A comparative water footprint analysis of the FRE2SH food production network

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Abstract

The WF of products produced within an alternative food production network (FRE2SH) that applies aquaponics and insect farming was determined. In determining the water footprint the water footprint assessment (WFA) method, created by the water footprint network (WFN) was utilized. Furthermore, a comparative analysis has been done by answering the following research questions; what will happen to the total water footprint of a Dutch consumer if all of the vegetables (e.g. lettuce) and fish (e.g. trout) were to be sourced from food products produced by FRE2SH. And what would happen to the water footprint of a Dutch consumer if his daily intake of calories and proteins where to be sourced from products produced by FRE2SH. Next, nine scenarios (e.g. S1P1-S1P9) were created in order to answer the former research question and eighteen scenarios (e.g. S2P1-S2P18) were created in for answering the second research question. Out of the all of the first nine scenarios, the results of S1P7 and S1P8 showed to be the most reliable. Similarly, out of the eighteen scenarios, the results pertaining to S2P7 and S2P8 were considered to be the most reliable. Furthermore, the results showed that the Dutch water footprint saw a reduction of 4-4,3 % if all of the fish and vegetables in the Dutch diet were to be replaced by fish and vegetables produced within FRE2SH. Also, in answering the latter research question, the water footprint saw a reduction of 14-50 % if all of the calories consumed daily by the Dutch were to be sourced by FRE2SH. And 79-87 % if all of the proteins consumed daily by the Dutch would be sourced from FRE2SH.

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1 INTRODUCTION

1.1 GENERAL BACKGROUND

Our current food production and supply system has proven to have big consequences for our planet and our human wellness in general. Issues like resource scarcity, environmental pollution, climate change and human and animal disease are becoming increasingly prevalent. As a result, the stability of the natural biophysical systems that underlie the stability of human civilization are constantly challenged. Furthermore, With the exponential growth of the human population and massive development of urbanization these issues accumulate even further. Conversely, alternatives are being tested within the scope of applied technology, genetic manipulation and local food resilience solutions based on natural and biomimicry sciences. However, within the context of political and economic driven realities such alternatives tend to compete with the establishment. If however seen in a more holistic scenario such alternatives tend to make much more sense and produce better securities for humankind (1–5).

The Eindhoven based network for: Food, Recreation, Energy, Education, Safety and Health (**FRE2SH)**, is a network of individuals that is actively applying the alternatives, it thinks, are necessary for addressing the issues when It comes to food production (resource scarcity, food waste, malnutrition etc.). The network organizes and coordinates the supply and demand of food through the application of many innovative technological (vertical farming, permaculture, alternative food) and socio-economic (sharing and circular economy) innovations. Furthermore, the network is guided by the principle of cooperative and participatory human sustainable development (sustainocracy). What this means is that all of the actions that are taken by the network are guided by core human values (basic needs, cooperation, awareness, safety and security) instead of economical values like profit, market efficiency and self-maximization.

FRE2SH believes that combining production and consumption of food at walking distance, has a huge environmental impact along the entire chain of events. In the context of water consumption for example, studies have shown that a large part of the water consumed in the Netherlands is actually sourced outside of its boundaries (6). However the validity of the **FRE2SH** food production network has not yet been empirically validated. It is in this context that **FRE2SH** has decided to work together with an environmental science student from the **Avans University of Applied Sciences** (the author of this report) to conduct a water footprint assessment (WFA) of the **FRE2SH** food (production) network.

Since the **FRE2SH** food network applies technologies like aquaponics and given the global and local issues related to water management (e.g. water scarcity, water pollution etc.) it was chosen to look at the water footprint. Also, local studies on water consumption only consider water consumed within the boundaries of the Netherlands (7, 8). Even though, there is a global dimension to water consumption, since water-intensive products are internationally traded. Also, since freshwater renewal rates are limited it becomes imperative to study the production, consumption and trade patterns in relation to these limitations. Furthermore, given the work load, it makes more sense to look at just the water footprint instead of doing a complete environmental impact assessment which would require also to include other indicators (e.g. ecological footprint and carbon footprint).

1.2 Goal

The main goal of this project is determine the water footprint of the FRE2SH food production system and then comparing it with water footprint of Dutch consumers attributed to the conventional food production system, in a time span of 20 weeks.

Furthermore, in comparing the water footprint between the two systems. The following research questions were considered:

1. What would happen to the water footprint of a Dutch consumer if all the fish and vegetables he/she consumes is sourced from the products produced by FRE2SH?
2. What would happen to the water footprint of a Dutch consumer if the calories and protein he/she consumes per day were to be completely sourced by FRE2SH?

In order to answer the research questions and thus allow for the completion of the main goal of this project the following sub-goals were considered.

- Schematize the FRE2SH food network in terms of the food production process
- Determine the individual water footprint for each of the products produced within the FRE2SH food network
- Determine the water footprint per unit of nutritional value (e.g. calories, proteins) for each of the products produced within the FRE2SH food network
- Determine the total water footprint of all of the products produced within FRE2SH
- Determine the total water footprint per unit of nutritional value of all of the products produced within FRE2SH
- Determine the total water footprint of a Dutch consumer
- Determine the total caloric intake and protein intake of a Dutch consumer
- Find out what the diet consumption pattern of a Dutch citizen looks like

1.2.1 Hypothesis

It is hypothesized that the total water footprint would decrease if all of the fish, vegetables, calories and proteins he/she intakes, were to be sourced from food products produced within the FRE2SH food network.

1.3 Project Boundaries

Some boundaries are considered while this project is undergone.

