Water Footprint of Cow Milk Production

Case Study of a Finnish Farm

Anas Aamoum

Bachelor's thesis in Natural Resources
Degree Programme in Sustainable Coastal Management
Raseborg, 2015

ACKNOWLEDGEMENTS

At the completion of this work, I would love to thank everyone who helped me in its establishment.

I mainly thank my teacher Ms. Anna Granberg for her uninterrupted help to me during my period of study in NOVIA UAS and also during the time I worked on this thesis. She was truly very patient and of great assistance to me.

I also want to thank Mr. Hannu Karvonen, owner of the Paasikoski farm (Puolanka, Kainuu, Finland) and his family who accommodated me in their farm and taught me a lot about the milk production and generously shared with me the data I have used in this report.

And finally, I want to thank all my friends in Finland and Sweden who helped me during my study period in the Sustainable Coastal Management program.

ABSTRACT

BACHELOR'S THESIS

Author: Anas Aamoum
Degree Programme: Sustainable Coastal Management
Specialization:
Supervisor: Anna Granberg

Title: Water Footprint of Cow Milk Production, Case Study of a Finnish Farm

---

Date	Number of pages	Appendices
07.05.2015	43	1

Abstract

The following work is an attempt to calculate the water footprint of fresh milk production. The water footprint takes account of not only the quantity of water in the milk, but of all the water that was used and polluted to produce the milk. As the reader will see, the water footprint is a measure that goes deeply in all the processes related to the product considered to give an estimate of the amount of water involved.

In this work the reader will get acquainted with the water footprint and will see its application on a practical example from a Finnish dairy farm.

Language: English
Key words: virtual water, water footprint, cow milk, energy, wastewater

---

TABLE OF CONTENTS

1 Introduction

In modern farming a lot of energy is used. Energy inputs can be in different shapes, from man and animal power to fossil fuels and energy from nutrition. The sources of energy may vary but almost all of them have their impact on the environment. At the other end of the chain almost all human activities generate waste and so does farming. In a dairy farm a big part of the waste is wastewater. Needless to say, this waste generation also has its impact on the environment.

In this work the focus is put on the impact of milk production on fresh water; the water footprint will be introduced and the methods to calculate it will be presented. These methods will be used to assess the water footprint of the energy input and the generated wastewater on a Finnish dairy farm.

In the first part of this work there will be a description of the important elements related to the water footprint in this thesis. This will be followed by a second part in which the methods to calculate the water footprint are explained. In the end these methods will be used to calculate these footprints on a Finnish farm.

2 Scope of the work

In this part, the objective and the study questions of this thesis are presented. The significance of this work and the elements of interest are also explained.

2.1 Objective

The main purpose of this work is to calculate the water footprint of a conventional milk farm in Kainuu, Finland:

- ✓ The calculation of this water footprint will take into account the used water, the energy input and the wastewater generated.
- ✓ The result obtained will be compared to the water footprint of milk production from previous studies.

2.2 Clarification

In this thesis the "milk production" expression is always used to indicate the obtaining of milk directly from the cows and its storage in a cooling tank. No transportation or processing included.

2.3 Elements of interest

2.3.1 Freshwater

Even though the water is abundant in the planet, most of it is not fresh and cannot be used in agriculture. Of the total earth water, the freshwater portion is less than 3% and, 2.5% of it is frozen in the Arctic and Antarctica (Fry et al., 2005, p. 1).

The remaining 0.5% of water that is available for use is distributed in this fashion (see Figure 1)

- 10 000 000 km3 in underground aquifers.
- 119 000 km3 net rainfall after evaporation.
- 91 000 km3 in natural lakes.
- 5 000 km3 in man-made storage facilities.
- 2 120 km3 in rivers, constantly replaced from rainfall and melting snow and ice (Fry et al., 2005, p. 1).

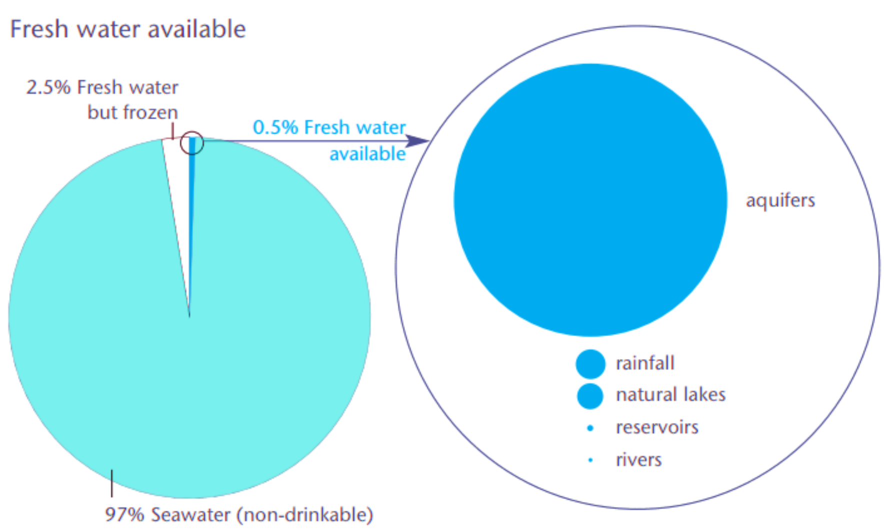


Figure 1 Freshwater portions From Total Water (Fry et al., 2005, p. 1)

The total fresh water available is 10 217 120 km^3. Of this amount, 42 921 km^3 (0.4%) of freshwater is renewed annually (FAO, 2014). The amount of earth fresh water is huge (1 km^3 = 10^{12} litres). A fair amount of it renews every year. Furthermore, human activities combined together use only 9% of the renewable freshwater source (FAO, 2014). The problem is not that humans may run out of water, the real problem is that freshwater is not always available where and when it is needed (Fry et al., 2005, p. 1).

Note that the renewable water resources represent the average annual flow of rivers (both surface and ground water. Meanwhile, the non-renewable water resources are the groundwater aquifers whose volume doesn't change in humane time-scale (FAO, 2003, p. 3). Also, note that the renewable water resources do not account of precipitation water.

2.3.2 Agriculture Water Withdrawal

As seen in Figure 2, agriculture is the biggest sector using freshwater in the world. In the global view, annually 69% (2 722 km^3/year) of the used freshwater (not the total freshwater) goes to agriculture (FAO, 2014).

