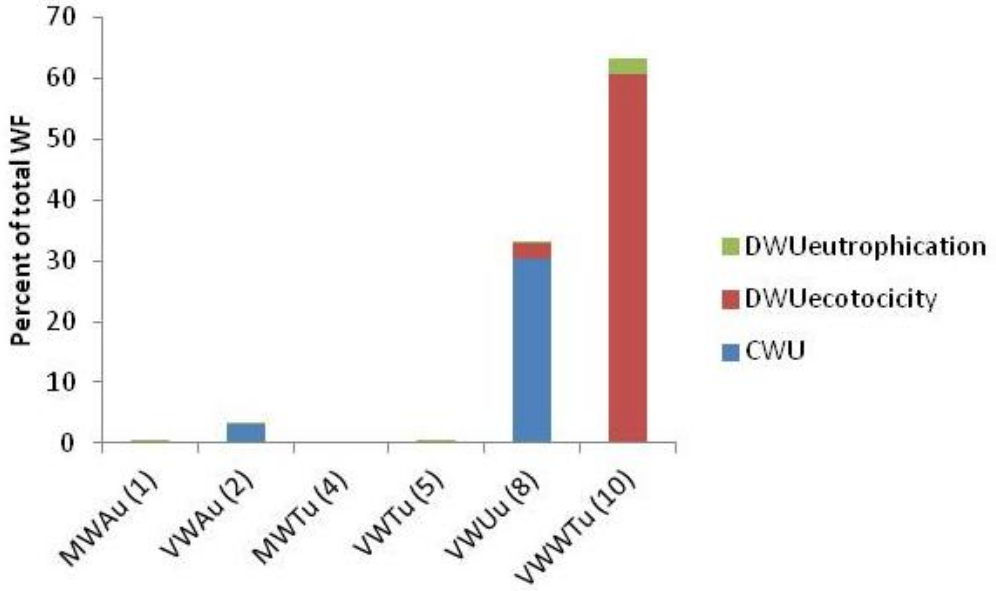

Figure 6. *Consumptive and degradative WF in percent of total WF for the stages, explained in table 1, at Umeå site.*

5.4 METHOD 2 – WATER FOOTPRINT NETWORK METHOD

The water footprint network method calculates a water footprint depending on the amount of consumed water and reference values for the emissions in the effluent water. The reference values in this study were available for nickel, zinc and total-P. The calculations with nickel contributed to a higher GW footprint than calculation with zinc and phosphorus (Table VIII:1). Therefore, the following calculations were performed with nickel.

Total water footprint for the water footprint network method is 13.05 Mm^3 for Umeå and 1.17 Mm^3 for Gothenburg. Consequently, the water footprint for Umeå is eleven times the water footprint for Gothenburg (Table 9). The distribution of WF in Umeå and Gothenburg follows, analogous to method 1, almost the same pattern. Therefore, the result for method 2 is only showed for Umeå, while the result for Gothenburg is available in appendix VIII (Table VIII:4, Table VIII:5).

The distribution of blue and grey WF indicates that blue water contributes with the main part of total WF. The total WF for Umeå comes from blue water, which contributes with 99.8 percent while 0.2 percent comes from grey water. For Gothenburg, around 99.7 percent of the total WF comes from blue water and 0.3percent come from grey water (Table 9).

Table 9. Blue, grey and total WF for Umeå and Gothenburg site. GW and total water footprint is calculated with nickel

WF	Umeå [m^3]	Umeå [% of WF]	Gothenburg [m^3]	Gothenburg [% of WF]
Blue WF	13 000 000	99.8	1 163 000	99.7
Grey WF	30 000	0.2	4 000	0.3
Total WF	**13 000 000**	**100**	**1 167 000**	**100**

Of the processes at Umeå site the electricity contributes with almost 99 percent of total WF and thermal energy for almost 1 percent. The other processes can be seen as negligible in comparison with the total WF. The precipitation chemical contributes with the largest contribution to grey water, almost 70 percent of the total GW footprint. Blue water is the major part for electricity (Figure 7).

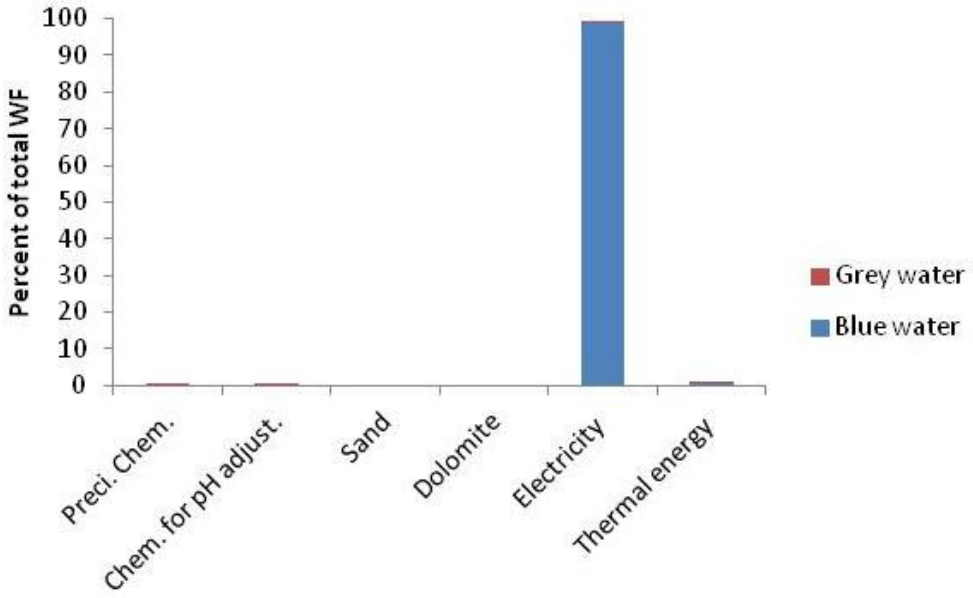

Figure 7. *Distribution of blue and grey WF calculated with method 2 for the processes at Umeå site, related towards the total water footprint.*

Summation of all processes shows that the water use stage at Umeå corresponds to more than 91 percent of total water footprint. Second-largest WF, 6 percent of total WF, gets from the water abstraction stage at Umeå and the waste water treatment plant at Umeå contributes with just about 1 percent. The other stages stand for less than 1 percent each (Figure 8).

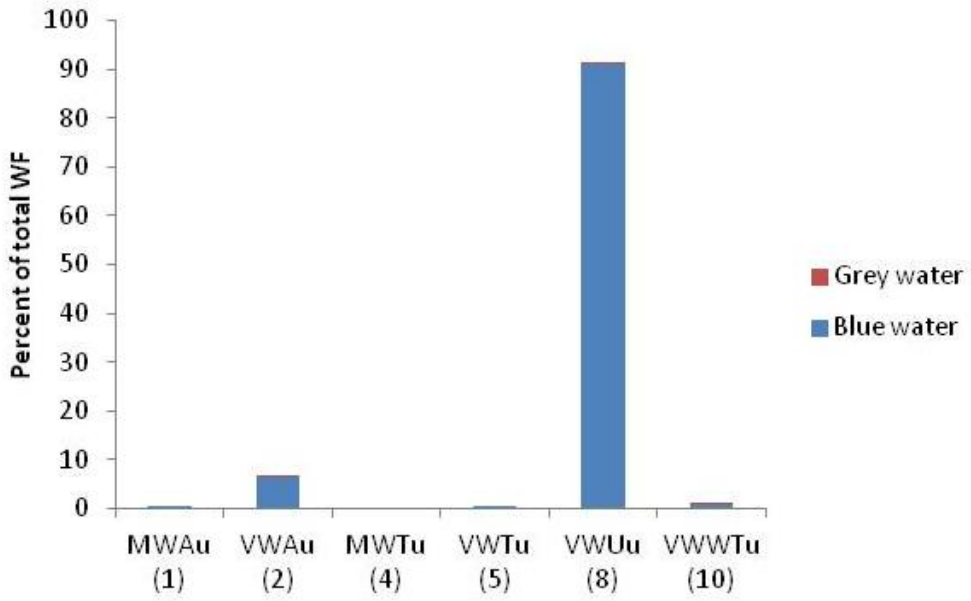

Figure 8. *Distribution of blue and grey WF calculated with method 2 for the stages, explained in table 1, at Umeå site, related towards the total water footprint.*

5.5 METHOD 3 – ECOLOGICAL SCARCITY METHOD

The Ecological scarcity method calculates water footprint based on ecofactors, both for water use and degradation. Total water footprint for Umeå site is 354.7 MEP and 37.5 MEP for Gothenburg. So, total water footprint for Umeå is around 9.5 times the water footprint for Gothenburg (Table 10).

Water use contributes with almost 11 percent of total ecopoints for Umeå and the summarized EP of emissions for 89 percent. Corresponding values for Gothenburg is 9 and 91 percent. Cadmium, mercury and nickel are the emission with highest contribution for both sites (Table 10). Since the result for Gothenburg is smaller but similar to the result for Umeå the WF values for processes and stages at Gothenburg are available in appendix IX (Table IX:3, Table IX:4).

Table 10. EP for water use and emissions at Umeå and Gothenburg, expressed as EP and percent of total EP

WF	Umeå [EP]	Umeå [%]	Gbg [EP]	Gbg [%]
Water use	37 500 000	10.6	3 260 000	8.7
AOX (as Cl^-)	273 000	0.08	23 000	0.06
COD	31 154 000	8.8	149 000	0.4
Nitrogen (as N)	8 000	0.002	630	0.002
Arsenic	8 100 000	2.3	980 000	2.6
Cadmium	123 600 000	34.9	14 850 000	39.6
Cr +III	532 000	0.2	29 000	0.08
Cr +IV	1 160 000	0.3	140 000	0.4
Copper	1 030 000	0.3	86 000	0.2
Lead	2 660 000	0.8	202 000	0.5
Mercury	33 630 000	9.5	4 060 000	10.8
Nickel	102 040 000	28.8	12 230 000	32.6
Zinc	8 483 000	2.4	945 000	2.5
PAHs	21 600	0.006	2 500	0.007
Phosphorus (as P)	4 399 000	1.2	540 000	1.4
Total EP - water use	37 500 000	10.6	3 260 000	8.7
Total EP - emission	317 100 000	89.4	34 240 000	91.3
Total EP	**354 700 000**	**100**	**37 500 000**	**100**

The precipitation chemical has the highest EP for the processes and contributes with 67 percent, where cadmium, mercury and nickel are the emissions that contribute most. Electricity has the second-largest part, almost 12 percent, and the main contributor is water use. The other processes can be seen as negligible (Figure 9).