- Two stakeholders within FRE2SH are considered in this study mainly: Duurzame Kost (food production based on aquaponics) and Wurmpie Wurmpie (worm farm)
- The project focus is on food products. Any materials for the construction and maintenance, housing e.g. plastics, building materials etc. are considered as outside of the scope of the project
- Economic factors are considered as outside of the scope of the project
- Considering time constraints, Social factors are considered outside of the scope of this project however this is subject to change

1.4 Reading Guide

First of all, Chapter 2 goes into the background information regarding water footprint in general. But it also goes into the water footprint related to the Dutch diet and finally it touches upon some alternative concepts of some alternative food systems. Secondly, Chapter 3 describes what method and the different types of data that was utilized within the study. Third of all, Chapter 4 describes the results of the project. Finally, chapter 5 covers the discussion conclusions and recommendations.

2 BACKGROUND

2.1 UNSUSTAINABLE WATER USE

There has been a growing body of research on water scarcity, pollution and water use in relation to the consumption of goods and services. First of all, two thirds of the global population (roughly 4 billion people) are living under conditions of severe water scarcity at least one month per year (9). There are many problems related to water scarcity, for example, damage to human health. For instance, people experience malnutrition because there is a lack of water for irrigation in agriculture. This problem concerns about one third of the global population whom are threatened to meet daily needs because of lack of water (10). Another problem that is related to water scarcity is biodiversity loss since sensitive species are unable to cope with a reduced availability of freshwater within their environment (11).

Secondly, as a result of nutrient enrichment of aquatic ecosystems due to nutrient leaching from e.g. agriculture. Eutrophication (algal blooms) occurs, which in turn leads to many problems within these waters (e.g. oxygen depletion, biodiversity loss etc.). Since aquatic ecosystems are quite vulnerable to nutrient enrichment many "coastal dead zones" have started to appear globally (see Figure 1) (12).

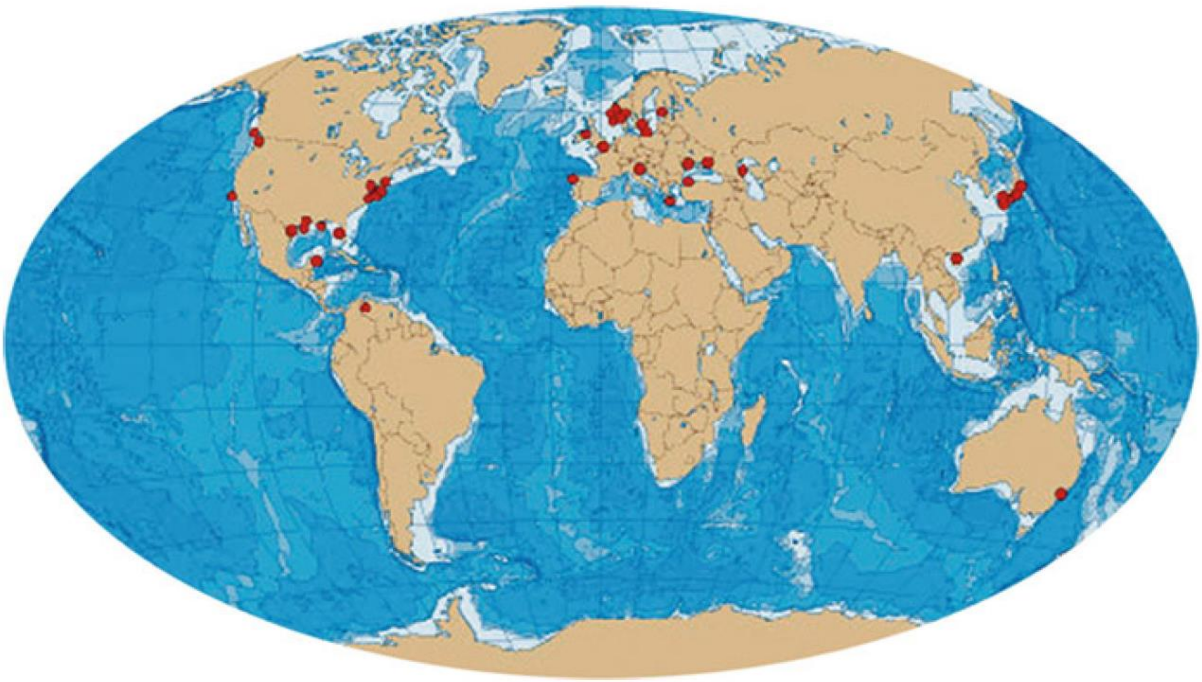

Figure 1 Major coastal Dead zones as a result of nutrient enrichment within aquatic systems (12)

There is scientific consensus on the fact that even though freshwater reserves are renewable, they still are a limited resource since withdrawal of water from a source (e.g. river basin, aquifer etc.) can exceed the renewal rate. Also, there is a recognition that water management has a global dimension to it since water intensive commodities are internationally traded (13). In fact, often enough water-intensive commodities are produced in regions where there is a limited or low water availability and then imported to countries where the levels of water availability is higher (14).

It is the present and future risks associated with stressors of freshwater that have moved the scientific community to develop methods to measure the degradation and consumption of freshwater. So that the environmental impacts associated these issues can be assessed. Also in order to help government develop policies that can help counter these impacts and ensure the equitable distribution of freshwater for current and future generations (15, 16). Amongst the methods that have been developed, water footprint (WF) indicator has become the focus of study for the past 15 years within academia.