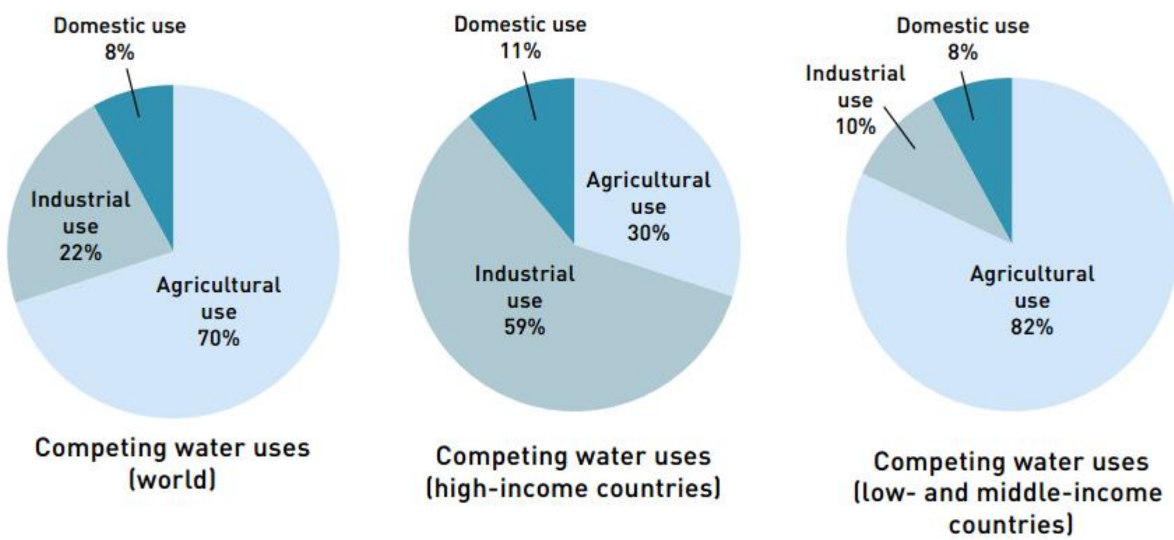


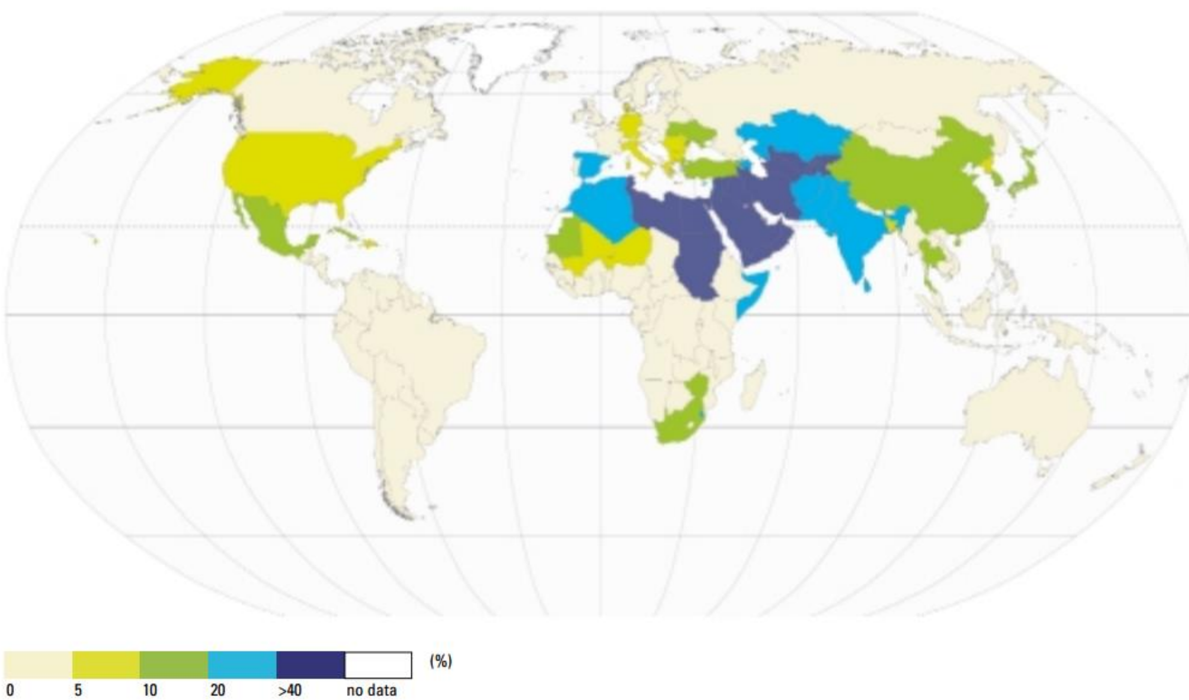
Figure 2 Fresh water usage by activity and income group countries. (The United Nations, 2003, p. 19)

In the low- and middle-income countries, the industrial sector is limited and therefore the agriculture has the biggest share of fresh water use. Meanwhile in the high-income countries the industrial activity share of freshwater use is almost the double of the agriculture share. This can be explained by the fact that many high income countries have a developed industry and import most of their food.

In a global perspective:

- 69% of water use goes to Agriculture.
- 9% of renewable water resources are used. Therefore it can be deduced that the amount of fresh water used by agriculture is equivalent to 0.6% of the renewable fresh water resources.

The following map (Figure 3) shows the percentage of water withdrawal from the renewable water sources by country:



The importance of agriculture in countries' water balance is shown here. Whereas agricultural water withdrawals account for little of the total renewable water resources in the majority of countries, certain regions, such as north-east Africa and western Asia, are notable in that their agricultural withdrawals add up to more than 40 percent of their total water resources – and in the Near and Middle East, they represent a staggering 1,000 percent.

Figure 3 The global agricultural water withdrawal from freshwater renewable sources (The United Nations, 2003, p. 208)

In most countries the agriculture water withdrawal is less than 5% of the renewable water sources. In some countries, however, this withdrawal is not sustainable at all! It goes up to almost 176% in North Africa, and 492% in the Arabian Peninsula (FAO, 2014). However, according to the same source, these two regions are the poorest in internal renewable fresh water resources per capita. Therefore, such an unsustainable use of freshwater is to be expected.

In Finland on the other hand, the relative usage of Fresh water for agriculture is low (less than 5% of the renewable water sources). However, since agriculture is the biggest user of fresh water, and since Finnish people consume a lot of milk, it will be interesting to see how much freshwater is involved in the milk production in Finland. And that is what this thesis attempts to do.

2.3.3 Energy and wastewater

In this thesis the water footprint of a dairy farm is calculated. The calculation takes into account the energy use and the wastewater generated:

- By energy is meant both fuel energy, electricity and energy from animal feed.
- By wastewater is meant the slurry generated from the barn.

2.4 Study questions

1) What is the total water footprint of the production of 1 litre of milk?
2) What is the water footprint from the energy supply of the production of 1 litre of milk?
3) What is the water footprint from the wastewater generation of the production of 1 litre of milk?

3 Water footprint

In this part, the definitions of the virtual water and the water footprints and its components are presented. Then, the method to calculate the water footprint is described.

3.1 Virtual water

The concept of virtual water is closely related to that of the water footprint. In the early 1990s, J.A Allan defined the virtual water as the volume of water required to produce a commodity or a service (Hoekstra & Chapagain, 2007, p. 36). It is the water incorporated, or embodied (in virtual sense), in the product (Hoekstra et al., 2011, p. 193). Note that the virtual water though it was used in the production process it is not visible on the final product. The term “virtual” is used because the total consumptive water used in the production is very large compared to the actual water content of the final product (Dourte & Fraisse, 2012, p. 4).

3.2 Water footprint definitions

“The water footprint is a measure of humanity’s appropriation of fresh water in volumes of water consumed and/or polluted.” (Water Footprint Network, s.d.). The concept of the water footprint (WF) was first introduced by Hoekstra. It is defined as the total of freshwater used to produce the goods and services consumed (Hoekstra & Chapagain, 2007, p. 36).

One other definition is that the water footprint calculates the consumptive water use for a considered entity (process, product, nation…). The consumptive water use describes the freshwater that evaporates, is incorporated into a product, is contaminated or is not returned to the same area where it was withdrawn (Dourte & Fraisse, 2012, p. 2).

- ✓ The water footprint calculation can cover way more than what the reader may estimate at first sight. For example, since water is required in the production of fuels, it is important to consider the WF of fuel energy when calculating the WF of a farm where fuels were used.
- ✓ Logically speaking, the higher a good or a service in the production chain, the higher its water footprint since it considers all water consumption and pollution in all steps of the production chain (Hoekstra et al., 2009, p. 31). E.g. the water footprint of a crop contains, among others, the calculated water footprint of the production of the fertilizers

3.2.1 Direct and indirect water footprint

In the calculation of the water footprint two categories are considered: the direct and the indirect water footprints. The direct water of a product footprint refers to the freshwater consumption and pollution that is associated to the water use by producer. It is distinct from the indirect water footprint, which refers to the water consumption and pollution that can be associated with the (non-water) inputs used by the producer (Hoekstra et al., 2011, p. 188).

For example, to make a loaf of bread, one would need 1 litre of water, and 1 cup of flour. The direct water footprint of the bread making is the water used during its making (1 litre). Meanwhile, the indirect water footprint of the bread making is the virtual water embedded in the cup of flour; which can be 3 litres. So the total water footprint of a loaf of bread is 4 litres, 1 litre direct water footprint, and 3 litres indirect water footprint. Hereafter (Figure 4), the example of the direct and indirect water footprints in the production chain of a food product:

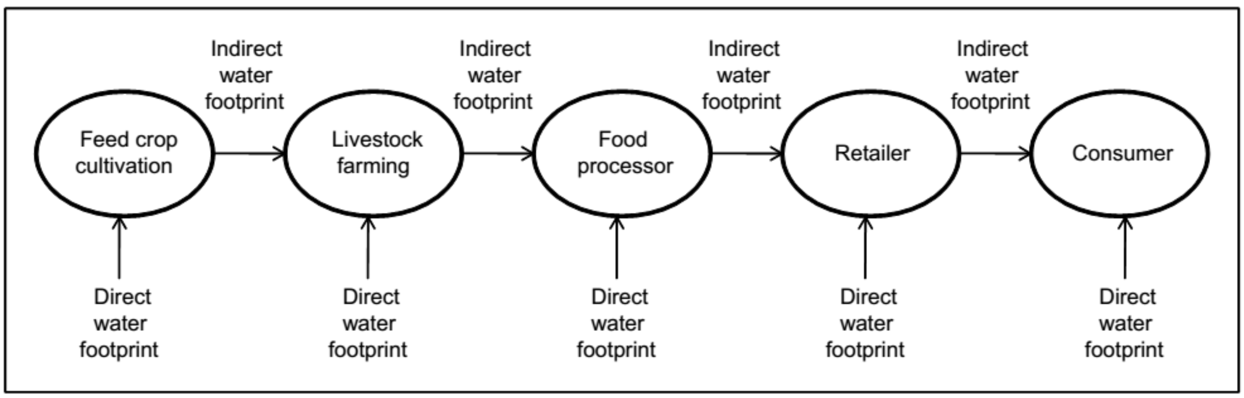


Figure 4 the direct and indirect water footprint in an example production chain (Hoekstra et al., 2009, p. 19)

3.2.2 Internal and external water footprint

The water footprint of a nation is composed of the internal water footprint and the external water footprint (Table 1). The internal water footprint is the appropriation of domestic water resources for producing goods and services that are consumed domestically (Hoekstra et al., 2011, p. 191). And the external water footprint is the appropriation of water resources in other nations for the production of goods and services that are imported into and consumed within the nation considered (Hoekstra et al., 2011, p. 189).