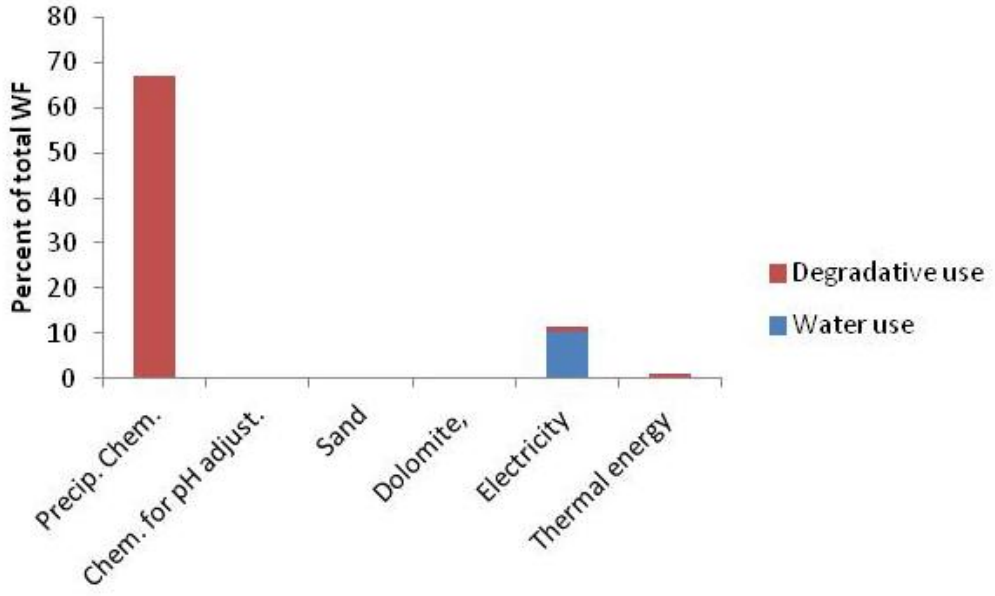

Figure 9. *Distribution of degradative and water use footprint for the processes at Umeå, as percent of the total WF for method 3.*

Wastewater treatment at Umeå site contributes with the major part of the total water footprint, around 87 percent, where almost everything comes from emissions. 12 percent of the water footprint arises in the water use stage at Umeå, where the main part comes from water use. The water abstraction stage at Umeå contributes with around 1 percent of total WF, while remaining stages stand for a negligible part (Figure 10).

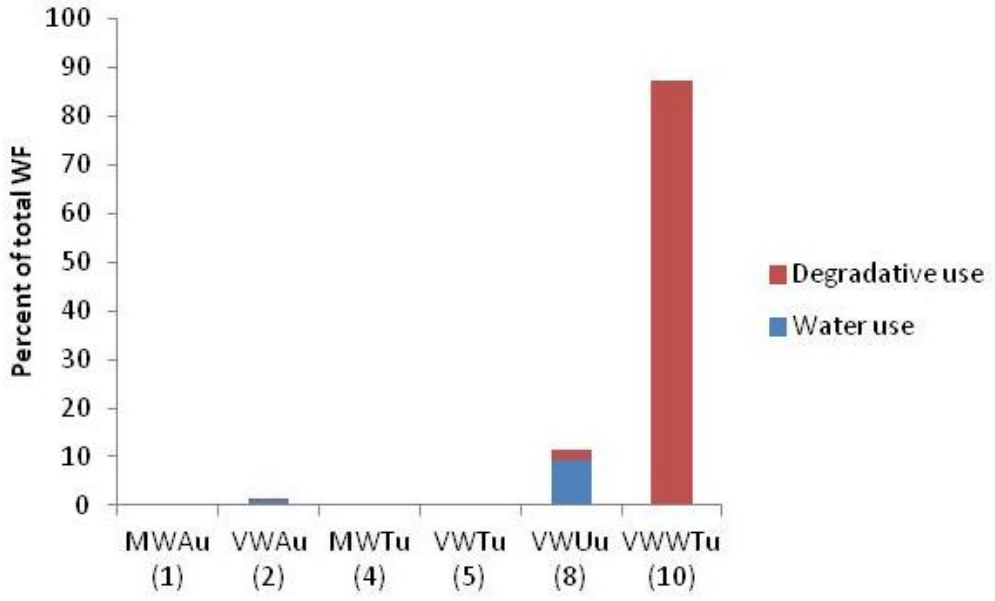

Figure 10. *Distribution of degradative and water use footprint for the stages, explained in table 1, at Umeå, as percent of the total WF for method 3.*

5.6 COMPARISON BETWEEN METHODS

This chapter concerns comparison between different footprints. First comparison is made for the three methods, the second is made for water footprint at different locations and the last comparison is made between water and carbon footprint. All footprints concern the processes at Umeå site.

5.6.1 Comparison between WF methods

WF for the three methods concerning freshwater use or consumption is 0.9 Mm^3 H_2Oe, 13 Mm^3 and 37,5 MEP. This result is an order of 1, 15 respective 42 times the WF magnitude for the H_2Oe method (Figure 11). Regarding to GW footprint the values for method 1 and method 3 are 56 and 10552 times the GW footprint for method 2.

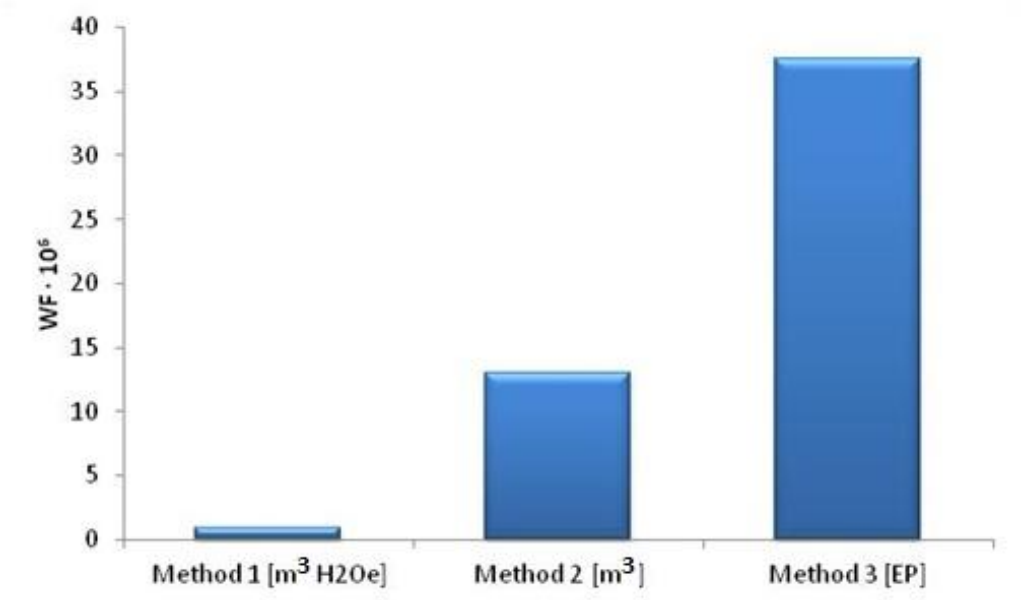

Figure 11. *Comparison between water use footprint for method 1, method 2 and method 3 in the units of Mm^3 H_2Oe,M m^3 respective MEP.*

5.6.2 Comparison between location

Concerning location in different countries the result shows that the ecological scarcity method responds with a higher WF relative the H_2Oe method for an increased scarcity. Still, the WFN method does not consider scarcity situation (Figure 12). Values for the calculations are available in table X:1.

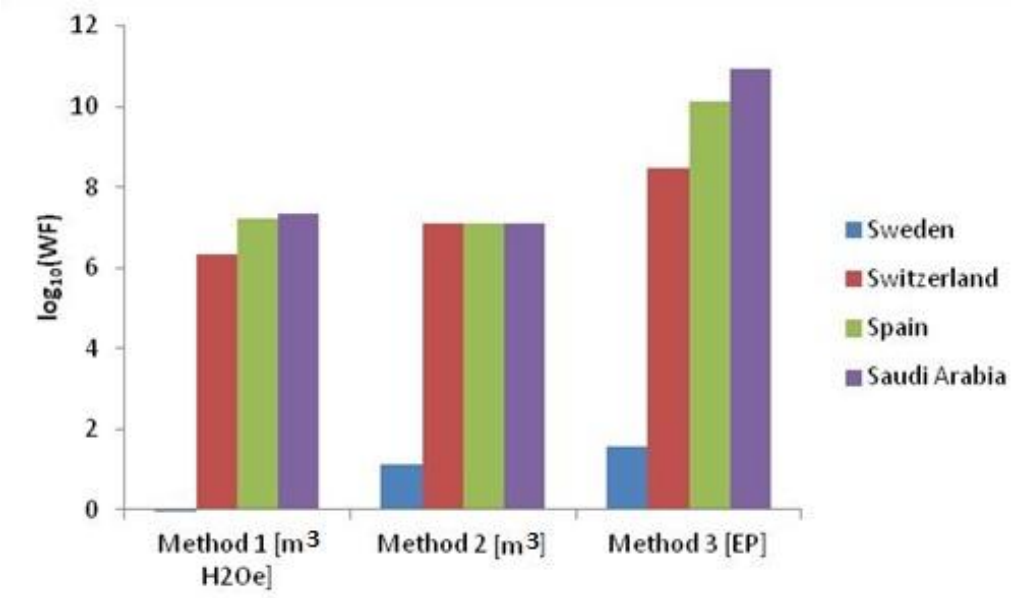

Figure 12. *The common logarithm of WF for Sweden, Switzerland, Spain and Saudi Arabia, calculated with method 1, method 2 and method 3.*

5.6.3 Comparison with carbon dioxide

WF values are larger than the carbon footprint for Umeå site, as much as 6, 30 and 820 times larger (Figure 13).

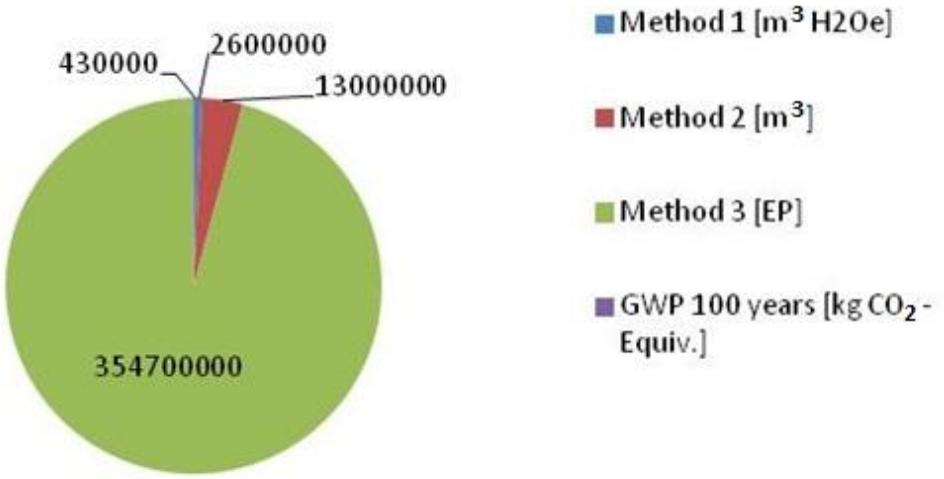

Figure 13. *WF values calculated with method 1, method 2 and method 3 compared with carbon footprint for Umeå site.*

Largest contributor to WF is the precipitation chemical, except for method 2. For method 2 and for carbon footprint electricity provides the biggest amount. Thermal energy and precipitation chemical contribute with almost the same percent to the total carbon footprint (Figure 14).