2.2 WATER FOOTPRINT

The concept of WF appeared around 2002, when it was first presented at an international meeting on virtual water trade (17). Arjen Y. Hoekstra, a professor at the university of Twente (Netherlands), proposed the WF as an indicator for the water use that is attributed to all goods and services consumed by a person or a group of persons (e.g. institutions, societies, nations). The promise was that the total WF would prove to become a useful indicator for a nation's call on global freshwater reserves. Also, at the consumer level it would prove to be useful to have a WF of an individual as a function of his or hers food diet and consumption pattern (13). This concept was based on the following premises:

1. The idea that freshwater is a global resource, since people in one place have the ability to make indirect use of fresh water elsewhere through virtual water trade (18). Furthermore, allocation of water on a local level for goods and services is increasingly driven by a global economy that lacks incentives for sustainable water use.
2. Since freshwater renewal rates are limited, these limitations must be studied within the context of consumption, production and trade patterns that they relate to.
3. In understanding the use of natural resources and its impacts, the problem must be approached from the perspective of supply chains and product life cycles.
4. A comprehensive approach to towards fresh water consumption must consider both and blue and green water consumption as well as water pollution.

2.2.1 Components of the water footprint indicator

To reiterate, the WF is a measure of the consumptive and degradative water use. this consumptive WF has three components namely:

1. Blue water footprint: this refers to the consumption of surface- or groundwater.
2. Green water footprint: this refers to the consumption of rain water and its inclusion broadens the perspective of water resources beyond the historical focus of water engineers on blue water.
3. Grey water footprint: also the so-called "degradative water footprint", refers to the total volume of water that is required to assimilate pollutants that enter the freshwater bodies.

2.2.2 Water footprint vs virtual water

The WF is similar to the virtual water in the context of the water that is used to produce a product (a.k.a. virtual water content). However, unlike the virtual water, the WF has a much wider application in that it does not only refer to the water volume, but also to the source of the water (e.g. green water, blue water, grey water) and where it comes from (19).

2.2.3 Direct, Indirect, Internal and External water use

In WF analysis, when looking at the level of consumers or producers, the WF can be looked at from several perspectives. Direct water footprint refers to the water that is consumed by people at home, or by producers within the boundaries of their production systems. The Indirect water footprint refers to the water that was used for producing: food, clothes, energy etc. Furthermore, when looking at the national level, there are also several perspectives that need to be considered e.g. Internal and External water footprint. The Internal water footprint is referred as the total volume of water that is consumed within the boundaries of a nation. Conversely, the external water footprint refers to the volume of water used in other countries to produce goods and services that is consumed by the inhabitants of the country in question (6, 19).

2.2.4 Water productivity, water self-sufficiency, water dependency and water scarcity

In water management there are many terms that are used to convey a certain condition of water in a region or of a process or product (19). When it comes to the quantification, analysis or assessment of WF, there is some important terminology to consider mainly:

- **Water productivity** - this is the inverse of WF and it refers to the product units that are produced per unit of water consumption and/or water pollution (product units/m3). It is similar to the terms labour productivity and land productivity, but instead the water production divided over the water input. You can have green, blue and grey water productivity.

- **Water self-sufficiency** - This is defined as the ratio of the internal WF to the total WF. It gives an idea about the degree to which a nation itself supplies water for the production of domestic goods and services. If all of the water that is needed for production of domestic goods and services then the water self-sufficiency approaches 100. If the demand of goods and services is supplied largely supplied through virtual water imports, then the water self-sufficiency approaches zero.

- **Water Dependency -** this is defined as the ratio of the external WF to the total water consumption of a nation. As the ratio approaches 100 the nations is more dependent and as it approaches zero, the nation is less dependent. Countries that have some level of virtual water import, as a de facto, depend on water sources available from others parts of the world.

- **Water Scarcity -** is defined as the lack of freshwater to meet demand

2.2.5 Different approaches to water footprint analysis

So far, there are two approaches that have been developed for the measurement of water use and water consumption from a life cycle perspective mainly:

- Water Footprint Assessment (WFA) developed by the water footprint network (WFN) – this approach is utilized to map the direct and indirect (volumetric) appropriation of water along the supply chain and asses its relevance in grander scheme of water resources management (16, 19).
- Impact-based Water Footprint that follows the Life Cycle Assessment methodology according to ISO 14046 (LCA WF method) – in this approach requirements and recommendations are provided in order to understand and address the freshwater use by accounting for volume of freshwater used in production systems and quantifying scarcity and pollution without, however, providing a specific method for impact assessment (16, 20).

In a broad sense, both of the methods are very similar and contain similar steps with regard to the quantification of water use, along with the impacts associated with water use and the collection of data. However, where they differ is in the way the WF result is communicated and in how the method is developed. WFA takes a global approach in its quantification and assessment of water use, hence, in this approach, global freshwater use is the main theme. Furthermore, this approach does not account for the local impacts related to freshwater scarcity. Also, the WFA reports the WF as a standalone single score indicator. Next, the WFA includes the green water footprints in the total WF. On the other hand, the LCA method focuses on local environmental impacts (e.g. local water scarcity and the human and environmental consequences associated with it) instead of global (fresh) water use. Also, LCA reports the WF as a set of indicators instead of just one. This is because, according to the LCA community;

> *"environmental problems are better addressed by more specific indicators in LCA, environmental problems directly related to water use are aimed to be quantified by water use impact assessment in LCA. This is an important difference as it directs the discussion whether green water (evapotranspiration from soil moisture) and grey water (water quality impairment) should be part of the water footprint metric"*

Next, the LCA method does not include the green water and grey water component in its quantification method. The justification for this is that there are more specific e.g. land use, toxicity or eutrophication indicators that regard environmental impacts associated with green and grey water (15, 16, 21).