Table 1 Internal and external water footprint

Internal water footprint	The volume of water used from domestic water resources
External water footprint	The volume of water used in other countries to produce goods and services imported and consumed by the inhabitants of the country

(Hoekstra & Chapagain, 2007, p. 36)

Figure 5 shows the distribution of the global internal and external water footprint by sector:

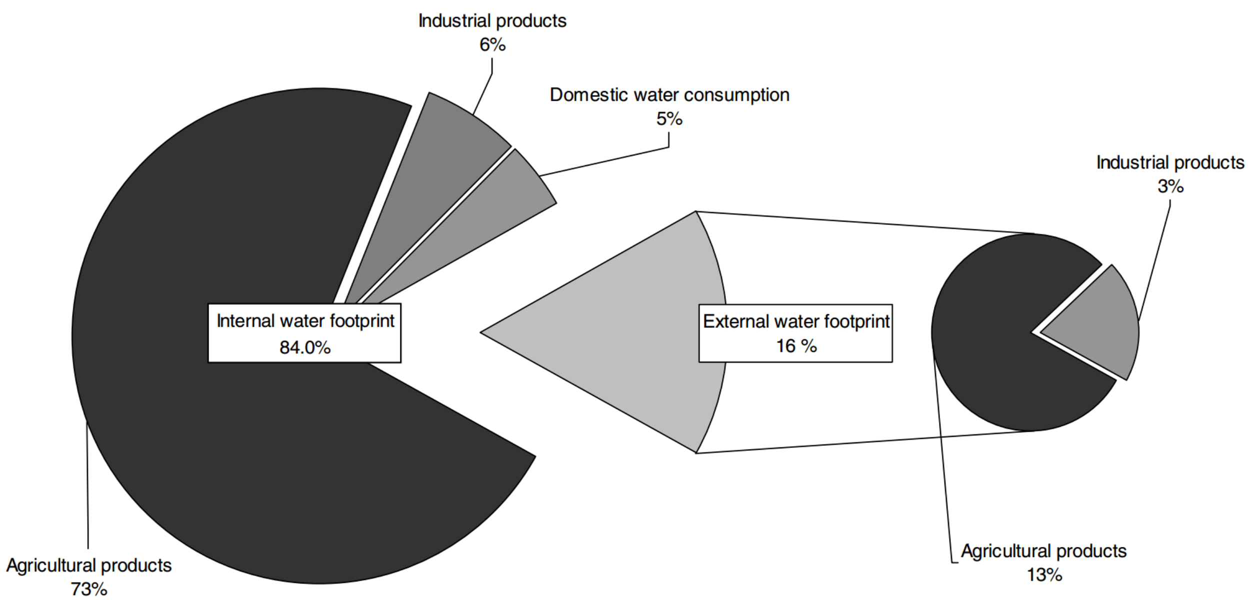


Figure 5 Contribution of different consumption categories to the global water footprint, with a distinction between the internal and external footprint (Hoekstra & Chapagain, 2007, p. 43)

Note that the global external water footprint is the sum of the water footprints of the products are produced in one country and used in another.

Similarly to the water withdrawal, the water footprint of the agriculture has the biggest share among the three sectors (agricultural, industrial and municipal) whether for internal or external water footprint. This can be explained by the fact that industrial products, such as fertilizers are used in agricultural production. Moreover, some agricultural products like crops are used in other agricultural products like livestock. These two factors lead to an increase of the water footprint of agriculture.

3.2.3 Blue, Green and Grey Water Footprint

Both the internal and the external water footprints include three different components: The blue water, the green water and the grey water.

- The blue water is the ground and surface water.
- The green water is the moisture stored in soil strata (Hoekstra & Chapagain, 2007, p. 38). It is the water from the rainfall.
- The grey water is the third component included in the water footprint. The grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Ercin et al., 2012, p. 393). It simply means the volume of the clean water needed to be mixed with polluted water to make the mixture (clean + polluted) water "clean" according to the water quality standards.
    - When calculating the water footprint of wastewater, one cubic meter of wastewater should not count for one, because it generally pollutes much more cubic meters of water after disposal (Hoekstra & Chapagain, 2007, p. 47).

Figure 6 explains more the first two components of the water footprint (blue and green):

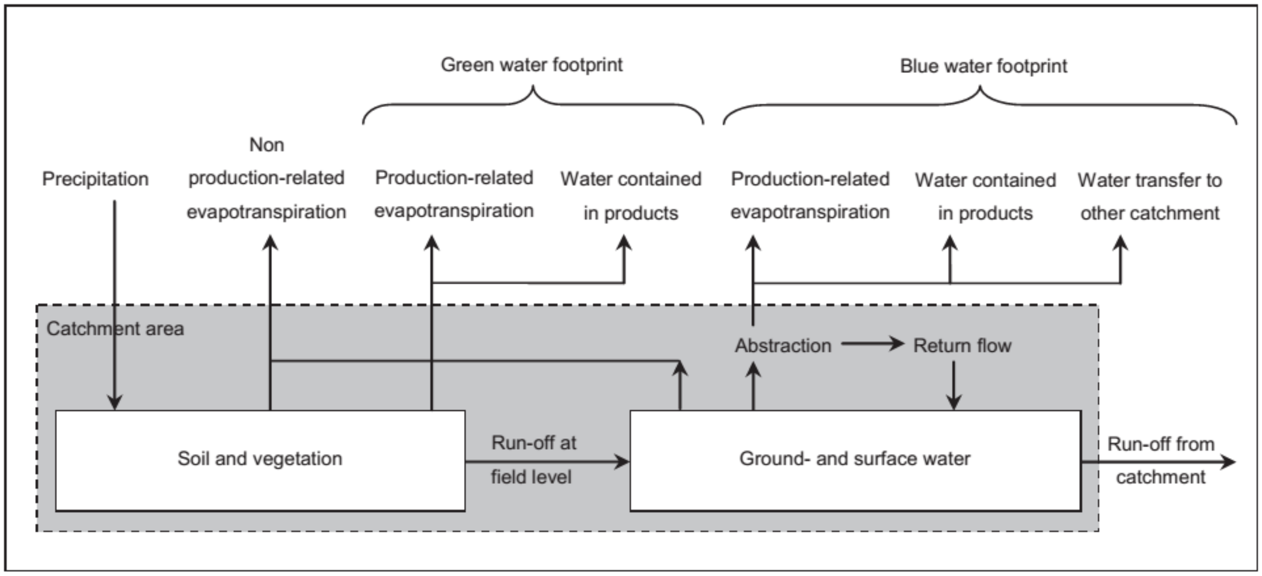


Figure 6 Green and Blue water footprints (Hoekstra et al., 2011, p. 20)

3.3 Virtual water vs. water footprint

According to Frontier Economics (2008, p. 18), the virtual water is a simple concept but not a reliable one when assessing the efficiency and sustainability of the water use. The water footprint offers a more reliable tool for the assessment of freshwater use:

1) The water footprint is not calculated only for products, but also for processes, businesses and nations. The water footprint also differentiates the water used to categories (direct/ indirect, blue/ green/ grey and internal/ external).
2) The water footprint is not only a number that indicates an amount of water. But it also indicates the source of this water, and can be extended to assess if those sources are used sustainably (Hoekstra et al., 2009).

The differences between the water footprint and the virtual water are compiled and summarizes in Table 2:

Table 2 Virtual Water Vs. Water Footprint

	Virtual water	Water footprint
Strong points	Simple concept	Includes different types of water Covers an assessment of sustainability
Weak points	Can be misleading to policy makers (Frontier Economics, 2008, p. 18)	More complicated concept

Note that in the case of a product (which is the case of the study case in this thesis) the total water footprint is equal to the virtual water content (Hoekstra et al., 2009, p. 31). Apart from that the water footprint of a product is a multidimensional indicator, whereas virtual-water content refers to a volume alone (Hoekstra et al., 2011, p. 193).