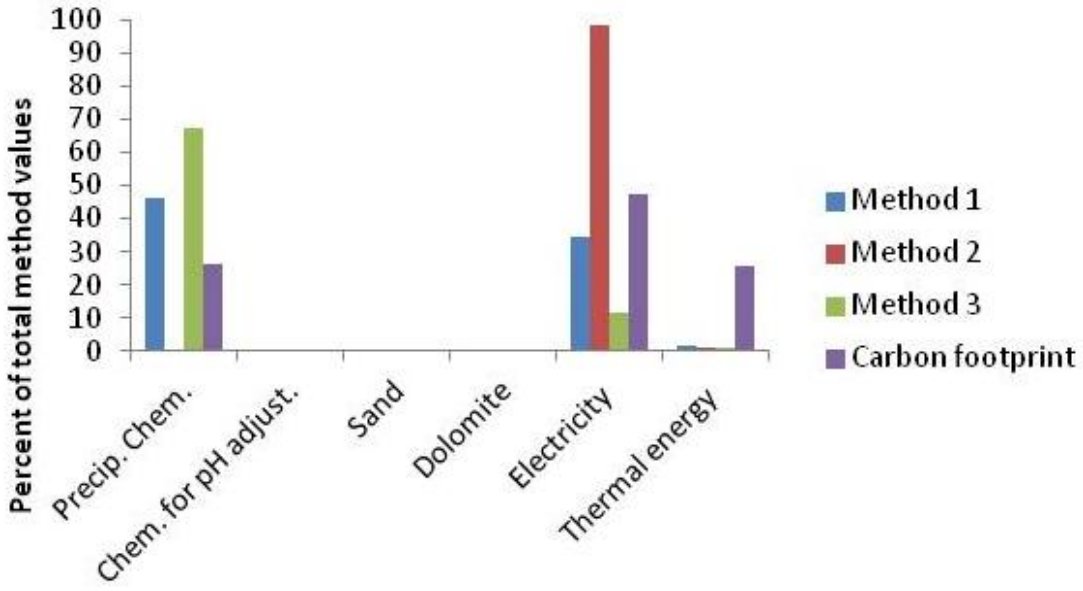

Figure 14. *Water footprint values and carbon footprint for the processes at Umeå site, compared as percent of the total footprint for each method.*

The result shows that the largest WF occurs in the WW treatment plant at Volvo for method 1 and method 3, while the water use stage at Volvo contribute most to the total WF for method 2 and to total carbon footprint (Figure 15). Values for water and carbon footprint are available in appendix XI (Table XI:1, Table XI:2 and Table XI:3).

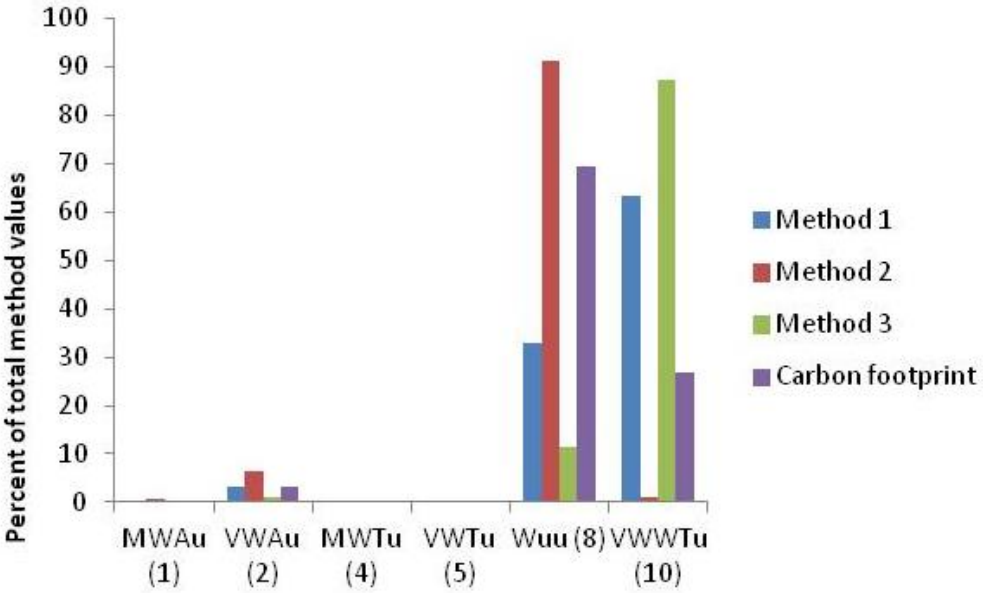

Figure 15. *Distribution of WF and carbon footprint for the stages at Umeå site, as percent of the total footprint for each method.*

5.7 CONCORDANCE WITH ISO 14046

The three midpoint impact assessment methods all consider water quantity and quality. In this study, the WFN takes water consumption into considerations while the other two methods account for water use. All methods calculate a WF based on water volumes,

but the Ecological scarcity method expresses WF in EP. Surface water and groundwater are assessed in all methods, but the WFN generally includes GrW. H_2Oe method accounts for water scarcity in a region but does not consider regionalization for emissions, just for well-developed in temperate regions. In contrast, the WFN method considers regionalization for emissions but not for water consumption. The Ecological scarcity method, on the other hand, can consider geographical circumstances for both water use and emissions. None of the methods accounts for emissions to soil and air in water footprint, while all methods can include some kind of temporal aspect (Table 11).

Table 11. The H_2Oe method, the WFN method and the ecological scarcity method are compared with the elementary flows included in ISO 14046 and an evaluation is made about their consisting with the criteria during this study. Text within brackets gives an indication of the methods in a general methodology and a hyphen is used where there is lack of information

Method/ Elementary flow	**H_2Oe**	**Water Footprint Network**	**Ecological scarcity**
Quantity of water used	Used volume	Consumed volume	Used volume
Resource type of water used	Surface water and groundwater	Surface water and groundwater, (GrW).	Surface water and ground water.
Water quality parameters and/or characteristics	Ecotoxicity and eutrophication (Recipe points)	Pollutant concentrations (Thermal pollution)	Indicators for 17 substances (Switzerland)
Forms of water used	(Consumptive) water use	Water consumption	Freshwater use
Geographical location of water withdrawals	WSI	-	Country specific or depending on scarcity situation (Regionalization possible).
Geographical location of water discharge	Recipe for well-developed countries in temperate regions (Recipe points)	Local water quality standards	Country specific for Switzerland (regionalization possible).
Temporal aspects of water use	Included in water consumption	Includes in water consumption	(Possible with periodic weighting)
Emission to air, water and soil with impact on water quality	-	-	-

6 DISCUSSION

6.1 CALCULATIONS OF WATER FOOTPRINT WITH THE THREE METHODS

All three methods evaluated in this study can be used to calculate water footprint values for the two industrial processes at Volvo. The methods are useful as LCIA methods in LCA and can therefore be seen as water footprint methods based on LCA. Furthermore, the methods differ in various ways such as evaluations of water scarcity situations and considerations of emissions. Regarding to Gabi software, it does not explain if water use in background processes is used or consumed. Gabi does not either describe where water is abstracted or released, that is to say there are a lack of time and location aspects. Berger et al (2012) shows that water consumption takes place in 43 countries worldwide. This should be kept in mind as WFs in this study are calculated as water use only took place in one country. According to Berger et al (2012) uncertainties about geographical differentiating would be reduced if water flows were separated depending on location in LCA databases. Beyond this, Gabi provides information about what type of water that has been used but the methods used in this study have not considered that aspect.

All three methods calculate a higher water footprint for the manufactory in Umeå than for the manufactory in Gothenburg. That can be seen as a reliable result since the studied production chain for cabins consume more water, electricity and chemicals than the truck production site in Gothenburg. Furthermore, for total WF the input products should be included, which would result in a higher water footprint for Gothenburg since the cabins produced in Umeå are included. However, the result shows that most of the water footprint occurs from the precipitation chemical and electricity. Consequently, a reduction of those processes in this study would lead to a reduction of the total water footprint. In general, many factories use chemicals and other processes during production, where the background processes are an important contributor to WF. So even if the factories are attentive about their own emissions, they need to be aware about the chemicals that are used for production of input products.

As for the units of water footprint, all methods have their own. The Ecological scarcity method differs from the other two in its expression of EP and exclusion of the term m^3. The other two methods both use m^3 as expression, but the H_2Oe method also includes a unit of water equivalent. Still, water footprint for those methods should be possible to compare since both convert the degradative use into water volumes. Concerning similarities between water footprint values, all three methods calculate a single value and the value is an indicator for all area of protection.

Water footprint values for the three methods differ both in numbers and units. Regarding water use, the size of the values for the WFN method and the Ecological scarcity method are 15 and 42 times the value for the H_2Oe method, respectively. For the degradative part the equivalent numbers are 0.017 and 184. This results in a total WF order of the magnitudes 1, 5 and 135. In an attempt to compare the major difference

between WF values, the natural logarithmic scale was applied for water use and degradative footprint (Figure 16). The largest contribution to the water footprint values for the H_2Oe method and the Ecological scarcity method is the degradative part, while water consumption is dominant for the WFN method. The distribution between consumptive and degradative water footprint for the H_2Oe method is around 30 and 70 percent and 10 and 90 percent for the Ecological scarcity method. The WFN method has a notable distribution of 0.2 and 99.8 percent, which means that the emissions have an almost inconsiderable influence. This indicates that the methods estimate reasons to environmental impact in different ways.

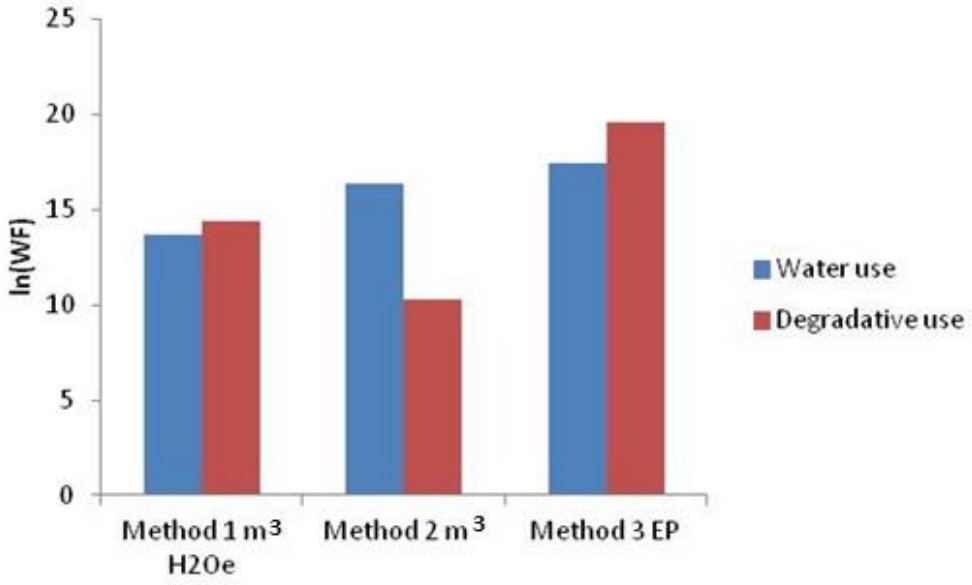

Figure 16. *Distribution of water use and degradative use footprint values for the three methods.*

The difference between the values is dependent on the various reference values and how the emissions are treated. However, the H_2Oe method relates both water consumption and degradation to a global value for WSI and Recipe. The reliability of the global values for WSI and Recipe can be discussed, but if everyone would use the same values it would unify WF in global perspective. The relatively low WF for the H_2Oe method could be due to the fact that there were only two Recipe point values representing many emissions, which could result in a lower footprint than if there were one Recipe point available for each emission. Furthermore, Sweden is a country with plenty of water compared to many other countries and the globalization gives a reasonable motivation to the low WF for water consumption. The Ecological scarcity method assesses water use depending on available water in a country while the WFN method gives the same WF as the volumes of used water. This study calculated different WF and Quinteiro et al. (2014) showed that freshwater use impact varies even though they applied same inventory data for several LCA methods. This indicates that WF for products calculated with different methods not should be compared.