Even though the LCA method is great for assessing the potential impacts in a complex supply chain. It is definitely less robust from an epistemic point of view, since unlike in the WFA method, a number of value choices are defined in non-physical metrics like for example scarcity equivalents (21).

2.3 Water footprint quantification and assessment (WFN Method)

When it comes to calculating the WF of an entity there are some activities that need to be taken into consideration namely:

- Setting the goals and scope of water footprint assessment
- Water footprint accounting
- Water footprint sustainability assessment

2.3.1 Setting goals and scope of water footprint assessment

Since WF can be specified in different entities, it is of imperative to specify on which entity one would like to focus. A specified entity can include: a process, a consumer or group, a geographical delineated area, a business or business sector and also the humanity as a whole. When defining the WF assessment goal, the following checklist can be considered:

- General
  - What is the ultimate target ? Awareness-raising, hotspot identification, policy formulation or quantitative target setting ?
  - Is there focus on one particular phase ? focus on accounting, sustainability assessment or response formation?
  - What is the scope of interest ? direct and or indirect water footprint ? Green, blue and/or grey water footprint ?
  - How to deal with time ? Aiming at assessment for one particular year at the average over a few years, or trend analysis?
- Process water footprint assessment
  - What process to consider ? One specific process or alternative substitutable processes (in order to compare the water footprints of alternative techniques)?
  - What scale ? one specific process in a specific location or the same process in different locations ?
- Business water footprint assessment
  - What is the scale of the study? A company unit, whole company or a whole sector ?

- What is the scope of interest? Business risk, product transparency, corporate environmental reporting, product labelling, benchmarking, business certification, identification of critical WF components, formulation of quantitative reduction target?

2.3.1.1 Defining the scope for water footprint accounting

When one needs to set up a WF account, it is important to define boundaries. What this is means is that it is important to define what should be included or excluded from the WF account. These boundaries should be based on the type or purpose of the WF account. In general the following checklist is considered when setting up a WF account:

- Consider, blue, green and/or grey WF : decide on what type of WF should be included/excluded in the WF account. This largely depends on the type of process that is studied.
- Where to truncate the analysis when going back along the supply chain ? : find out from which processes the WF should be included. The general rule is to include the WF of all processes, however if the WF of a particular process has small influence on the total WF, then this does not have to be added.
- Which level of spatiotemporal explication? : define the level of spatiotemporal detail (see Table 1).
- Which period of data ? define the period of the data that is used, since the period of data have an influence on the outcome.
- For consumers and businesses: consider direct and/or indirect water footprint ? in general the rule is to include both the direct and the indirect water use. However, this differs depending on the type of system that is analysed.

Table 1 Explication in water footprint accounting (19)

	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.

2.3.1.2 Defining the scope of water footprint sustainability assessment

The most important question to consider when thinking about the sustainability assessment is what perspective should be taken into account. This perspective can be geographic, a process, a product, a consumer or a producer. In the case of a product, process, consumer or producer, the focus is set on the contribution of the WF of product, process, consumer etc. to the larger picture. Furthermore, the contribution of a (chosen) perspective can be further defined in the following questions:

- What is the contribution of the specific process, product, consumer etc. to the global WF of humanity
- What is the contribution of the specific process, product, consumer etc. to the aggregated water footprints of the specific area geographic area ?

2.3.2 Water footprint accounting

In WF accounting there are different type of accounts (contexts) of WF namely the WF account of: a process or step, a product, a consumer or producer, a group of producers or a group of consumers and a geographically delineated area. The WF of a process forms the foundation for the calculation of the other types of WF accounts (see Figure 2).

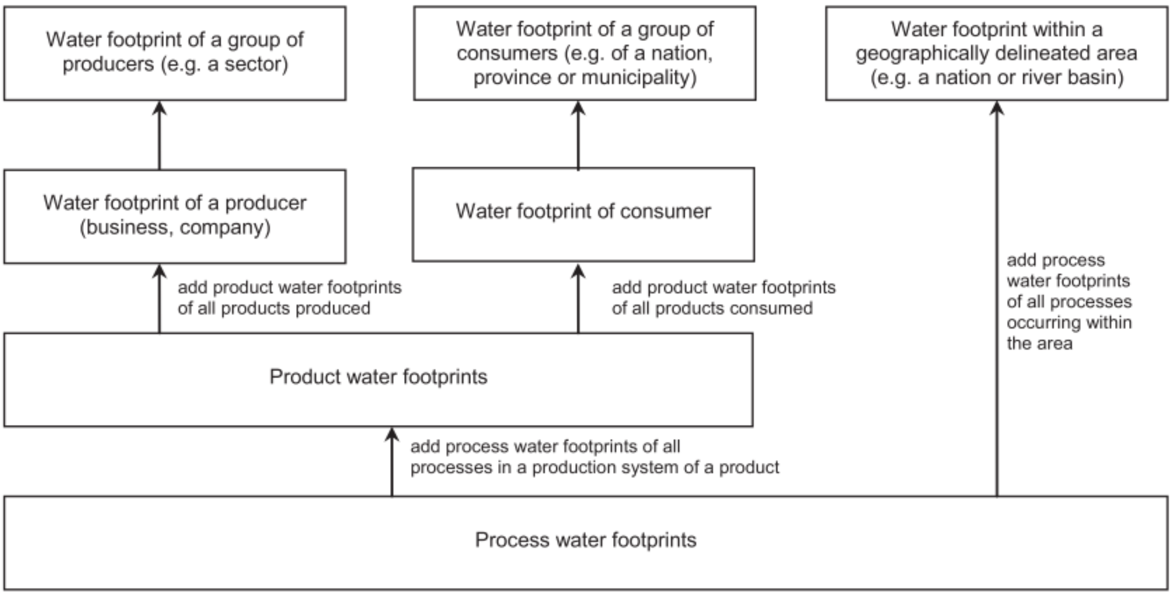

Figure 2 Process water footprint as the basic foundation for WF accounting (19)

First of all, the footprint of a product is also known as the water aggregated WF of the processes or steps that were taken to produce the product (this is measured over the whole of the production supply chain). Secondly, the WF of a consumer is sum of the water footprints of all of the products that are consumed by the consumer. Thirdly, The WF of a community is the sum of the WF of all its members. Next, the WF of a nation is the sum of the WF of all the nation's inhabitants. Also, the WF of a business is the sum of the water footprints of the final products that are produced by the business. Finally, the WF within a geographically delineated area is the sum of the water footprints of all of the processes that are taking place within the boundaries of the area.