3.4 Calculation of water footprint:

Hoekstra et al (2011, p. 4), propose the following order when calculating a water footprint (Figure 7):

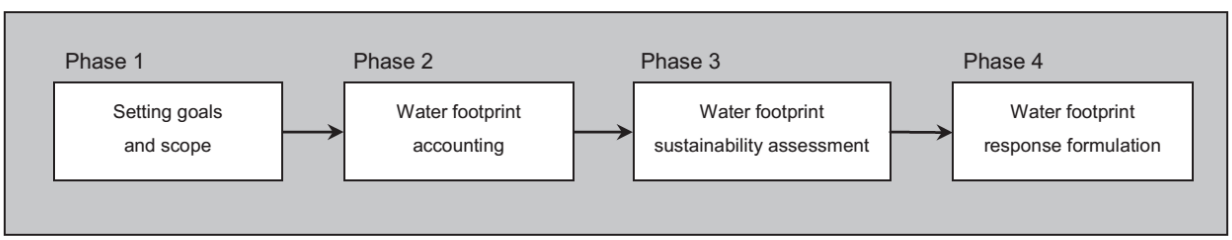


Figure 7 the four phases of water footprint assessment (Hoekstra et al., 2011, p. 4)

The first phase "goals and scope" is needed to be in order to be clear about the choices made in the water footprint study. The phase of water footprint accounting is the phase in which data are collected and accounts are developed. The scope and level of detail in the accounting depends on the decisions made in the previous phase. After the accounting phase is the phase of sustainability assessment, in which the water footprint is evaluated from an environmental perspective, as well as from a social and economic perspective. In the final phase, response options, strategies or policies are formulated. It is not necessary to include all the steps in one study. In the first phase of setting goals and scope, one can decide to focus only on accounting or stop after the phase of sustainability assessment, leaving the discussion about response for later (Hoekstra et al., 2011, pp. 4, 5).

In this work, the focus is only on the first and second phases which include the definition of the scope and the determination of the water footprint (Figure 7).

3.4.1 Scope and goals

The scope of the water footprint accounting is the entity whose water footprint is calculated. The possible scopes according to the Water Footprint Assessment Manual are (Hoekstra et al., 2011, p. 7):

- water footprint of a process step
- water footprint of a product
- water footprint of a consumer
- water footprint of a group of consumers:
  - water footprint of consumers in a nation
  - water footprint of consumers in a municipality, province or other administrative unit
  - water footprint of consumers in a catchment area or river basin
- water footprint within a geographically delineated area
  - water footprint within a nation
  - water footprint within a municipality, province or other administrative unit
  - water footprint within a catchment area or river basin
- water footprint of a business
- water footprint of a business sector
- water footprint of humanity as a whole (Hoekstra et al., 2011, p. 7)

According to the Water Footprint Assessment Manual (Hoekstra et al., 2011, p. 8); when accounting the water footprint of a product, the goals can be determined by answering the following questions:

- ✓ What is the ultimate target? Awareness-raising, hotspot identification, policy formulation or quantitative target setting?
- ✓ On which phase is the focus on? Accounting, sustainability assessment or response formulation?
- ✓ What is the scope of interest? Direct and/or indirect water footprint? Green, blue and/or grey water footprint?
- ✓ What is the time resolution of the study? A month, a year, 10 years?
- ✓ What product to consider?
- ✓ What scale? The source of the product? From one field, one company, or many companies? (Hoekstra et al., 2011, p. 8)

3.4.2 Water footprint accounting

In this thesis the objective is to calculate the water footprint of a product. The water footprint of a product is the sum of the water footprints of the processes to make it divided by the quantity of the product made:

$$WF_{product} = \frac{\sum_{i=1}^{n} WF_{process,i}}{P\ [quantity]}$$

Figure 8 Water Footprint of a product (Dourte & Fraisse, 2012, p. 4)

The calculation of the water footprint presented hereafter are all for the process water footprint calculation.

3.4.2.1 The level of water footprint accounting

Hoekstra et al (2011) show in their Manual that there are 3 spatiotemporal levels when accounting the water footprint (table 3):

Table 3 Spatiotemporal Levels When Accounting the Water Footprint

	Spatial explication	Temporal explication	Source of required data on water use	Typical use of the accounts
Level A	Global average	Annual	Available literature and databases on typical water consumption and pollution by product or process.	Awareness-raising; rough identification of components contributing most to the overall water footprint; development of global projections of water consumption.
Level B	National, regional or catchment-specific	Annual or monthly	As above, but use of nationally, regionally or catchment specific data.	Rough identification of spatial spreading and variability; knowledge base for hotspot identification and water allocation decisions.
Level C	Small catchment or field-specific	Monthly or daily	Empirical data or (if not directly measurable) best estimates on water consumption and pollution, specified by location and over the year.	Knowledge base for carrying out a water footprint sustainability assessment; formulation of a strategy to reduce water footprints and associated local impacts.

Note: The three levels can be distinguished for all forms of water footprint accounting (for example, product, national, corporate accounts).

(Hoekstra et al., 2011, p. 12)

In Table 3, the level A is for a more general and broad perspective and is used for purposes such as awareness raising and decision making. The levels B and C are more specific and considered when working with more precise data. The purposes of the B and C levels of accounting are more action oriented (sustainability assessment, and response formulation).

3.4.2.2 The Accounting of The Blue Water Footprint:

The blue water footprint of a process is the sum of the evaporated blue water, the incorporated blue water and the lost return flow:

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

Figure 9 Blue Water Footprint of a Process (Hoekstra et al., 2009, p. 20)

The lost return flow is the part of the blue water that is used in the product but not incorporated, not evaporated and not returned to the same catchment (Hoekstra et al., 2011, p. 26).

Since the water footprint is calculated for a period of time, the unit of the blue water footprint is [Volume/ time].

3.4.2.3 The Accounting of The Green Water Footprint

The green water footprint is a measure of the use of the green water. It accounts the volume of rainwater consumed during the production process (Hoekstra et al., 2011, p. 30):

$$WF_{proc,green} = GreenWaterEvaporation + GreenWaterIncorporation$$

Figure 10 The Green Water Footprint of Proces (Hoekstra et al., 2009, p. 21)

The green water footprint is relevant for agricultural and forestry products and is also expressed in [Volume/ Time] (Hoekstra et al., 2011, p. 30).

The water incorporation is the water that the plants incorporate during their growing. The water evaporation (or evapotranspiration) is the water that evaporates from the soil during the growing of the plant.

3.4.2.4 The Accounting of The Grey Water Footprint:

The grey water footprint is an indicator of water pollution. If a process generates pollutants, this water footprint calculates how much water, in natural conditions, is needed to keep the mixture (water + pollutants) within the accepted environmental levels.

The grey water footprint is calculated by dividing the pollutant load (L, in mass/time) by the difference between the ambient water quality standard for that pollutant (the maximum acceptable concentration cmax, in mass/volume) and its natural concentration in the receiving water body (cnat, in mass/volume):

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

Figure 11 Grey water footprint of a process (Hoekstra et al., 2011, p. 32)

In absence of data, the grey water footprint can be estimated by setting the amount of water that would be needed to dilute a certain amount of the pollutant load.

4 Study case

In this study, the water footprint of a Finnish dairy farm is calculated; Paasikoski farm in Puolanka, Kainuu Finland.

4.1 Presentation of the farm:

Paasikoski-tila (Paasikoski farm) is situated in the Kainuu region in Finland. It is a cold region with long winters. The farm itself is very modern and is run by the couple Hannu and Susanna Karvonen. The main purpose of this farm is milk production.

In the farm, there is a farm house, a barn, a field for hay cultivation and many tractors for agriculture and snow removal purposes. The couple is working on the farm full time, though in winter there is much less work to do than in summer.

In this work, this farm is referred to either with Paasikoski, Paasikoski-tila or Paasikoski farm.

Figure 12 A part from Paasikoski-tila with machines on the left and hay bales on the right. (Photo: Anas Aamoum)

Figure 13 The milking cows in Paasikoski-tila. (Photo: Anas Aamoum)

The cows get both normal hay and concentrated feed, and the milking is done by machines.

4.2 Figures about Paasikoski-tila:

Table 4 present the facts about Paasikoski-tila in numbers. The table 4 describes the size of the livestock (including milking cows), the amount of feed and water they consume, and the energy input and the wastewater output of the farm.

Table 4 Paasikoski-tila, Facts and Figures

Livestock	17 milking cows, 9 heifers, 6 calves and one bull.
Production	120 000 L of Milk per year (Average of 8300 L of milk per milking cow per year)
Amount of water consumed by the livestock	683 000 L per year
Feed consumption	300 000 kg per year of hay 72 000 kg per year of cereals
Hay fields	35 ha (timothy)
Hay production	12 000 kg per year per hectare
Fertilizer's use	6000 kg per year
Seeds	150 kg per year (timothy)
Energy supply	120 m3 woodchips 5000 litres of Diesel 15 m3 firewood 37 000 kW/h electricity
Manure slurry	1050 m3 per year

4.3 Accounting of the water footprint

4.3.1 Scope and goals

The scope of this calculation is the milk produced in Paasikoski-tila. The goal of this calculation is determined by answering the following questions:

- What is the ultimate target?
  - Target quantification.
- On which phase is the focus on?
  - The focus is in the accounting phase.
- What is the scope of interest? Direct and/or indirect water footprint? Green, blue and/or grey water footprint?
  - The scope is on both direct and indirect water footprint. The calculation of the footprint addresses both blue water, green water and grey water.
- What is the time resolution of the study?
  - Yearly.
- What product to consider?
  - Cow milk. The calculation is done for the unit litre.
- What scale?
  - The data is gathered from a Finnish dairy farm.