The difference between numbers of comprised emissions can indicate the difference between the other two methods. The WFN method calculates grey water footprint based on one emission, while the Ecological scarcity method in this case calculates an aggregated footprint for 16 different emissions. An improved calculation with the latter method would include all emissions, and would increase the WF value for each emission, but that would lead to a costly and time-consuming process. Furthermore, dilution of the most harmful chemical to a harmless concentration would result in a comfortable situation, but lead to a thought about general pollution situations. If, for example, a manufactory release one pollution while another manufactory releases many pollutions in smaller or the same amount as the first factory, would the WF for those manufactories then be evaluated as equivalent? There is no answer to the question in this study but the Ecological scarcity method deals with this problem in one way, by considering all emissions with an available ecofactor. Therefore, there is a big difference between values for those methods.

Another disparity in treating of degradative water use is that the WFN method uses values for the recipient body and the Ecological scarcity method weighs the emissions as if they were released in Switzerland. WF for the WFN method is therefore dependent of the choice of reference values by the user and the guidelines in the country. Sweden has quite strict guidelines related to some other countries and that would mean that a Swedish water footprint would be higher than that of a country with lower priority of water quality. This would affect manufactories located in a country with high priority of water quality with a high water footprint.

6.2 WATER FOOTPRINT DEPENDING ON LOCATION

The three methods respond differently by the location. The WFN method does not consider the water scarcity situation for water use, while the other two show different results. The Ecological scarcity method responds to a greater extent for water scarcity than the H_2Oe method, but both methods generate a higher water footprint for increased scarcity. Manufactories in countries exposed to high water scarcity can take advantage by the WFN method, while they are vulnerable for water footprint calculated with the other two methods. This means that countries already suffering from water scarcity would be treated unfairly if water footprint calculated with the H_2Oe method and the Ecological scarcity method was used as a tool on the global market. Conversely, countries not suffering from water scarcity could take advantages of this fact. Increased knowledge about water footprint would possibly contribute to a better water quality worldwide, but the consequences for already exposed countries need to be considered.

6.3 WATER AND CARBON FOOTPRINT

There are differences between water and carbon footprint in this study. Comparison between the total footprint values for each method almost makes the carbon footprint value negligible, but different indicators are used and it would not be an appropriate comparison. Instead it is more interesting to compare the particular trend for each method, concerning the contribution between processes and stages. Those trends show that water footprint calculated with method 1 and 3 indicates the highest value for the

precipitation chemical and the WW treatment plant, while WF calculated with method 2 and carbon footprint shows the highest value for electricity and the water use stage. Similar to this study, Quinteiro et al. (2014) showed that the evaluated methods indicate on different hotspots, production stages or sub-system, in the system depending on used freshwater method. Even though the trend for method 3 and carbon footprint is similar, the result in this study indicates that a process positive in the aspect of environmental impact regarding to water use does not necessarily need to be positive in the aspect of climate change.

6.4 CONCORDANCE WITH ISO 14046

There are differences between the methods and in this study none of the methods consider all elementary flows in ISO 14046. The first difference between the methods is that method 1 and 2 consider water consumption and method 3 considers water use. In this study this difference only matters for the cooling water at Umeå site, since there is no information about where and when water in background processes is abstracted and released. According to the temporary aspect the methods only consider temporary variations in terms of water use. In the WFN method temporary aspects are included merely because water consumption is used instead of water use. This creates a risk that the two other methods, as well as the WFN method, can overlook information about how water abstraction affects the environment in different periods. For example, if water scarcity is high and large volumes of water are used, it would cause more damage than if there was a period with good water access.

The concordances with ISO should not be seen as a complete review of how the methods treat the flows, especially not in general. Due to time constraints the criteria could not be evaluated further and the result can just be seen as an intermediate rating. The major problems during the evaluation about how the methods concern the elementary flows were lack of information and understanding about the methods. Still, the user can influence how the LCIA methods should be applied. All methods can in some extent be adapted and concern almost all criteria, but this study excluded two criteria which is a reflection of a general methodology. The first exception concerns the WFN method and the criterion for geographical location of water withdrawals, since this method does not consider water scarcity situation. The second exception concerns the last criterion for ISO 14046, that the elementary flow *should include information about emission to air, water and soil with impact on water quality*. This criterion has not been concerned for any method in this study, which means that it has not been done any considerations about emissions to soil and air, even though it may affect water quality. However, all criteria for elementary flows in ISO 14046 should be included where there is *relevant*. Therefore, the methods, perhaps not the WFN method, satisfies ISO requirement for element flow if the user can motivate that all relevant information is included.

6.5 CONSIDERATION OF INVENTORY DATA AND CHOOSE OF CALCULATION METHODS

The inventory data result from Gabi shows that there are many emissions related to production of trucks, mainly for processes used in the manufactories. This indicates that there is a challenge to prioritize which emissions that should be considered in a water footprint method. Of all emissions only 16 were analyzed during calculation with the ecological scarcity method. This indicates that a lot of information gets lost. Even with the H_2Oe method, which includes environmental mechanisms that concern phosphorus and ecotoxicity chemicals converted into 14DCB, there is a loss of information. The WFN method only considers information about one chemical, but still there is a need to know the most harmful chemical. Altogether, water footprint calculations need a lot of data regardless of method to give acceptable results. Comparable to this, Berger et al. (2012) made a conclusion that impact assessment methods require lots of inventory data. As well as they mentioned that inventory data are, often for background processes, difficult to collect. This means that large amounts of data get lost in at least two steps, during data collection and in the transformation of inventory data into WF values. The need for large quantity of information would be a demanding work in several areas such as time, knowledge and funding. Still, the work will be necessary in some extend if water footprint should be a useful tool and retain as much information as possible.

Many available methods for water footprint calculations exist and nine of them are mentioned in this report. Four of them satisfied the established criteria, but other methods, unknown for the writer, would probably be suitable for this study. This does not affect the result, but it indicates that it is a need to find unified criteria for water footprint methods. Some methods even require equal information during calculation, which probably points out that several methods have been based on each other or other common methods. This may depends on the ongoing development and the fact that this is a relatively new concept. With the information obtained during this project, the choice of methods can be seen as sufficient, but it would be interesting to investigate additional methods. All the methods in this study generate a single value for water footprint, which is a good indicator for a general public, but more informed actors would possible argue that those values may not give enough information. Therefore, it could be interesting to evaluate more complex methods to be able to compare the differences in data accuracy and results.

6.6 LIMITATIONS

This study had a limited time frame and and the time constraints contributed to incomplete data collection. Therefore, several assumptions and exclusions were made for inventory data. First, no further data than the data available in Ecowater were selected. Second, the processes that not were available in Gabi were excluded. The components in EcoWater that not was available as processes in Gabi were activated carbon, chemical for de-greasing, chemical for phosphating, coagulation agent, chemical for flocculation and sludge. However, some of the processes used in Gabi may not be representative for the real chemicals presented in EcoWater. However, the

processes included in this study are available in appendix V and the WF can only be representative for those processes. Still, the result can give a hint of the total water footprint for the manufactories in Umeå and Gothenburg.

6.7 FURTHER ISSUES

There are many ways to calculate water footprint and different opinions exist about how to do it. It is important to relate water use and consumption to the local existing water scarcity, but this study does not tell anything about the necessary accuracy. At the same time a relevant ambition in water footprint is to avoid punishing the countries suffering from water scarcity, meaning that there is a need for compromising between water scarcity and the evaluation of a country. Further, countries with a developed or strong water policy should not be punished, as they are in the WFN method and to some extent in the Ecological scarcity method. Therefore, according to guidelines, it may be beneficial with a global method, even though environmental impact related to water is dependent on local situations. Finally, a water footprint would support good water policy even for the countries with weak natural conditions.

In the future there is a need for a global water footprint policy such as a decision of the emissions that should be included as well as how WF should address thermal pollution. Regarding to water use and consumption, it needs to be clarified what is suitable. ISO 14046 refers to water use in the draft and therefore it would probably be necessary to develop methods towards water use. Furthermore, for water footprint it is important that the person performing the evaluation has adequate knowledge about the processes related to water quality and an understanding for hydrology.

This study also examined how different locations affect water footprint regarding to water use and for the Ecological scarcity method the emission was valid for Switzerland instead of Sweden. Therefore, in further work it would be interesting to investigate how water footprint depends on the location for the degradative part. It would also be interesting to evaluate methods where in which GrW is included since the agriculture uses large amounts of water. Moreover, it would be an idea to look more closely to the methods evaluated in this study and in which range they can be used.

Water footprint is a useful measurement on environmental impact from water use, but that to be able to use it as a tool there are too much uncertainty in the performance. Hopefully, the new ISO standard will contribute to a more convenient concurrence between the calculations of water footprint with different methods.

7 CONCLUSIONS

- It is possible to calculate WF for Volvo trucks with the H_2Oe method, the WFN method and the Ecological scarcity method. Though, the results should only be seen as a hint of a total water footprint since assumptions and limitations are made for secondary data.
- The precipitation chemical and electricity contribute with the highest water footprint in this study.
- A lot of LCI data are not considered when water footprint is calculated; the amount of lost data differs depending on the method used.
- It is not possible to compare water footprints calculated with different methods.
- An important point in water footprint calculations is to clarify limitations and explain validity of the used method; this makes the result more pleasing to the user.
- Water footprint should not be related to carbon footprint in terms of environmental impact, since the result shows that one process may have a high water footprint while another have a high carbon footprint.

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APPENDIX I – GLOSSARY

AoP **Area of protection** – refer in this report to human health, ecosystem quality and resources.

BW **Blue water** – surface and groundwater (Hoekstra, et al., 2011)

Blue water footprint – the volume of BW used to produce goods or services, as the volume evaporated or corporated into the product (Hoekstra, et al., 2011).

Characterization factor – The relationship between inventory data and magnitude of assessed environmental impact in LCIA (Frischknecht, et al., 2009).

CWU **Consumptive use** – extraction of freshwater that not is returned to the same catchment, due to transfer to another aquifer, evaporation or as incorporation in products (Berger & Finkbeiner, 2010).

Critical load – the pollutant load, reaching a water body, that will cause harmful effects and damage to water consumer (Hoekstra, et al., 2011).