2.3.2.1.1 Units of water footprint

For a process, the WF is generally expressed as water volume per unit of time ex. (m3/year) however, it can also be expressed in terms of water volume per product (m3/product unit). In the context of a product, the WF is always expressed in as water volume per product unit example;

m3/mass, m3/unit of money, m3/piece, m3/unit of energy(kcal, joule etc.). The WF of a business is always expressed as water volume per unit of time (m3/year), for group the WF is expressed as water volume per capita per unit of time (ex. m3/cap/year). Finally, the WF of a geographically delineated area is always expressed as water volume per unit of time.

2.3.3 Water footprint sustainability assessment

To start off, in order to understand what the calculated WF actually means in the bigger picture, one needs to compare it to a background. Just as in the case of the sustainable assessment when using the ecological footprint, one needs to compare the latter to the biologically productive space that is available.

Secondly, sustainability has three aspects to it: environmental, social and economic. Also, there impacts associated to the different dimensions of sustainability, usually two levels (e.g. primary, secondary impacts). Furthermore, the WF has different colours e.g. green WF, blue WF and grey WF.

Finally, Sustainability of water footprints can be approached a number of different perspectives. Mainly; from the geographic perspective, from perspective of a process, from the perspective of the product, from the perspective of the producer and lastly from the perspective of the consumer.

2.3.3.1 Sustainability assessment of a geographic area

In this perspective the question usually asked is, is the total WF within a geographic area sustainable ? examples of this not being the case include; instances where the environmental flow requirements or ambient water quality standards are compromised. Also in instances where for example the allocation of water is distributed in an unfair or inefficient way.

When evaluating the WF of a geographic area the point of focus generally is at the level of a river basin or catchment area. At this level, the green and blue WF can reasonably be compared to the green and blue water availability. Also, at this level the grey WF can be compared to the available waste assimilation capacity of the catchment.

Furthermore, when assessing the sustainability of catchment or a river basin. Generally three perspectives are considered: environmental, social and economic. For each of these perspectives different criterion apply (see Table 2). In the case of either the blue, green or grey WF does not adhere to one of the sustainability criteria mentioned in Table 2, the WF should not be considered as geographically sustainable.

If for a given geographic area (e.g. catchment, river basin etc.) the environmental, social or economic criterion are not met, the region is considered a so-called hotspot (19). What this means is that within that specific are the WF is not sustainable.

Table 2 sustainability perspectives and their respective criterion when assessing water footprint of a geographic area [1] (19)

Perspective	Criterion
Environmental	**Ambient water quality standards**: quality of water should remain agreed upon limits. **Environmental flow requirements**: river- and groundwater flows should remain within certain limits compared to natural runoff, so that

[1] The criterion discussed in this table can be mathematically determined, the methods are described in detail in the water footprint sustainability section of the book: The Water Footprint Assessment Manual: setting the global standard.

	ecosystems and livelihoods that depend on river and groundwater can be maintained.
Social	**Basic human needs**: a minimum supply of freshwater should be allocated in order to meet demand for achieving human basic needs (e.g. water supply for drinking, cooking, food production). **rules of fairness**: this includes the principle of user and the polluter pays. It's not sustainable if people downstream have a blue WF that is the cause of issues downstream while people living downstream are not properly compensated by people living upstream. Furthermore, because freshwater is a public good it is not fair, and therefore not sustainable when some user consume more than their fair share from a freshwater source.
Economic	"water needs to be allocated and used in an economically efficient way. The benefits of a (green, blue or grey) WF that results from using water for a certain purpose should outweigh the cost associated with this WF, including externalities, opportunity costs and a scarcity rent"

Assessing primary and secondary impacts

After a hotspot has been localized and the severity of the hotspot as been determined, it becomes possible to assess the primary and the secondary impacts associated with the hotspot in more detail (if this is the scope set for the assessment). The primary impacts can be identified in different levels of detail. Simple models like a water balance model or a water quality model, can be utilized to estimate the effect of the green, blue or grey WF on the catchment's hydrology or water quality respectively. Important primary impact variables include: run-off and associated water levels, some water quality parameters that are relevant to the case studied. In order to get meaningful outcomes, all of the variables should be compared to some established baseline hydrological and water quality conditions. The best conditions to take as baseline are the natural conditions pertaining to the catchment (19).

In the case of secondary impacts pertaining to blue, green, and grey water footprints the of a geographic area, the literature is ubiquitous. However, it is still a major challenge to structure a environmental, social or economic impact assessment. Essentially, for a broad assessment, one generally needs to make a distinction between environmental, social and economic impacts. the questions that firs pops up is, which impact variables should be taken into account. Environmental variables generally include parameters like: biodiversity los, abundance of species, loss of habitat. Social variables include: employment, human health, food security, and welfare distribution. In the case of economy the variables include income n different sectors of the economy affected by the water perturbation of the specific study case (19).