4.3.2 Calculation of the water footprint

The product for which the water footprint is calculated is cow milk. The water footprint of the process of milk production will be first calculated, and then divided by the quantity produced.

The farm is considered as a system which has inputs and outputs. The inputs are different forms of energy and water and the outputs are milk and wastewater. The energy is in the form of fodder, electricity, fuels and woodchips, while the wastewater is in the form of manure slurry as seen in Figure 14:

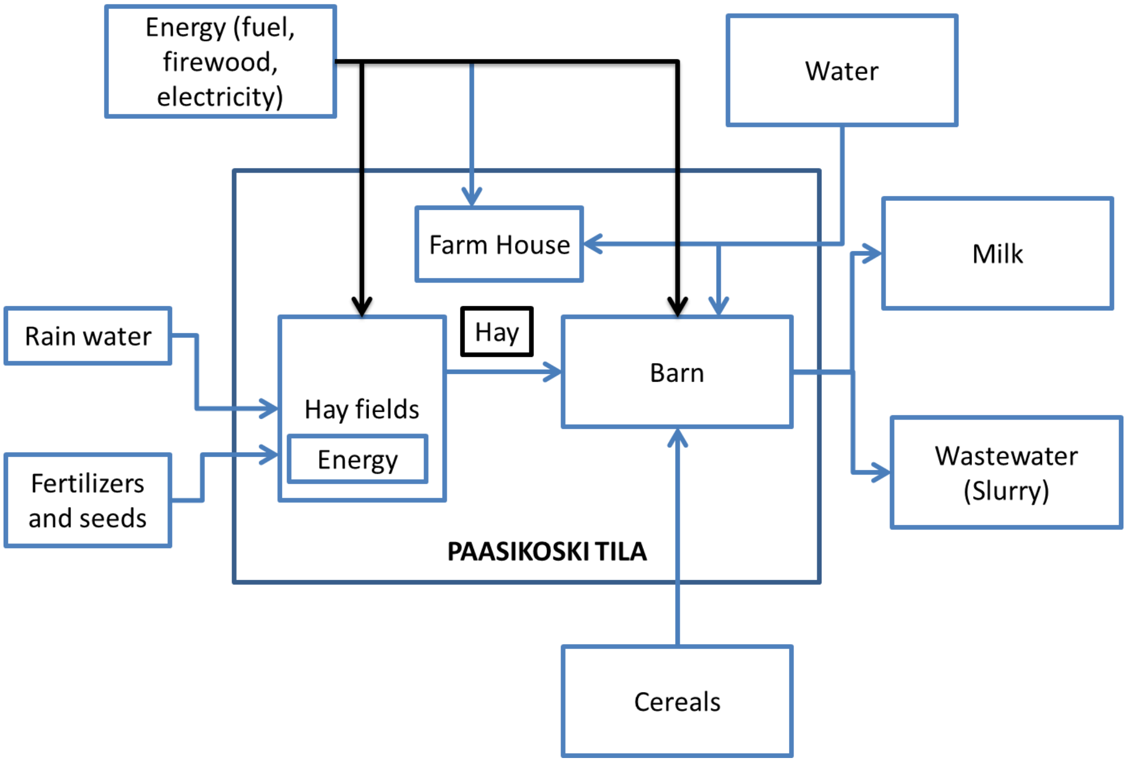


Figure 14 Process of Paasikoski-tila

4.3.2.1 The level of the water footprint accounting

Table 5 shows the level of water footprint accounting in this case:

Table 5 Figure 15 Level of Water Footprint Accounting for Paasikoski-tila

Category	Level	Explication
Spatial	C	Field specific (Paasikoski farm)
Temporal	B	Annual
Source of Data	A - C	Available literature + measured data
Use of The Accounts	A	Awareness raising

To do the accounting, the reasoning will be divided into three parts. First calculate the water footprint of the barn, which is linked to what the cows consume and their manure. Then the WF of the farm house which will give the WF of the farmers, and finally the water footprint of the fuel and wood energy which is present in all parts of the farm.

4.3.2.2 The barn

The water footprints related to the barn are the water footprints related to the milking cows. The only data that indicates a direct water footprint is the amount of water the cows drink (the water used for barn cleaning is negligible in comparison with the amount of water drunk by the livestock):

- Direct blue WF of the barn= 683 000 (litres/ year)

For the indirect blue water footprint, there is the concentrated fodder of the cows and the hay. The concentrated fodder is cereal pellets. According to the literature (Mekonnen & Hoekstra, 2010), the water footprint of cereal pellets in Finland is:

- Blue WF of the cereal pellets = 1000 (litres/ ton)
- Green WF of the cereal pellets = 525 (litres/ ton)

The cows eat 72 tonnes of cereals per year, this makes:

- Blue WF of the cereal pellets consumed in Paasikoski = 72 000 (litres/ year)
- Green WF of the cereal pellets consumed in Paasikoski = 37 800 (litres/ year)

Since there is no irrigation of the hay fields, they have no blue water footprint. Unfortunately, there is no data on the water footprint of timothy. On the other hand, according to Hannu Karvonen (Owner of Paasikoski-tila), the fresh hay harvested (300 000 kg) has about 80% water content, so the green water footprint of incorporation can be estimated:

- Green WF of incorporation of hay harvested in Paasikoski = 0.8 * 300 000 = 240 000 (litres/ year)

For the evapotranspiration there is no available data for timothy in Finland. From this document (Söderman & Wesanterä, 1964), one can safely estimate that the evapotranspiration rate is around 70 mm per month. Considering that the timothy grows for 3 months before harvesting, the water footprint can be calculated as follow: Evapotranspiration rate * time * surface of fields.

- Green WF of evapotranspiration of hay harvested in Paasikoski = 0.06 * 3 * 350 000 = 63 000 m^3 = 63 000 000 (litres/ year)

Therefore:

Indirect blue WF of the barn = Blue WF of the cereal pellets consumed in Paasikoski = 72 000 (litres/ year)

Indirect Green WF of the barn = Green WF of the cereal pellets consumed in Paasikoski + Green WF of hay harvested in Paasikoski = 37 800 + (240 000 + 63 000 000) **= 63 277 800 (litres/ year)**

The manure produced is 1050 m^3 per year. Since there is no data about the concentration of pollutants in this manure, in this work it is estimated that to assimilate the pollutants, the amount of water needed is 10 times the amount of the manure:

Direct Grey WF of the barn = 1 050 000 * 10 = 10 500 000 (Litres/ year)

4.3.2.3 The farm house

On average an adult Finn uses 155 litres of water per day (Lähteenoja et al., 2007, p. 4). This amount is divided between personal hygiene, toilet flushing, laundry and kitchen. In the farm house, two adults and two children (4 and 2 years old) live. Since the children use less water that the adults, because they neither use the kitchen, nor do the laundry nor the shower by themselves, their water usage is smaller compared to the adults, their combined daily water use is estimated here to 100 litres. The daily water usage of the house farm is estimated to be 400 litres.

Direct blue WF of the farm house = 400 * 365 = 146 000 (litres/ year)

No data is available for the wastewater of the house, however, it is safe to estimate that it is negligible compared to the amount of manure.

4.3.2.4 The energy input

The farm uses annually 120 m^3 of woodchips, 5000 litres of Diesel, 15 m^3 of firewood and 37 000 kW/h electricity.

According to the literature (Mekonnen et al., 2015) the water footprint of electricity in Finland is between 6 and 10 m^3 per GJ. In this calculation, the average, 8 m^3 per GJ, is chosen. By definition 1 J = 1/3 600 000 kWh. Therefore:

- **WF of electricity** = 37 000 * 8000 * (3 600 000 / 1 000 000 000) = **1 065 600 (Litres / Year)**

According to the literature (AEBIOM, 2008, p. 27), in average, the energy content of wood logs is 5500 MJ per m^3, and the energy content of wood chips is 3600 MJ per m^3. Therefore the amount of energy provided from wood (120 m^3 woodchips and 15 m^3 firewood) in Paasikoski-tila:

- 120 * 3600 + 15 * 5500 = 514 500 MJ = 514.5 GJ

According to (Mekonnen et al., 2015), the WF of firewood (logs or chips) per energy unit is in average 49 m^3 per GJ. Therefore:

- WF of wood usage = 514.5 * 49 = 25 210.5 m^3 = 25 210 500 (Litres per year)

According to (Francke & Castro, 2013, p. 42), the water footprint of a litre of Diesel is 37.6 litres divided equally between grey and blue water footprint. On the other hand, 5 000 Litres of Diesel is used in Paasikoski farm every year, therefore:

WF of Diesel usage = 5 000 * 37.6 = 188 000 (litres/ year) (divided equally between grey and blue WFs)

5 Results

The results are summarized in the Table 6.