DWU **Degradative use** – is a critical dilution volume and describes the water quality change due to emission as a theoretical water volume (Ridoutt & Pfister, 2012). In other words, it refers to withdrawals and quality change into the same watershed (Berger & Finkbeiner, 2010).

Direct water footprint – refers to the pollutions and freshwater use connected directly to the consumer or producer (Hoekstra, et al., 2011).

Elementary water flows – water entering or leaving the studied system, from and into the environment (ISO, 2013b).

GW **Grey water** – the volume freshwater needed to dilute polluted wastewater to obtain similar quality as the natural background concentration and to satisfy conformed standards (Hoekstra, et al., 2011).

Grey water footprint – an indicator for the freshwater pollutions from a product. *See grey water* (Hoekstra, et al., 2011).

GrW **Green water** – Precipitation on land that is stored in the soil or temporally stays on top of the soil or vegetation (Hoekstra, et al., 2011).

Green water footprint – the GrW used during production of a product. Normally used for agricultural and forest, such as rainwater evaporation from field and incorporation into the crops or wood products (Hoekstra, et al., 2011).

-	**Indirect water use** – the water consumption and pollution linked to the production, and water included in the production of input products, of a product that are used of a consumer (Hoekstra, et al., 2011).
1 L H_2Oe	**Reference unit** – represents the burden on a water system with a global average WSI due to extraction of 1 litre water (Ridoutt & Pfister, 2012).
	Natural concentration – or background concentration is the concentration, within a water body, that would be if no human disturbances take place in the catchment (Hoekstra, et al., 2011).
	Product – goods or service (ISO, 2013b)
	Return flow – the water withdrawals that are transferred back to the same catchment and therefore can be used again (Hoekstra, et al., 2011).
	Scarcity – Water scarcity is when freshwater use exceeds the regeneration of water in an area (Kounina, et al., 2012).
	Water availability – total water flow minus the environmental requirements (Hoekstra, et al., 2011).
	Water consumption – water removal from a water drainage basin but not returned to the same (ISO, 2013b).
WF	**Water footprint** – generally it address water use in LCA (Berger & Finkbeiner, 2010).
	Water footprint profile – an array of impact related to water is considered (ISO, 2013b).
	Water quality – refers to parameters used for classification of biological, physical and chemical properties of freshwater (Kounina, et al., 2012).
	Water type – different types of water are for example surface water, groundwater and precipitation stored as soil moisture (Kounina, et al., 2012).
WSI	**Water Stress Index** – *see chapter 3.2*
	Water use – the total requirements of freshwater input into product system (Berger & Finkbeiner, 2010).
	Water withdrawal – temporally or permanently anthropogenic removal of water from any drainage basin or water body. Water abstraction is sometimes used for this concept (ISO, 2013b).

APPENDIX II – IMPACT CATEGORIES AND INDICATORS FOR RECIPE

In Recipe, there are 18 available midpoint impact categories (Table II:1). Freshwater eutrophication and freshwater ecotoxicity were assumed to concern freshwater use and were used in calculation for water footprint in the H_2Oe method.

Table II:1. Eighteen midpoint impact categories, indicators and characterization factors for Recipe points

Midpoint impact categories	Unit	Midpoint indicators	Unit	Characterisation factor
climate change	kg (CO2 to air)	infra-red radioactive forcing	$W \cdot yr/m^2$	global warming potential
ozone depletion	kg (CFC-115 to air)	stratospheric ozone concentration	ppt·yr	ozone depletion potential
terrestrial acidification	kg (SO2 to air)	base saturation	$Yr \cdot m^2$	terrestrial acidification potential
freshwater eutrophication	kg (P to freshwater)	phosphorus concentration	$Yr \cdot kg/m^3$	freshwater eutrophication potential
marine eutrophication	kg (N to freshwater)	nitrogen concentration	$Yr \cdot kg/m^3$	marine eutrophication potential
human toxicity	kg (14DCB to urban air)	hazard-weighted dose	–	human toxicity potential
photochemical oxidant formation	kg (NMVOC6 to air)	Photochemical ozone concentration	kg	photochemical oxidant formation potential
particulate matter formation	kg (PM10 to air)	PM10 intake	kg	particulate matter formation potential
terrestrial ecotoxicity	kg (14DCB to industrial soil)	hazard-weighted concentration	$m^2 \cdot yr$	terrestrial ecotoxicity potential
freshwater ecotoxicity	kg (14DCB to freshwater)	hazard-weighted concentration	$m^2 \cdot yr$	freshwater ecotoxicity potential
marine ecotoxicity	kg (14-DCB7 to marine	hazard-weighted concentration	$m^2 \cdot yr$	marine ecotoxicity

	water)			potential
ionising radiation	kg (U235 to air)	absorbed dose	Man·Sv	ionising radiation potential
agricultural land occupation	m2´yr (agri-cultural land)	occupation	m^2·yr	agricultural land occupation potential
urban land occupation	m2´yr (urban land)	occupation	m^2·yr	urban land occupation potential
natural land transformation	m2 (natural land)	transformation	m^2	natural land transformation potential
water depletion	m3 (water)	amount of water	m^3	water depletion potential
mineral resource depletion	kg (Fe)	grade decrease	kg-1	mineral depletion potential
fossil resource depletion	kg (oil†)	lower heating value	MJ	fossil depletion potential

APPENDIX III – ECOFACTORS FOR FRESHWATER

Ecofactors for water pollutions are assessed depending on different impact mechanisms. The impact mechanisms are either impacts or links proven, presumed or seen as a principal impact for determining the ecofactor (Frischknecht, et al., 2009). The impact mechanisms are showed in table III:1.

Table III:1. Impact mechanisms for the pollutants assessed with ecofactors (Frischknecht, et al., 2009)

	Impact mechanism	**Abbreviation**
Environ-	Eutrophication	E
mental	Oxygen consumption	OC
	Toxicity in fish	TF
	Bioaccumulation	BA
Human	Metabolic disturbances	MD
	Carcinogenicity	C
	Mutagenesis	M
	Embryonal damage	ED
	Other/further types of damages	Other

Eco factors for emission to freshwater (Table III:2) are related to the situation in whole Switzerland, and represent therefore an “average” situation in the country. To receive ecopoints values for the parameters in questions, those ecofactors are multiplied with the outcomes from an LCI analysis. For an aggregated score all ecopoints for a system can be added together (Frischknecht, et al., 2009). There was a value available for radioactive emission, but this emission was excluded since I could not transform the unit into kg. But this assumption can be seen as good, because the flow consist entirely of radium and radium is not included as an emission in the total ecofactor for radioactive emission (Table III:2).

Table III:2. Ecofactors for freshwater consumption and emissions to surface water and their impact mechanisms. Ecofactors for emissions have Switzerland as system boundary (Frischknecht, et al., 2009)

Freshwater consumption	Ecofactor 2006 UBP per	Impact mechanism	Comment
Sweden	2.8 m^3		
Switzerland	22 m^3		
Spain	990 m^3		
Very high/Extreme scarcity	6200/22000 m^3		
Emission to surface waters			
Nitrogen (as N)	64 g N	E, TF	
Phosphorus (as P)	1 200 g P	E	
COD	2.3 g	OC	
Arsenic	8 000 g	BA, MD, C, ED	
Lead	4 400 g	BA, MD	
Cadmium	290 000 g	BA, MD, C, ED	
Chromium	7 600 g	BA, MD	
Copper	14 000 g	BA, MD	
Nickel	6 800 g	BA, MD	
Mercury	880 000 g	BA, MD	
Zinc	5 000 g	BA, MD	
Radioactive emissions	1 100 kBqC14-eq		*Not used here**
AOX (as Cl^-)	200 g Cl	BA, MD, Other	
Chloroform	1 500 g	C, Other	
PAHs	11 000 g	C	
Benzo(a)pyrene	210 000 g		*Not used here*
Endocrine disruptors	8700000 kg E2-eq		*Not used here*

APPENDIX IV – CASE STUDY DATA

The water and WW flows were calculated from the water balance in data from Volvo trucks. The values are representative for production of 30,000 trucks (EcoWater, 2013).

Dataset for the water abstraction stage is modelled from electricity used for pump. The data set for water treatment stage is modelled from different sources of data; stage 4 are modelled with data from the municipal water work in Umeå but with assumptions about sand and dolomite, stage 5 and 7 are modelled with data from Volvo Trucks with assumption of the reverse osmosis from IVL staff while stage 6 where modelled with data from the LCA database EcoInvent (GaBi4) for water treatment. Further, dataset for the water use site is modelled based on data from Volvo trucks, the data for the manufactory in Umeå were more comprehensive than the data for Gothenburg so if data were missing assumption for Gothenburg was made as the same value as for Umeå site. Finally the dataset for the WW treatment stages were modelled with data from Volvos own WW treatment in Umeå and the WW treatment in Gothenburg where modelled with data from both Stena Recycling and Volvo Trucks. Reduction of the pollutions chemical oxygen demand (COD), nickel (Ni), zinc (Zn) and phosphorus (P) in waste water were 90, 98, 99 and 99 percent (Table IV:1, Table IV:2) (EcoWater, 2013).

In original data P, Zn and Ni are expressed two times in the original report; both as single substances and substances included in chemicals. Flows of those substances, and COD, were modelled as single substances in WW while they were accounted as incorporated in input chemicals. Emissions of P, Zn, Ni and COD in WW are measured by Volvo in Umeå, but still some assumptions are made by EcoWater. At Volvo in Gothenburg there is no measurements done, because they use another WW treatment plant, so emissions values at Gothenburg are assumed in EcoWater.