2.3.3.2 Sustainability assessment of a process

Essentially there are two criteria which attribute to a process being sustainable or not:

1. Geographic context: *"the process WF is not sustainable if the process is situated within a hotspot. So, when the process is situated in a certain catchment area in a certain period of the year in which the total WF is unsustainable from either the environmental, social or economic perspective."*
2. Characteristic of the process itself: *"the WF is unsustainable in itself – independent of the geographic context – when the WF of the process can be reduced or avoided altogether."*

It is important to note that for the green, blue and grey WF the two criteria need to be assessed separately. What is meant with the first criterium is that as long as the WF of a particular process contributes to a hotspot in which its overall WF is unsustainable, the WF of this process is unsustainable as well. In other words, when the WF of a process contributes to a hotspot, the process itself is unsustainable because is part of an unsustainable situation (19).

With regard to the second criteria: the blue, grey or green WF of a process is unsustainable if the footprint in itself can be reduced or removed altogether as a result of available better technologies (19).

2.3.3.3 *Sustainability assessment of a product*

The WF of a product is generally determined by summing up the WF of all of the processes that constitute the production of the production of the project. Therefore, the sustainability of the product depends on the sustainability of each of the underlying processes that constitute product. And since the WF of each of the process is considered individually, the same two criteria apply as discussed in the previous section. Generally an account is created (see Table 3) in which for each of processes underlying the product, the two criteria are assessed and thus a final estimation can be found on whether the product WF is sustainable or not (19).

Table 3 framework for assessing the sustainability of the water footprint of a product (19)

Data derived from the product water footprint account			*Check the sustainability of the total water footprint in the catchment in which the process is located*	*Check the sustainability of the water footprint of the process itself*	*Conclusion*		*Check relevance from product perspective*	*Check whether response is required*
Process step[a]	*Catchment in which the process is located*[b]	*Water footprint (m^3 per unit of final product)*	*Is the catchment a hotspot?*	*Can the water footprint be reduced or avoided altogether?*	*Is this a sustainable component in the product water footprint?*	*Fraction of the product water footprint that is not sustainable*	*Share above threshold of one per cent*[c]	*Is this a priority component?*
1	A	45	no	no	yes		yes	no
	B	35	**yes**	**yes**	**no**	35%	yes	**yes**
2	A	10	no	no	yes		yes	no
3	C	6	no	no	yes		yes	no
	D	2	**yes**	no	**no**	2%	yes	**yes**
	E	1.1	no	**yes**	**no**	1.1%	yes	**yes**
4	F	0.5	**yes**	no	**no**	0.5%	no	no
5	A	0.3	no	no	yes		no	no
6	A	0.1	no	**yes**	**no**	0.1%	no	no
total		100				38.7%		

[a] The production system of the product consists of a number of sequential or parallel process steps (see Section 3.4.2).
[b] A process step (for example, growing a particular crop which is an ingredient to the product considered) can be located in different catchments.
[c] Choosing the threshold can be subject to debate.

2.3.3.4 Sustainability assessment of a producer (business)

The WF of a business is also considered as the sum of the total water footprints of the products produced by the business. That is why, in order for one to assess the sustainability of business, one needs to assess the sustainability of water footprints of the products produced by the company. Furthermore, the sustainability assessment of the WF of the products produced by the business can then be used to see which products, and with that, which processes are responsible for the unsustainability of the company (19).

2.3.3.5 Sustainability assessment of a consumer

Since the WF of a consumer is known as the sum of the total WF of all of the products consumed by the individual. One needs to look at the sustainability of the WF of the individual products that are consumed by the individual. However, just looking at the WF of each individual product consumed is not enough. Therefore, one needs to also consider the total WF of the consumer as a whole. In this case, another criterion comes into play, which is the question of looking at the fair share that is allowed to be consumed by an individual in the context of limited global fresh water resources. For many individuals, the total WF will be dominated by only a few water intensive components. For example, in the case of meat eaters, the largest WF will come from the meat component of their consumption. In the case a consumer has a large WF, the focus should then be on products of concern, which generally point to "luxury" goods that have relatively large WF. large scale production of these types of products generally come at big environmental and social costs (e.g. environmental pollution, food security etc.). water intensive luxury goods other than meat products include: agriculture based cosmetic products and first-generation biodiesel and bio-ethanol. Production of these types of products at a limited scale does not necessarily immediately contribute to the unsustainability of the products – assuming of course that the production of these goods does not take place in a hot spot.

The assessment of WF of consumers can also be expanded to the nation level. On this level the criteria becomes than assessing whether the nation (group of consumers) have a WF that is greater or less than their fair share in the context of the global limited freshwater resources (19).

2.4 WATER ABSTRACTION AND USE OF THE DUTCH

2.4.1 total water abstraction and use of the Netherlands

According to the Dutch Environmental Data Compendium, in the past 30 years, there has been no significant trend in the total abstraction and the use of water in the Netherlands. Even though the economy has grown substantially in this period (see Figure 3 & Figure 4). The total water abstraction and the use of groundwater did see a slight decrease over the past 30 years. However, the water abstraction and use of surface water did fluctuate from year to year. In terms of drinking (tap) water however, the water use has remained stable over the past 30 years, though compared to the end of the previous century. Even though there has been extensive growth in population and consumption patterns (22).