Table 6 Water Footprint of Paasikoski-tila Detailed (in m³ per year = 1000 litres / year)

Part of the process	Category	Blue	Green	Grey	Total	Data source
Barn	Water drunk by the cows	683 (direct)			683	Calculation
	Hay consumed by the cows		64 240 (indirect)		64 240	Estimation
	Cereal pellets consumed by the cows	72 (indirect)	37.8 (indirect)		109.8	From Literature
	Manure			10 500 (direct)	10 500	Estimation
Farm House	Water consumed by people	146 (direct)			146	Estimation + Literature
The fields	Fertilizer					Unavailable
	Timothy seeds					Unavailable
Energy	Electricity				1065.6 (indirect)	From Literature
	Wood				25210.5 (indirect)	From Literature
	Diesel		94 (indirect)	94 (indirect)	188	From Literature
Total		901	64 371.8	10 594	**102 142.9**	

The accounting of the water footprint of Paasikoski farm in this work, has resulted in an amount of 102 142 900 Litre / year. This water footprint is distributed as in Figure 15:

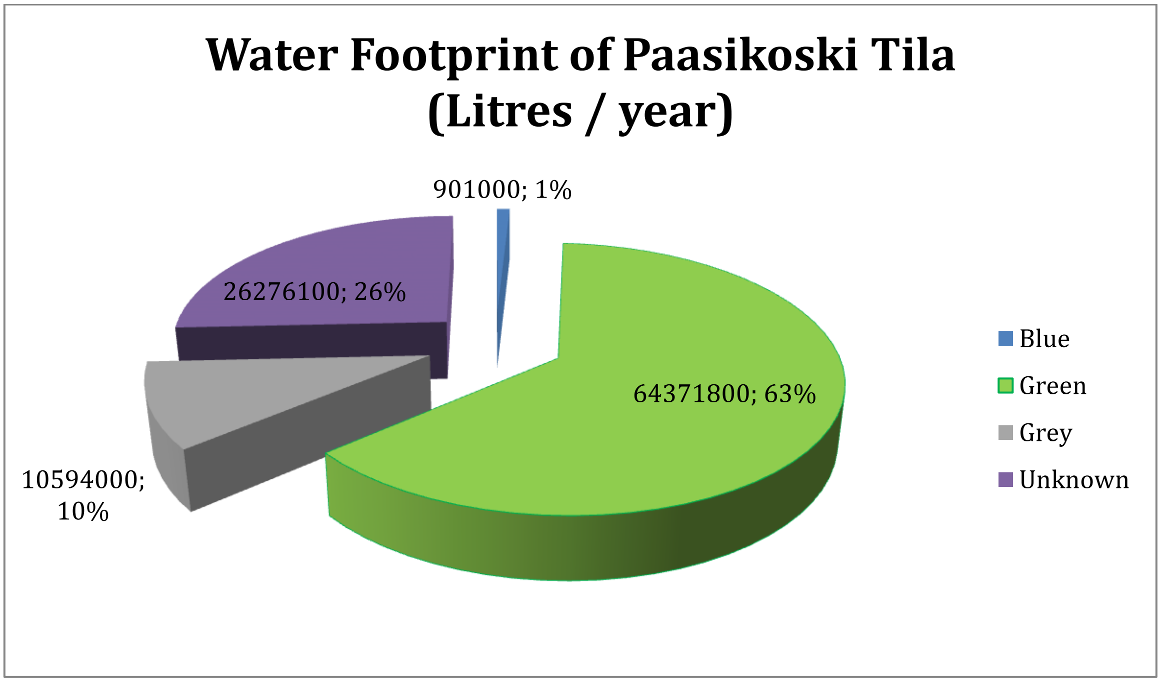


Figure 15 Water Footprint of Paasikoski-tila

Note that whenever the results are presented in percentages, those percentages are true whether for the WF of Paasikoski, the WF of 1 litre of milk or the WF of 1 kg of milk. This is possible thanks to the fact that the WF of a unit of milk is obtained by dividing the WF of Paasikoski by the amount of milk produced.

The biggest shares of the water footprint are reserved to the hay, the firewood and woodchips and the manure. In the literature, there isn't an indication of how much of the firewood (chips or logs) WF is grey, green or blue, thus a portion of 26% of the water footprint origin is unknown.

In Finland however, it is possible to perform an estimation for this matter; for the wood logs, since there is no irrigation of forests, nor import, neither fertilization, it can be estimated that all the water footprint of the firewood logs is green. Therefore:

- WF of wood logs = 15 * 5500 * 49 = 4 042 500 (Litres/ year, Green) (See 4.3.2.3)

On the other hand, for the wood chips, to calculate the water footprint, not only the water needed for growing the trees must be taken into account but also the water footprint of the wood chipper machine. For this purpose, a wood chipper from a Finnish company is taken as an example; according to a Finnish wood chippers manufacturer (Kesla), the Kesla C645D has a power of 220 kW and can produce 160 m^3 of wood chips per hour.

In Paasikoski, an amount of 120 m^3 of wood chips is used every year and those wood chips have a water footprint equal to:

- WF of wood chips = 120 * 3 600 * 49 = 21 168 000 (Litres/ year) (see 4.3.2.3)

In this water footprint, there is the water footprint of the wood growing (green) and the water footprint of the chipping. The chipping machine needs 45 minutes to produce 120 m^3 of chips (160 m^3 per hour). This in term of energy is 0.75 * 220 = 165 kWh.

According to (Staffell, 2011), the energy density of Diesel is 36 MJ per litre.

165 kWh = 165 * 3.6 = 594 MJ. Therefore, the amount of Diesel needed to run the wood chipping machine is 594 / 36 = 16.5 litres.

- The water footprint of the chipping machine = 16.5 * 37.6 = 620 Litres (divided equally between grey and blue water footprint).

Therefore:

- **the green water footprint of the wood chips** = The water footprint of the wood chips – the water footprint of the chipping machine = **21 167 380 (Litres/year)**

With the estimation of the water footprint of the wood chips taken into account, the distribution of the water footprint of Paasikoski farm is shown in Table 7:

Table 7 Detailed Water footprint of Paasikoski, with wood chips WF estimates (m3 per year)

Part of the process	Category	Blue	Green	Grey	Total	Data source
Barn	Water drunk by the cows	683 (direct)			683	Calculation
	Hay consumed by the cows		64 240 (indirect)		64 240	Estimation
	Cereal pellets consumed by the cows	72 (indirect)	37.8 (indirect)		109.8	From Literature
	Manure			10 500 (direct)	10 500	Estimation
Farm House	Water consumed by people	146 (direct)			146	Estimation + Literature
The fields	Fertilizer					Unavailable
	Timothy seeds					Unavailable
Energy	Electricity				1 065.6 (indirect)	From Literature
	Wood	**0.31**	**25 209.88**	**0.31**	25 210.5 (indirect)	From Literature + Estimation
	Diesel		94 (indirect)	94 (indirect)	188	From Literature
Total		901.31	89 581.68	10 594.31	102 142.9	

The water footprint of Paasikoski farm with this estimation is distributed as follow (Figure 16):

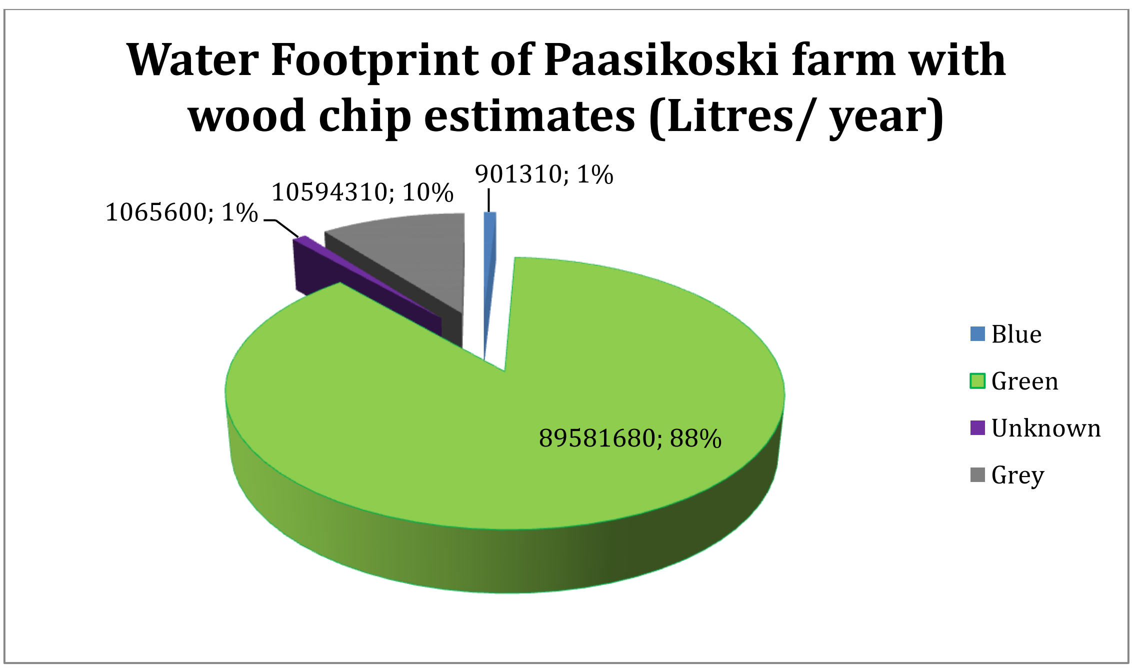


Figure 16 WF of Paasikoski-tila with woodchips estimates

Only 1% of the water footprint of the milk production of Paasikoski-tila is actually blue water (water that is used directly in the liquid water form). This shows that water footprint really takes account of the virtual water-content of the product that one cannot intuitively guess without a deep study.