Table IV:1. Processes and amount of water, electricity and chemicals used for Umeå site. The symbol column tell from which and to which stage the water (w), resource (r), emission (e) or effluent water (ew) is released and received

SEAT stage	**Symbol**	**Base scenario**	
		Process	*Amount*
1. MWA_U	$f_{w1,0\text{-}1}$	Surface water*	14 797 m^3
	$f_{r1,1}$	Electricity	14 797 kWh
2. VWA_U	$f_{w1,0\text{-}2}$	Surface water	391 719 m^3
	$f_{r1,2}$	Electricity	195 860 kWh
4. MWT_U	$f_{w1,1\text{-}4}$	Water	14 797 m^3
	$f_{r1,4}$	Electricity	5 919 kWh
	$f_{r12,4}$	Dolomite	0.15 kg
	$f_{r13,4}$	Sand	0.15 kg
5. VWT_U	$f_{w1,4\text{-}5}$	Water	11 647 m^3
	$f_{r1,5}$	Electricity	14 850 kWh
8. VWU_U	$f_{w1,2\text{-}8}$	Water	381 00 m^3
	$f_{w1,4\text{-}8}$	Water	3 150 m^3
	$f_{w1,5\text{-}8}$	Water	9 900 m^3
	$f_{w1,2\text{-}8}$	Water	10719 m^3
	$f_{r1,8}$	Electricity	2 790 000 kWh
	$f_{r2,8}$	District heating	3 810 000 kWh
	$f_{ew,10}$	WW (cooling water)	381000 m^3
10. $VWWT_U$	$f_{w2,5\text{-}10}$	Water	1 747 m^3
	$f_{w2,8\text{-}10}$	Water	21519 m^3
	$f_{r1,10}$	Electricity	23 260 kWh
	$f_{r9,10}$	Precipitation chem. .	142500 kg
	$f_{r10,10}$	Chem. for pH adjustment	28 800 kg
	$f_{e2,10}$	COD	13330 kg
	$f_{e3,10}$	P	3.4 kg
	$f_{e4,10}$	Ni	4.4 kg
	$f_{e5,10}$	Zn	1.2 kg
	$f_{ew,10}$	WW	23255 m^3

Table IV:2. Processes and amount of water, electricity and chemicals used for Gothenburg site. The symbol column tell from which and to which stage the water (w), resource (r), emission (e) or effluent water (ew) is released and received

SEAT stage	**Symbol**	**Base scenario**	
		Process	*Amount*
3. MWA$_G$	$f_{w1,0-3}$	Surface water	1 625 m^3
	$f_{r1,3}$	Electricity	813 kWh
6. MWT$_G$	$f_{w1,3-6}$	Water	1 625 m^3
	$f_{r1,6}$	Electricity	650 kWh
	$f_{r9,6}$	Precipitation chemical (FeCl)	25 kg
	$f_{r14,6}$	Chlorine	0.16 kg
7. VWT$_G$	$f_{w1,6-7}$	Water	1 235 m^3
	$f_{r1,7}$	Electricity	1 575 kWh
9. VWU$_G$	$f_{w1,6-9}$	Water	390 m^3
	$f_{w1,7-9}$	Water	1 050 m^3
	$f_{r1,9}$	Electricity	252 000 kWh
11. SWWT$_G$	$f_{w2,9-11}$	WW	1 440 m^3
	$f_{r1,11}$	Electricity	1 439 kWh
	$f_{r9,11}$	Precipitation chem. (FeCl)	17250 kg
	$f_{e2,11}$	COD	41 kg
	$f_{e3,11}$	P	0.43 kg
	$f_{e4,11}$	Ni	0.53 kg
	$f_{e5,11}$	Zn	0.14 kg
	$f_{ew,11}$	WW	1437 m^3

The total water use is 406516 m^3 in Umeå and 1625 m^3 in Gothenburg. In contrast, the water consumption for respective site is 2261 m^3 and 188 m^3 (Table IV:3).

Table IV:3. Water use and consumption for Umeå and Gothenburg

Quantity of water used	*Site/Stage*	*Water volume [m^3]*
Use	Umeå, total	406516
	Cooling water	381000
Consumption	Umeå, total	2261
	VWU_U (8)	2250
	$VWWT_U$ (10)	11
Use	Gothenburg, total	1625
Consumption	Gothenburg, total	188
	VWT_G (7)	185
	$SWWT_G$ (11)	3

APPENDIX V – PROCESSES IN GABI

Data from the case study of Volvo trucks were used as raw data during the modelling in Gabi. The flows for Umeå (Table IV:1) and for Gothenburg (Table IV:2) that were included in the modelling were adapted after the same amount of water, electricity and chemicals as were mentioned in the report by Ecowater (2013). The resources included in the case study of Volvo trucks were adapted into comparable processes in Gabi (Table V:1). However, the processes that were included in the case study report but excluded in this study were activated carbon, chemical for de-greasing, chemical for phosphating, coagulation agent, chemical for flocculation and sludge.

Table V:1. Resources used during production of trucks in the case study and their counterpart used in Gabi for water footprint calculations.

Resource in case study	*Process in Gabi*	*Unit*	*Comments*
Surface water	Water (groundwater)	m^3	Artificial groundwater in case study
Surface water	Water (river water)	m^3	
Electricity	SE: Electricity grid mix PE	kWh	
Dolomite	RER: Dolomite, at plant	kg	
Sand	CH: Sand, at mine	kg	
District heating	SE: Thermal energy from biomass (solid) PE	kWh	
Precipitation chemical (FeCl)	CH: (III) chloride, 40% in H2O, at plant	kg	40 % of the chemical contains FeCl
Chem. for pH adjustment	CH: Limestone, milled, packed, at plant	kg	Limestone
Chlorine		kg	
COD	Chemical oxygen demand (COD) [analytical measures to freshwater]	kg	
P	Phosphorus [inorganic emission to freshwater]	kg	
Ni	Nickel (+II) [heavy metals to freshwater]	kg	
Zn	Zn (+II) [heavy metals to freshwater]	kg	
WW ($f_{ew,X}$)		m^3	

APPENDIX VI – COMPREHENDING LCI RESULT

A more comprehending result from Gabi for Umeå site is available in table VI:1.

Table VI:1. Detailed Gabi result for Umeå

Gabi results	*Umeå [kg]*
Flows	26900000000
Resources	**13400000000**
Energy resources	163000
Land use	0
Material resources	13400000000
Non renewable elements	4390
Non renewable resources	771000
Renewable resources	13400000000
Water	13400000000
Water	8930000
Water (ground water)	19600000
Water (lake water)	1560000000
Water (rain water)	61200000
Water (river water)	11800000000
Water (sea water)	136000
Water, salt, sole	0
Water,turbine use, unspecified natural origin	0
Air	15300000
Carbon dioxide	1630000
Nitrogen	0
Oxygen	-57000
Deposited goods	536000
Emissions to air	102000000
Emissions to fresh water	13400000000
Analytical measures to fresh water	13900
Adsorbable organic halogen compounds (AOX)	1.36
Biological oxygen demand (BOD)	62.2
Chemical oxygen demand (COD)	13500
Nitrogenous Matter (unspecified, as N)	0.12
Solids (dissolved)	262
Total dissolved organic bounded carbon	19.5
Total organic bounded carbon	20.2
ecoinvent long-term to fresh water	14300
Ammonium / ammonia	0.01
Antimony	0.34
Barium	3.77
Beryllium	0.19
Biological oxygen demand, BSB5 (Ecoinvent)	35.9
Boron	16.2
Bromine	0.06
Chloride	199

Chromium (+VI)	1.04
Cobalt	3.26
Copper (+II)	4.27
Dissolved organic carbon, DOC (Ecoinvent)	44.1
Fluoride	75.9
Hydrogen sulphide	0.11
Iodide	0
Iron	327
Lead (+II)	0.48
Manganese (+II)	108
Metal ions (unspecific)	8.03
Molybdenum	0.7
Nitrate	94.6
Nitrite	0
Nitrogen organic bounded	0.02
Phosphate	304
Potassium	701
Scandium	0.32
Selenium	0.53
Silver	0.02
Sodium (+I)	908
Solids (suspended)	2640
Strontium	35
Sulphate	8660
Thallium	0.04
Tin (+IV)	0.38
Total organic carbon, TOC (Ecoinvent)	44.1
Tungsten	0.52
Vanadium (+III)	1.01
Waste heat	0
Zinc (+II)	27.4
Heavy metals to fresh water	173
Antimony	0.07
Arsenic (+V)	1.02
Cadmium (+II)	0.43
Cesium	0
Chromium (+III)	0.07
Chromium (+VI)	0.15
Chromium (unspecified)	0.01
Cobalt	0.01
Copper (+II)	0.07
Heavy metals to water (unspecified)	0
Iron	136
Lead (+II)	0.61
Manganese (+II)	16.4
Mercury (+II)	0.04
Molybdenum	0.38
Nickel (+II)	15

Selenium	0.08
Silver	0
Strontium	0.9
Tantalum	0
Thallium	0
Tin (+IV)	0
Titanium	0.08
Tungsten	0.02
Vanadium (+III)	0.19
Zinc (+II)	1.7
Inorganic emissions to fresh water	13000
Acid (calculated as H+)	0
Aluminium (+III)	239
Aluminium ion (+III)	0
Ammonia	4.75
Ammonium (total N)	0
Ammonium / ammonia	10.9
Barium	0.3
Beryllium	0
Borate	0
Boron	1.72
Bromate	11.2
Bromide	0
Bromine	0.42
Calcium (+II)	2700
Carbon disulphide	0
Carbonate	196
Chlorate	85.6
Chloride	2110
Chlorine	0
Chlorine (dissolved)	19.4
Copper ion (+II/+III)	0
Cyanide	0.11
Dichromate	0
Fluoride	121
Fluorine	0
Hexaflourosilicates	0.01
Hydrogen chloride	0
Hydrogen cyanide (prussic acid)	0
Hydrogen fluoride (hydrofluoric acid)	0
Hydrogen peroxide	0.24
Hydrogen sulphide	0
Hydroxide	0.02
Hypochlorite	0.03
Inorganic dissolved matter (unspecified)	0
Inorganic salts and acids (unspecified)	0
Iodide	0.03
Iron ion (+II/+III)	0

Lithium	0.02
Magnesium (+III)	1260
Magnesium chloride	0
Magnesium ion (+II)	0
Metal ions (unspecific)	0.01
Nickel ion (+III)	0
Nitrate	3280
Nitrite	0.28
Nitrogen	1.04
Nitrogen (as total N)	0.05
Nitrogen organic bounded	46.3
Phosphate	72.8
Phosphorus	3.67
Potassium	266
Rubidium	0
Scandium	0.01
Silicate particles	0
Sodium (+I)	287
Sodium chloride (rock salt)	0.01
Sodium hypochlorite	0.69
Sodium sulphate	4.99
Sulphate	2240
Sulphide	0.4
Sulphite	0.23
Sulphur	0.07
Sulphur trioxide	0
Sulphuric acid	0
Urea	0
Zinc ion (+II)	0
Organic emissions to fresh water	733
Halogenated organic emissions to fresh water	0.05
1,2-Dibromoethane	0
2-Chlorotoluene	0
Chlorinated hydrocarbons (unspecified)	0
Chlorobenzene	0.02
Chloromethane (methyl chloride)	0
Chlorous dissolvent	0.02
Dichlorobenzene (o-DCB; 1,2-dichlorobenzene)	0
Dichloroethane (ethylene dichloride)	0
Dichloromethane (methylene chloride)	0
Dichloropropane	0
Pentachlorophenol (PCP)	0
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	0
Tetrachloroethene (perchloroethylene)	0
Trichloromethane (chloroform)	0
Vinyl chloride (VCM; chloroethene)	0
Hydrocarbons to fresh water	24.4
2-Methyl-2-butene	0

Acenaphthene	0
Acenaphthylene	0
Acetic acid	0.01
Acetonitrile	0
Acrylonitrile	0
Alkane (unspecified)	0.03
Alkene (unspecified)	0
Aniline	0
Anthracene	0
Aromatic hydrocarbons (unspecified)	0.13
Benzene	0.07
Benzo{a}anthracene	0
Benzofluoranthene	0
Butene	0
Butylene glycol (butane diol)	0
Butyrolactone	0
Chrysene	0
Cresol (methyl phenol)	0
Ethanol	0
Ethene (ethylene)	0
Ethyl benzene	0.01
Ethylene acetate (ethyl acetate)	0
Ethylene oxide	0
Fatty acids (calculated as total carbon)	0.87
Fluoranthene	0
Formaldehyde (methanal)	0
Hexane (isomers)	0
Hydrocarbons (unspecified)	0.19
Methanol	4.97
Methyl tert-butylether	0
Naphthalene	0
Oil (unspecified)	17.9
Phenol (hydroxy benzene)	0.04
Polycyclic aromatic hydrocarbons (PAH, unspec.)	0
Propanol (iso-propanol; isopropanol)	0
Propene	0.02
Propylene oxide	0.01
Sodium formate	0
Toluene (methyl benzene)	0.03
Triethylene glycol	0
VOC (unspecified)	0.1
Xylene (isomers; dimethyl benzene)	0.03
Xylene (meta-Xylene; 1,3-Dimethylbenzene)	0
Xylene (ortho-Xylene; 1,2-Dimethylbenzene)	0
1-Butanol	0
1-Pentanol	0
1-Pentene	0
2-Aminopropanol	0