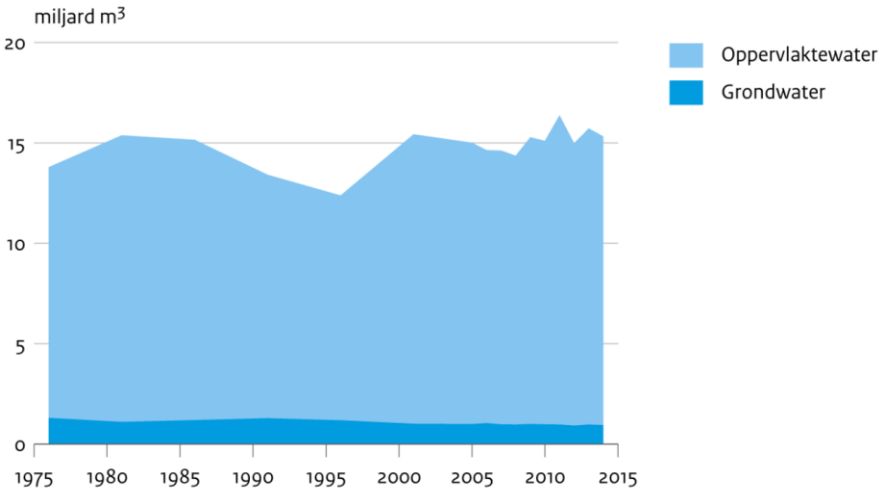

Figure 3 Water abstraction over the past 30 years the Netherlands (22)

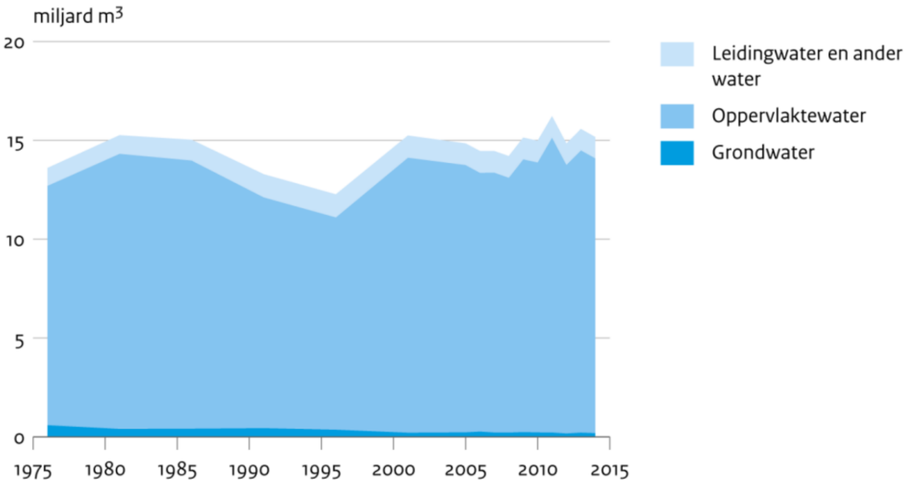

Figure 4 Water use over the past 30 years the Netherlands (22)

Firs of all, the most important consumers of surface water are the energy companies which utilize the water as cooling water in energy production. In fact, 90-95 % of all of the consumptive surface water is attributed to cooling water in the production of electricity. Also, fluctuations that are witnessed in the abstraction of surface water are the result of fluctuating quantities of cooling water. On another note, in 2014 almost two thirds (i.e. 68%) of the total water abstraction and use was attributed to this sector (see Figure 5 & Figure 6) (22).

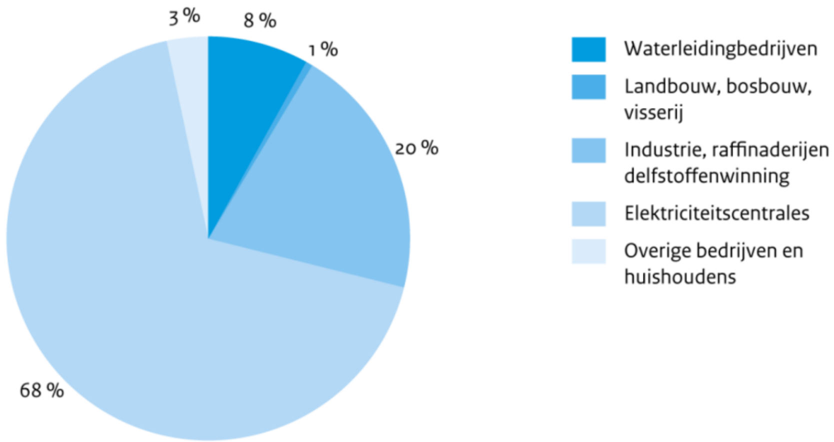

Figure 5 water abstraction in the Netherlands in 2014 (22)

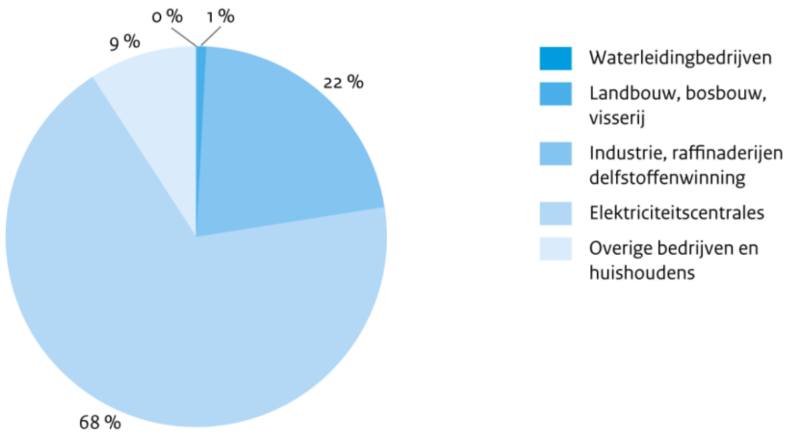

Figure 6 water abstraction in the Netherlands in 2014 (22)

Secondly, tap-water companies are the biggest consumers of groundwater. Furthermore, the share of groundwater consumption within the tap-water production did see much of a change in the past 10 years. Households are the biggest consumers of tap-water. And because of water-saving policies, the per capita consumption of tap-water by households have seen a significant drop during the mid-90's. In dry years (e.x. 2003 and 2006), groundwater and tap-water use generally witness an increase of a few percentage points as a result of demand from the agricultural sector and from households (22).