In previous studies the water footprint was always calculated for the 1 kg of milk and not 1 litre of milk, it is therefore important to include it in this study.

Since 1 litre of milk weights 1.03 kg, then the production of Paasikoski is 123600 kg (120 000 l) of milk per year. The water footprint of fresh milk from Paasikoski farm is equal to the yearly WF of Paasikoski farm divided by the quantity of fresh milk produced in a year. The water footprint of fresh milk from Paasikoski farm is given in Table 8.

Table 8 Summary of the WFs of Paasikoski Farm and Milk produced in Litres

	Blue WF	Green WF	Grey WF	Total WF
Paasikoski farm (yearly)	901 310	89 581 680	10 594 310	102 142 900
1 litre of Milk (division by 120 000)	7.5	746.5	88.3	851.2
1 kg of Milk (division by 123 600)	7.3	724.8	85.7	826.4

The water footprint of 1 litre of fresh milk from Paasikoski farm is presented in Figure 17.

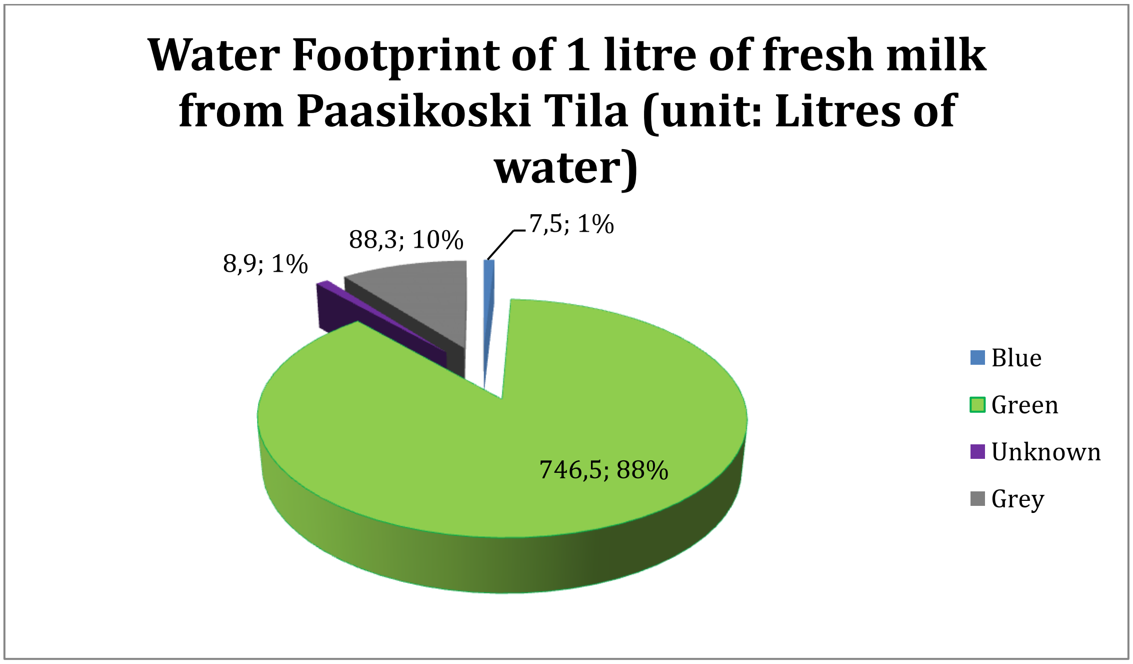


Figure 17 Water footprint of 1 litre of milk from Paasikoski-tila

Lastly, all the products used in Paasikoski farm can be argued to be domestic except the diesel which is definitely imported from abroad. Therefore:

- External water footprint of Paasikoski-tila = 188 000 (Litres/ year) (0.1%)
- Internal water footprint of Paasikoski-tila = 102 142 900 – 188 000 = 101954900 (Litres/ year)

5.1 Answers to the study questions

The energy sources for which the water footprint was accounted are the fuel, the firewood (logs and wood chips) and the electricity. Meanwhile, the water footprint of the wastewater took account of the manure slurry. The water footprint calculated was distributed as shown in Figure 18.

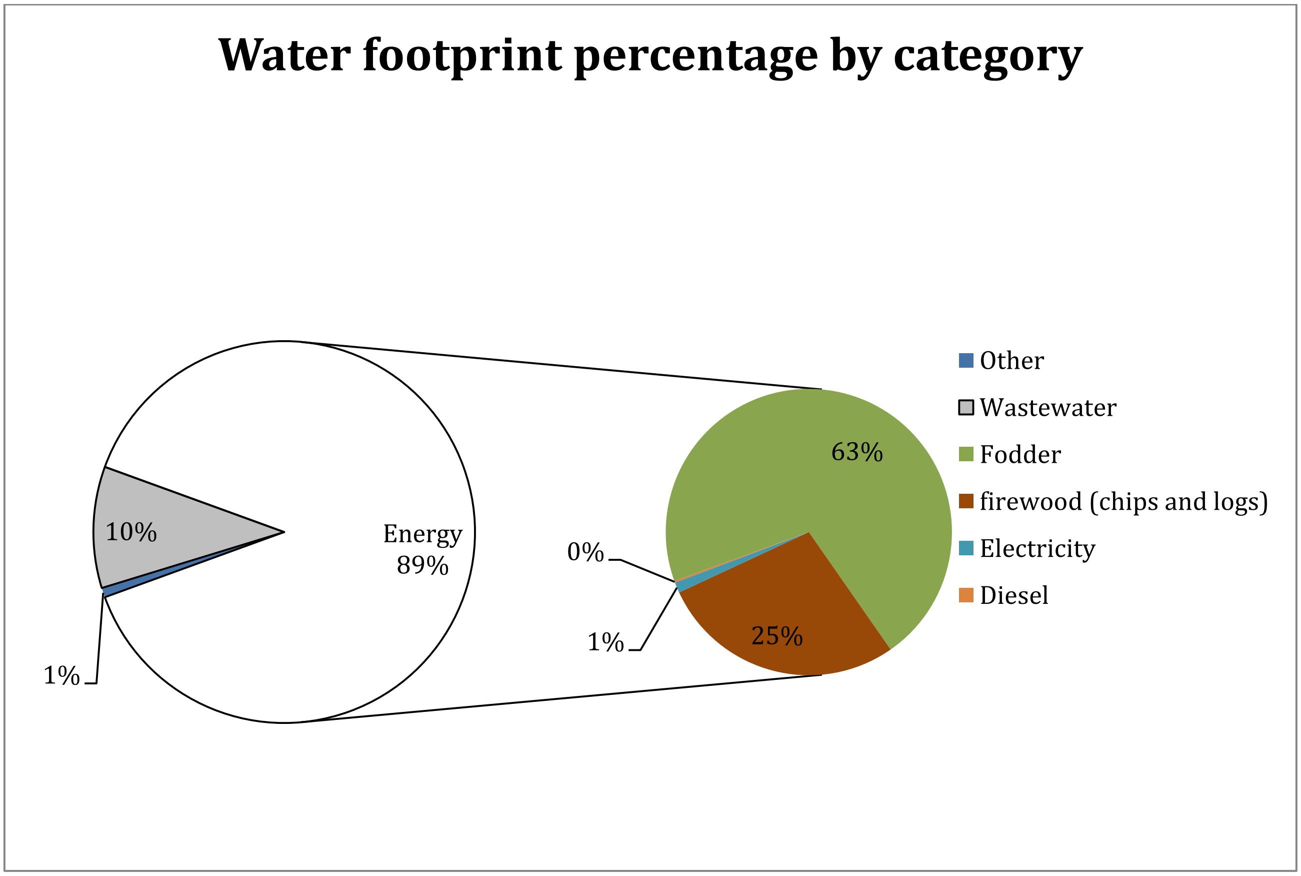


Figure 18 Water footprint of Paasikoski-tila, percentage and value per category

Most of the water footprint is from the energy, and in the second place comes wastewater. The actual water footprint of the water used directly in the farm (direct blue water) is negligible compared to the other components. This proves once more that in a product there is much more virtual and indirect water than water used directly to produce it. On the other hand, milk being high in the production chain, bigger indirect water footprint was expected (more indirect water).