Acetaldehyde (Ethanal)	0
Acetone (dimethylcetone)	0
Acetyl chloride	0
Carbon, organically bound	708
Chloramine	0
Chloroacetic acid	0
Chloroacetyl chloride	0
Chlorosulfonic acid	0
Cumene (isopropylbenzene)	0.04
Diethylamine	0
Dimethylamine	0
Dipropylamine	0
Ethylamine	0
Ethylenediamine	0
Formamide	0
Formate	0
Formic acid	0
iso-Butanol	0
Isopropylamine	0
Lactic acid	0
Methyl acetate	0
Methyl acrylate	0.01
Methyl amine	0
Methyl isobutyl ketone	0
Methylformat	0
n-Butyl acetate	0
Nitrobenzene	0
Organic chlorine compounds (unspecified)	0
Organic compounds (dissolved)	0
Organic compounds (unspecified)	1.05
Propionaldehyde	0
Propionic acid	0
Propylamine	0
t-Butylamine	0
Trimethylamine	0
Other emissions to fresh water	12900000000
Detergent (unspecified)	0
Unused primary energy from geothermal	0
Unused primary energy from hydro power	0
Waste heat	0
Water (river water from technosphere, cooling water)	4850000
Water (river water from technosphere, turbined)	12900000000
Water (river water from technosphere, waste water)	473000
Particles to fresh water	6210
Metals (unspecified)	0
Silicon dioxide (silica)	0

Soil loss by erosion into water	6080
Solids (suspended)	131
Suspended solids, unspecified	0.49
Radioactive emissions to fresh water	460000000
Americium (Am241)	0
Antimony (Sb122)	0
Antimony (Sb124)	0
Antimony (Sb125)	0
Barium (Ba140)	0
Carbon (C14)	0
Cerium (Ce141)	0
Cerium (Ce144)	0
Cesium (Cs134)	0
Cesium (Cs136)	0
Cesium (Cs137)	0
Chromium (Cr51)	0
Cobalt (Co57)	0
Cobalt (Co58)	0
Cobalt (Co60)	0
Curium (Cm alpha)	0
Hydrogen-3, Tritium	0
Iodine (I129)	0
Iodine (I131)	0
Iodine (I133)	0
Iron (Fe59)	0
Lanthanum (La140)	0
Lead (Pb210)	0
Manganese (Mn54)	0
Molybdenum (Mo99)	0
Plutonium (Pu alpha)	0
Polonium (Po210)	0
Potassium (K40)	0
Protactinium (Pa234m)	0
Radioactive isotopes (unspecific)	0
Radium (Ra224)	0
Radium (Ra226)	460000000
Radium (Ra228)	0
Ruthenium (Ru103)	0
Ruthenium (Ru106)	0
Silver (Ag110m)	0
Sodium (Na24)	0
Strontium (Sr89)	0
Strontium (Sr90)	0
Technetium (Tc99m)	0
Tellurium (Te123m)	0
Tellurium (Te132)	0
Thorium (Th228)	0
Thorium (Th230)	0

Thorium (Th232)	0
Thorium (Th234)	0
Uranium	0
Uranium (U234)	0
Uranium (U235)	0
Uranium (U238)	0
Zinc (Zn65)	0
Zirconium (Zr95)	0
Emissions to sea water	39900
Emissions to agricultural soil	38
Emissions to industrial soil	83.8

APPENDIX VII – RESULT FOR METHOD 1

The result, specified in number, calculated with method 1 for stages and processes at Umeå is presented in table VII:1 and table VII:2.

Table VII:1. Percent of the total water footprint with the H_2Oe method for the processes at Umeå site

WF Umeå [%]	Precipitation chem. (FeCl)	Chem. for pH adjustment (Limestone)	Sand	Dolo-mite	Electricity	Thermal energy
CWU	0.025	-	-	-	32.81	0.25
$DWU_{ecotoxicity}$	43.71	0.083	-	-	1.55	1.19
$DWU_{eutrofication}$	2.47	0.0032	-	-	0.012	0.067
Total DWU	46.18	0.087	-	-	1.56	1.26
Total	**46.21**	**0.087**	**-**	**-**	**34.38**	**1.50**

Table VII:2. Percent of the total water footprint from the H_2Oe-method for the different stages, including the processes, at Umeå site

WF Umeå [%]	MWAu (1)	VWAu (2)	MWTu (4)	VWTu (5)	VWUu (8)	VWWTu (10)
CWU	0.20	3.11	0.064	0.16	30.32	0.28
$DWU_{ecotoxicity}$	0.0075	0.10	0.0030	0.0076	2.61	60.53
$DWU_{eutrofication}$	-	0.00078	-	-	0.078	2.55
DWU_{total}	0.0076	0.10	0.0030	0.0076	2.69	63.07
Total	**0.20**	**3.21**	**0.067**	**0.17**	**33.00**	**63.35**

The result, specified in number, calculated with method 1 for stages and processes at Gothenburg site is presented in table VII:3 and table VII:4.

Table VII:3. Percent of the total water footprint with the H_2Oe method for the processes at Gothenburg site

WF Gbg [%]	Precipitation chemical (FeCl)	Chlorine	Electricity
CWU	0.029	-	27.43
$DWU_{ecotoxicity}$	49.20	-	1.30
$DWU_{eutrophication}$	2.78	-	0.01
Total DWU	51.99	-	1.31
Total	**52.01**	**-**	**28.74**

Table VII:4. Percent of the total water footprint from the H_2Oe-method for the different stages, including the processes, at Gothenburg site

WF Gbg [%]	MWAg (3)	MWTg (6)	VWTg (7)	VWUg (9)	SWWTg (11)
CWU	0.13	0.070	0.17	26.95	0.18
DWU $_{ecotoxicity}$	0.0041	0.075	0.0080	1.27	68.27
DWU $_{eutrophication}$	-	0.0041	-	0.0099	2.86
Total DWU	0.0041	0.079	0.0080	1.28	71.13
Total	**0.13**	**0.15**	**0.18**	**28.24**	**71.31**

APPENDIX VIII – RESULT FOR METHOD 2

The result, specified in number, calculated with method 2 for stages and processes at Umeå and Gothenburg site is presented in table VIII:1, VIII:2, VIII:3, VIII:4, and VIII:5.

Table VIII:1. Total water footprint for Umeå and Gothenburg site calculated for nickel, zinc and phosphorous

WF, method 2	Umeå [m^3]	Umeå [% of WG]	Gbg [m^3]	Gbg [% of GW]
Nickel (+II)	30100	100	3600	100
Zinc (+II)	344	11.43	383	10.62
Phosphorus	370	12.32	454	12.60

Table VIII:2. Blue, grey and total WF for the processes at Umeå site, as percent of the total WF for Umeå. Grey and total water footprint is calculated with nickel and method 2

WF, processes [% of WF]	Precipitation chemical (FeCl)	Chem. for pH adjustment (Limestone)	Sand	Dolomite	Electricity	Thermal energy
Blue WF	0.077	0.00021	-	-	98.75	0.74
Grey WF	0.16	0.00026	-	-	0.00052	0.0017
Total WF	0.24	0.00047	-	-	98.75	0.74

Table VIII:3. Blue, grey and total WF for the stages at Umeå site, as percent of the total WF for Umeå. Grey and total water footprint is calculated with nickel and method 2

WF, stages [% of WF]	MWAu (1)	VWAu (2)	MWTu (4)	VWTu (5)	VWUu (8)	VWWTu (10)
Blue WF	0.59	6.43	0.19	0.48	91.24	0.83
Grey WF	-	-	-	-	0.0022	0.23
Total WF	0.59	6.43	0.19	0.48	91.24	1.06

Table VIII:4. Blue, grey and total WF for the processes at Gothenburg site, as percent of the total WF for Umeå. Grey and total water footprint is calculated with nickel and method 2

WF, Processes [% of WF]	Precipitation chemical (FeCl)	Chlorine	Electricity
Blue WF	0.10	-	99.45
Grey WF	0.22	-	0.00053
Total WF	0.32	-	99.45

Table VIII:5. Blue, grey and total WF for the stages at Gothenburg site, as percent of the total WF for Gothenburg. Grey and total water footprint is calculated with nickel and method 2

WF, stages [%]	MWAg (3)	MWTg (6)	VWTg (7)	VWUg (9)	SWWTg (11)
Blue WF	0.45	0.25	0.61	97.71	0.66
Grey WF	-	0.00032	-	0.00052	0.31
Total WF	0.45	0.25	0.61	97.71	0.97

APPENDIX IX – RESULT FOR METHOD 3

Water footprint calculated with method 3 are present as percent of total EP for Umeå and Gothenburg site in table IX:1, IX:2, IX:3 and IX:4.

Table IX:1. EP in percent for the processes at Umeå site

Processer WF [%]	Precipitation chemical (FeCl)	Chem. for pH adjustment (Limestone)	Sand	Dolomite	Electricity	Thermal energy
Water use	0.0079	-	-	-	10.18	0.077
AOX (as Cl^-)	0.00013	-	-	-	0.073	0.0036
COD	0.11	0.0032	-	-	0.020	0.0047
Nitrogen (as N)	0	0	0	0	0.0020	0.00026
Arsenic	2.26	0.0039	-	-	0.024	0.0064
Cadmium	34.34	0.028	-	-	0.26	0.22
Cr +III	0	0	0	0	0.092	0.058
Cr +IV	0.32	0.0016	-	-	0.0015	0.00074
Copper	0.14	0.00015	-	-	0.076	0.072
Lead	0.070	0.00019	-	-	0.55	0.14
Mercury	9.39	0.011	-	-	0.065	0.012
Nickel	20.02	0.032	-	-	0.065	0.21
Zinc	0.43	0.0013	-	-	0.18	0.082
PAHs	0.0058	-	-	-	0.00011	-
Phosphorus (as P)	0.019	0.00086	-	-	0.047	0.023
Total EP water use	0.0079	-	-	-	10.18	0.077
Total EP for emission	67.12	0.082	-	-	1.46	0.83
Total EP	**67.12**	**0.082**	**-**	**-**	**11.64**	**0.91**

Table IX:2. EP in percent for the stages at Umeå site

WF [%], stages	MWAu (1)	VWAu (2)	MWTu (4)	VWTu (5)	VWUu (8)	VWWTu (10)
Water use	0.00058	0.96	0.020	0.050	9.40	0.086
AOX (as Cl^-)	0	0.0047	0.00014	0.00036	0.071	0.00069
COD	0	0.0013	-	-	0.023	8.76
Nitrogen (as N)	0	0.00013	-	-	0.0021	-
Arsenic	0	0.0015	-	0.00012	0.028	2.27
Cadmium	0	0.017	0.00051	0.0013	0.46	34.37
Cr +III	0	0.0059	0.00018	0.00045	0.14	0.00070
Cr +IV	0	-	-	-	0.0021	0.33
Copper	0	0.0049	0.00015	0.00037	0.14	0.14
Lead	0	0.036	0.0011	0.0027	0.64	0.064
Mercury	0	0.0042	0.00013	0.00032	0.072	9.40
Nickel	0	0.0042	0.00013	0.00032	0.27	28.49
Zinc	0	0.012	0.00035	0.00089	0.25	2.13
PAHs	0	-	-	-	0.00015	0.0059
Phosphorus (as P)	0	0.0030	-	0.00023	0.066	1.17
Total EP water use	0.00058	0.96	0.020	0.050	9.40	0.086
Total EP for emission	0	0.094	0.0028	0.0071	2.18	87.13
Total EP	**0.00066**	**1.06**	**0.023**	**0.057**	**11.58**	**87.22**

Table IX:3. EP in percent for the processes at Gothenburg site

WF [%], Processes	Precipitation chemical (FeCl)	Chlorine	Electricity
Water use	0.0091	-	8.67
AOX (as Cl^-)	0.00015	-	0.062
COD	0.13	-	0.017
Nitrogen (as N)	0	-	0.0017
Arsenic	2.59	-	0.020
Cadmium	39.38	-	0.22
Cr +III	0	-	0.078
Cr +IV	0.37	-	0.0013
Copper	0.17	-	0.064
Lead	0.069	-	0.47
Mercury	10.77	-	0.056
Nickel	22.96	-	0.056
Zinc	0.50	-	0.16
PAHs	0.0067	-	-
Phosphorus (as P)	0.022	-	0.040
Total EP for water use	0.0091	-	8.67
Total EP for emission	76.96	-	1.25
Total EP	**76.97**	**-**	**9.91**

Table IX:4. EP in percent for the stages at Gothenburg site

WF [%], stages	MWAg (3)	MWTg (6)	VWTg (7)	VWUg (9)	SWWTg (11)
Water use	0.040	0.022	0.053	8.51	0.058
AOX (as Cl^-)	0.00020	0.00016	0.00038	0.061	0.00050
COD	-	0.00023	0.00010	0.017	0.38
Nitrogen (as N)	-	-	-	0.0017	-
Arsenic	-	0.0038	0.00012	0.020	2.59
Cadmium	0.00071	0.058	0.0014	0.22	39.32
Cr +III	0.00025	0.00020	0.00048	0.077	0.00044
Cr +IV	-	0.00054	-	0.0013	0.37
Copper	0.00020	0.00040	0.00040	0.063	0.17
Lead	0.0015	0.0013	0.0029	0.47	0.071
Mercury	0.00018	0.016	0.00034	0.055	10.76
Nickel	0.00018	0.033	0.00034	0.055	32.54
Zinc	0.00050	0.0011	0.00095	0.15	2.37
PAHs	-	-	-	-	0.0067
Phosphorus (as P)	0.00013	0.00014	0.00025	0.039	1.40
Total EP for water use	0.040	0.022	0.053	8.51	0.058
Total EP for emission	0.0040	0.11	0.0077	1.22	89.96
Total EP	**0.044**	**0.14**	**0.061**	**9.74**	**90.02**

APPENDIX X – COMPARISON BETWEEN LOCATION

Water use footprint values for different location in Umeå site is visualized in table X:1. WF has been calculated for Sweden, Switzerland, Spain and Saudi Arabia with method 1 and method 3.

Table X:1. WF calculated with the H_2Oe, WFN and ecological scarcity method for Umeå site. WF is also calculated for the H_2Oe method and ecological scarcity method as if Umeå site were located in different countries. The values for WSI and EF come from a supplement material to Pfister et al. **(2009)** [1)] and Frischknecht et al. **(2009)** [2)]

		Water use	**Ratio with Swedish WF**
Sweden			
H_2Oe method	WSI = 0.0402[1)]		
	WF (use)	895 000 m^3 H_2Oe	1.00
WFN method			
	WF (use)	13 000 000 m^3	1.00
Ecological scarcity method	EF = 2.8[2)]		
	WF (use)	37 000 000 EP	1.00
Switzerland			
H_2Oe method	WSI = 0.0923[1)]		
	WF (use)	2 060 000 m^3 H_2Oe	2.30
Ecological scarcity method	EF = 22[2)]		
	WF (use)	295 000 000 EP	7.86
Spain			
H_2Oe method	WSI = 0.715[1)]		
	WF (use)	15 900 000 m^3 H_2Oe	17.79
Ecological scarcity method	EF = 990[2)]		
	WF (use)	13 300 000 000 EP	353.57
Saudi Arabia			
H_2Oe method	WSI = 0.995[1)]		
	WF (use) [H_2Oe]	22 200 000 m^3 H_2Oe	24.75
Ecological scarcity method	$EF_{high\ scarcity}$ = 6200[2)]		
	$WF_{high\ scarcity}$ (use)	83 100 000 000 EP	2214.29

APPENDIX XI – COMPARISON WITH CARBON DIOXIDE

Total values for the three WF method and carbon footprint as well as one comparison between WF and carbon footprint, are visualized in table XI:1.

Table XI:1. Total WF calculated with the H_2Oe, WFN and Ecological scarcity method and the total carbon footprint received from Gabi for Umeå site located in Sweden

Umeå	Total value	Times CO_2-equiv.
Method 1 [m^3 H_2Oe]	2 620 000	6
Method 2 [m^3]	13 000 000	30.17
Method 3 [EP]	355 000 000	819.8
GWP 100 years [kg CO_2-Equiv.]	433 000	1

Distribution of WF and carbon footprint, presented in values, for the processes and stages at Umeå site are available in table XI:2 and table XI:3.

Table XI:2. WF calculated with the H_2Oe, WFN and Ecological scarcity method and carbon footprint received from Gabi for the processes at Umeå site

Umeå, processes [%]	Precipitation chemical (FeCl)	Chem. for pH adjustment (Limestone)	Sand	Dolomite	Electricity	Thermal energy
Method 1	46.21	0.087	-	-	34.38	1.50
Method 2	0.24	0.00047	-	-	98.75	0.74
Method 3	67.12	0.082	-	-	11.64	0.91
GWP 100 yr	26.33	0.15	-	-	47.61	25.91

Table XI:3. WF calculated with the H_2Oe, WFN and Ecological scarcity method and carbon footprint received from Gabi for the stages at Umeå site located in Sweden

Umeå, stages [%]	MWAu (1)	VWAu (2)	MWTu (4)	VWTu (5)	VWUu (8)	VWWTu (10)
Method 1	0.20	3.21	0.067	0.17	33.00	63.35
Method 2	0.59	6.43	0.19	0.48	91.24	1.06
Method 3	0.00066	1.06	0.023	0.057	11.58	87.22
GWP 100 yr	0.23	3.06	0.093	0.23	69.53	26.85

APPENDIX XII – EXAMPLES OF CALCULATION

Calculation examples for water footprints at Umeå are available under the following subtitles, one for each method. In the results of this study were all processes calculated separately. The stages were calculated as the sum of all concerned processes. Electricity and the precipitation chemical were used in many stages and the total amount of those processes was accounted with a factor representing the part of processes to each stage.

Method 1- The H_2Oe method

This method uses equation one, two and three for calculation, where WSI_i for Sweden is 0.0402, WSI_{global} is 0.602 and $RECIPE_{points,global}$ is 1.86 x 10^{-6} RECIPE points. The flows used for the total production in Umeå are available in table XII:1.

Table XII:1. Flows received from Gabi that were used in the H_2Oe method

Umeå	Quantity
ReCiPe 1.07 Midpoint (H) - Freshwater ecotoxicity [kg 1,4-DB eq]	3 086.4
ReCiPe 1.07 Midpoint (H) - Freshwater eutrophication [kg P eq]	128.1
Water [L]	13 404 188 814

$$CWU(H_2O) = \sum_i \frac{CWU_i \times WSI_i}{WSI_{global}}$$

$$CWU(H_2O) = \sum_i \frac{13404188814\ \text{L} \times 0.0402}{0.602} \approx 895096994\ L$$

$$DWU(H_2Oe) = \frac{RECIPE\ points\ (emission\ to\ water\ for\ product\ system)}{RECIPE\ points\ global\ (average\ for\ 1l\ consumptive\ water\ use)}$$

$$DWU(H_2Oe) = \frac{3087.4 + 128.1}{1.86\ \text{x}\ 10^{-6}} \approx 1728763441\ L$$

$$Water\ footprint\ (H_2Oe) = CWU(H_2Oe) + DWU(H_2Oe)$$

$$Water\ footprint\ (H_2Oe) = 895096994 + 1728763441 = 2623860435\ L = 2.62\ Mm^3$$

All processes were calculated similar to this example and thereafter summarized depending on attached stage.

Method 2 –The Water Footprint Network Method

Blue water is calculated with equation 10, but this study includes all water flows except the cooling water. Grey water in the WFN method was calculated through equation 12 with nickel as emission. C_{max} is 0.5 mg/L and C_{nat} is 0.00072 mg/L for nickel. Total water footprint is calculated as the sum of blue and grey water. The flows used for the example in Umeå are available in table XII:2.

Table XII:2. An example of flows received from Gabi that were used in the WFN method

Umeå	**Flow**
Water [m^3]	13 404 189
Nickel (+II) [kg]	15.01
Cooling water [m^3]	381 000

$$WF_{proc,blue} = BlueWaterEvaporation + BlueWaterIncorporation + LostReturnFlow$$

$$WF_{proc,blue} = 13404189 - 381000 = 13023189 \text{ m}^3$$

$$WF_{proc,grey} = \frac{L}{c_{max} - c_{nat}}$$

$$WF_{proc,grey} = \frac{15.01\ kg}{(0.5 - 0.00072) \times 10^{-6} kg/L} = 30063291\ L = 30063\ m^3$$

$$F = WF_{proc,blue} + WF_{proc,grey}$$

$$WF = 13023189 + 30063 = 43086480\ m^3$$

Water footprints were calculated similar for all processes and stages.

Method 3- The Ecological scarcity method

The ecological scarcity method uses EP and applies equation 15 for calculation of water footprint. EF for Sweden and water use is 2.8 EP/m^3 and for arsenic is EF 8,000 EP/g arsenic. The flows used for the example in Umeå are available in table XII:3.

Table XII:3. An example of flows received from Gabi that were used in the Ecological scarcity method

Umeå	Flow
Water [m^3]	13 404 189
Arsenic [g]	1 018

$$EF_{TOT} = \sum_i EF_i * Load_i$$

$$EF_{Water} = 2.8 \times 13404189 \approx 37531729 \text{ EP}$$

$$EF_{Arsenic} = 8{,}000 \frac{EP}{g} \times 1018\ g = 8144000\ EP$$

All emissions available with an ecofactor were calculated similar to this example and thereafter were all emissions and water use summarized into a total water footprint. This was made for all the processes and stages in both Umeå and Gothenburg.