Most of water footprint of the energy comes actually from the fodder and not from fossil fuels or electricity. The second bigger water footprint of energy is fire wood. This is logical since both fodder and firewood have of green water footprint, while the electricity and diesel have no green water footprint.

6 Discussion

According to the literature (Mekonnen & Hoekstra, 2010), in Finland, for cattle having mixed fodder (industrial and grazing), the water footprint of 1 kg of milk is 751 Litres green, 25 litres blue and 30 litres grey making a total of 806 Litres. The percentage of the green water footprint in the literature is 93%, 3% for the blue and 4% for the grey.

In the literature (Mekonnen & Hoekstra, 2010), the water footprint of milk was calculated by compiling a big set of statistics from different countries, about the average milk production per animal, and the average water used for drinking and services (e.g. cleaning the farm yard). The biggest amount of the water footprint comes from the feed which affects grey and green water footprint. Those two components are calculated by using statistics about leaching and a crop water use model. The numbers in this study and in the literature show an interesting resemblance (Table 9):

Table 9 Comparison between the water footprint from Paasikoski and from the literature

Water Footprint of a 1 kg of Milk (in Litre)	Green		Blue		Grey		Total
	Value	%	Value	%	Value	%	Value
This study	725	88	8	1	87	10	826
Literature	751	93	25	3	30	4	806

This resemblance is an indicator that most of the estimations done were not very far from the real WF of Paasikoski-tila. However, the estimation of the grey water footprint remains the most uncertain since it has no backup neither from data nor from literature; The concentration of the pollutants in the manure and in the water bodies of Kainuu were unavailable during the establishment of this work.

Also, there was no data about the fertilizers and the timothy seeds water footprint and therefore they were not included in the accounting of the water footprint. They may very well have increased it, but it is also possible that the Grey water footprint estimate was already too big that it has included thee WF of fertilizers and seeds (numerically speaking).

Since the electricity has different sources, it can't be known for sure which source provides the electricity of Paasikoski farm (hydraulic, wood, coal…). The literature gives an estimate for the total water footprint which was used in this work.

7 Conclusion

The result found for the water footprint of fresh milk, 826 litres of water used to produce 1 kg of milk, is an amount that sounds surprisingly high at first, but is understandable once all the calculations are done. Against initial guesses, the water drunk by the cows is a negligible portion of this footprint (less than 1%). Most of the water footprint in this studied case is green water footprint (rain water) that was mainly used for the production of firewood (25%) and fodder (63%). Since Finland gets abundant amounts of rain water (precipitation or snow) yearly, it can be assumed that this green water footprint does not present a sustainability issue. On the other hand, it is probable that the estimation of the grey water was too generous leading to its portion being significantly bigger than the literature (10% Vs. 4%). However, the grey water footprint of milk production remains relatively small in both cases.

The accounting of the water footprint is an effective way to raise the awareness of how much water is at stake in the production of our daily life products. However, to do a reliable water footprint accounting, one needs an extensive research coupled with enough laboratory analysis and data gathering. From meteorological records, to water flows in each specific regions and sources of each product used, an extensive water footprint calculation can be very demanding. Nevertheless, the estimations still remain good enough to achieve the purpose of giving the reader an idea about the real amount of water used, and perhaps a very detailed study would just present more complications without really adding much to this purpose.

8 References

AEBIOM, 2008. *Wood Fuels Handbook.* Legnaro: AIEL - Italian Agriforestry Energy Association.

Dourte, D. R. & Fraisse, C. W., 2012. *What is a Water Footprint?: An Overview and Applications in Agriculture,* s.l.: University of Florida, IFAS.

Ercin, A. E., Aldaya, M. M. & Hoekstra, A. Y., 2012. The water footprint of soy milk and soy burger and equivalent animal products. *Ecological Indicators,* December, I(18), pp. 392-402.

FAO, 2003. *FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (Water Reports 23).* Rome: FAO.

FAO, 2014. *AQUASTAT database.* [Online]
Available at: http://www.fao.org/nr/aquastat
[Accessed 3 May 2015].

Francke, I. & Castro, J., 2013. Carbon and water footprint analysis of a soap bar produced in Brazil by Natura Cosmetics. *Water Resources and Industry,* Volume 1-2, pp. 37-48.

Frontier Economics, 2008. *The concept of "virtual water" - a critical review,* Melbourne: Frontier Economics.

Fry, A., Haden, E., Martin, M. & Martin, R., 2005. *Water facts and trends,* s.l.: World Business Coucnil For Sustainable development.

Hoekstra, A. Y. & Chapagain, A. K., 2007. Water footprints of Nations: Water use by people as a function of their consumption pattern. *Water Resources Management,* pp. 35-48.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. & Mekonnen, M. M., 2009. *Water Footprint Manual "Sate of the Art 2009".* Enschede: The Water Footprint Network.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. & Mekonnen, M. M., 2011. *The Water Footprint Assessment Manual.* 1st ed. London: Earthscan.

Lähteenoja, S., Lettenmeier, M., Kauppinen, T., Luoto, K., Moisio, T., Salo, M., Tamminen, P. & Veuro, S., 2007. *Natural resource consumption caused by Finnish households,* Helsinki: Finnish Association for Nature Conservation.

Mekonnen, M. & Hoekstra, A., 2010. *The green, blue and grey water footprint of crops and derived crop products,* Delft, the Netherlands: UNESCO-IHE.

Mekonnen, M. & Hoekstra, A., 2010. *The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48,* Delft, the Netherlands: UNESCO-IHE.

Mekonnen, M., Hoekstra, A. & Gerbens-Leenes, P. W., 2015. *The consumptive water footprint of electricity and,* s.l.: Royal Society of Chemistry.

Söderman, D. & Wesanterä, J., 1964. *Some Monthly Values of Evapotranspiration in Finland Computed From Aerological Data,* Helsinki: University of Helsinki.

Staffell, I., 2011. *The Energy and Fuel Data Sheet,* Birmingham: University of Birmingham.

The United Nations, 2003. *"Water For People, Water For Life", The United Nations World Water Development Report.* Barcelona: Co-published UNESCO, Berghahn Books.

The United Nations, 2003. *Water for People, Water for Life | Executive Summary.* s.l.:Co-published UNESCO, Berghahn Books .

Water Footprint Network, n.d. *What is a water footprint.* [Online]
Available at: http://waterfootprint.org/en/water-footprint/what-is-water-footprint/
[Accessed 4 May 2015].

APPENDIX
Answers Given by Hannu Karvonen about the data of his farm (Paasikoski-tila)

1- How many cows do you have?	We totaly have 33 cows which include 17 milking cows, 9 heffers and 6 calves plus one (1) bull
2- How many of these cows are milking?	As I said 17 of them are milking
3- How much milk do these cows produce?	They produce 120 000 liters per year. Average production per milking cow is 8300 per year.
4- How much water do these cows drink?	We can calculate estimated water usage per year if we put to getter produced milk and manure that cows generate. 120k + 450k that make 570 000 liters. Then we need to take attention from heffers and calves which need estimate that 40k liters per year and final we can calculate water which is need to wash equipments were we have 365 * 200 ltr makes 73000 liters. Total...683000 liters per year.
5- How much feed do the cows eat on a monthly basis? Hay and cereals?	Hay in year about 300 000 kg, which dry food amount is average 35 percent rest water. Cereals they eat 72 000 kg per year.
6- How many hectares of hay field do you have?	35 at the moment
7- How much hay is produced by a hectare of land?	Fresh hay without drying (dry food percent below 20). Around 12000 kg per year.
8- Do you use fertilizers in these fields? If so, what kind and how much per hectare?	Yes we do. We use 250 kg twice per year makes that 500 kg per hectare. But we are not fertilizering every hectare what we are harvesting hay. Total we use 6000 kg of fertilizer per year. Basically they include ammonium nitrate and nitrogen
9- Do you use seeds in these fields? If so, what kind and how much per hectare?	We seed about 4 hectares per year, and we use 150 kg of seed. Timothy mainly.
10- How is the energy supplied in the farm?	Wood ship, firewoods, diesel fuel and electric from net.
11- On a yearly basis, how much fuel, woodchips and electrical energy is supplied to the farm?	Woodship 120 m3 diesel fuel 5000 liters firewoods 15 m3 electric 37000 kW/h
12- If you want, you can answer the previous question with regards to the winter season and the summer season?	

13- The slurry sink (where the wastes from the barn go)? What is its volume and how much time it takes to fill up?	We have 3 tanks which volumes are 200 m3, 500 m3 and 500 m3. We only using one 500 m3 and,that small 200 m3. They fill up in 8 months.