2.4.2 Water abstraction and consumption of the Dutch agricultural sector

First of all, In the years of 2013 and 2014, there has been an average consumption of water in the agriculture sector if you take into account water consumption over 2001-2014 (see Figure 7). The amount of water that is consumed really depends on the amount of precipitation that falls in the growing season. However, significant differences in precipitation can occur. For example, the amount of precipitation that took place in the months March and April of 2014, saw significantly less rain around the river catchment area of the Maas. While in the months of July and August of 2014 the precipitation was significantly more (23).

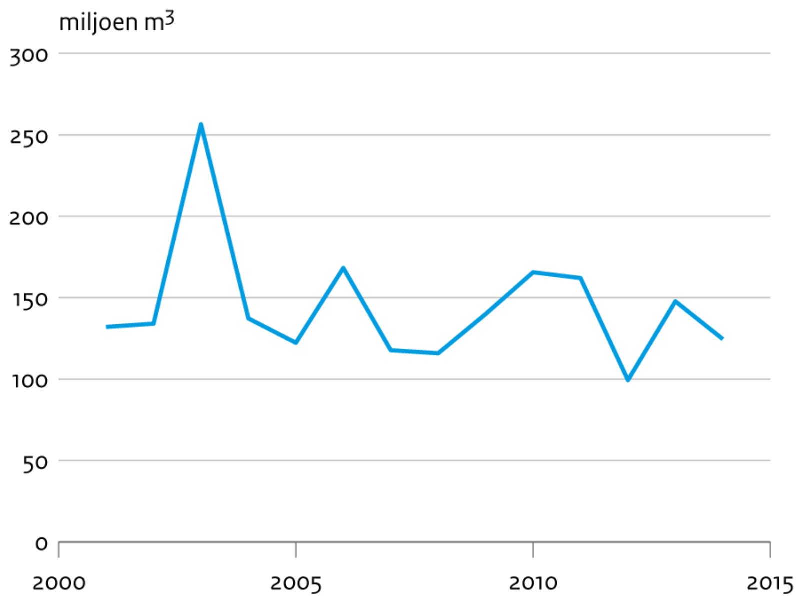

Figure 7 Water consumption in the Dutch agricultural sector (23)

Secondly, the water consumed in the Dutch agricultural sector is comprised of surface water, ground water and tap-water. The largest share of the water consumed in Dutch agriculture is attributed to tap-water. In fact, around 50 % of the total water consumed is attributed to tap-water (see Figure 8). This water is for the most part used in livestock farming as drink water and water for cleaning purposes. Ground- and surface water are mostly used for irrigation purposes. When there is a lot of precipitation the amount of surface- and groundwater is understandably less (23).

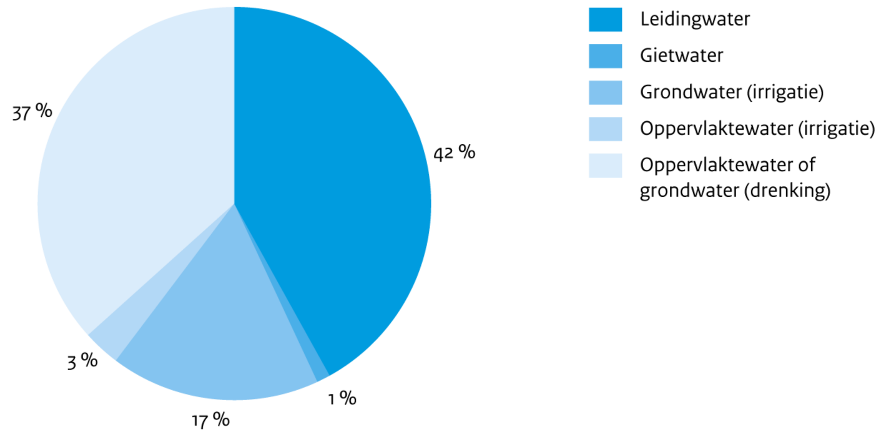

Figure 8 Composition of the water consumed in Dutch Agriculture (23)

Actually, irrigation is the most important purpose of surface and ground water consumption within the agricultural sector. Irrigation takes place on grasslands, in agriculture and in horticulture (23).

2.4.3 Water abstraction and consumption of a Dutch household

According to the Dutch Environmental Data compendium, the water consumed by a Dutch household has reduced significantly. This is due to the fact that the water consumption of household appliances has reduced significantly due to technological improvements (see Table 4) (24).

Table 4 Water consumption of the Dutch household (24)

	1995	1998	2001	2004	2007	2010	2013
	litres per capita per day						
Bad	9,0	6,7	3,7	2,8	2,5	2,8	1,8
Douche	38,3	39,7	42,0	43,7	49,8	48,6	51,4
Wastafel	4,2	5,1	5,2	5,1	5,3	5,0	5,2
Toiletspoeling	42,0	40,2	39,3	35,8	37,1	33,7	33,8
Wassen hand	2,1	2,1	1,8	1,5	1,7	1,1	1,4
Wasmachine	25,5	23,2	22,8	18,0	15,5	14,3	14,3
Afwassen hand	4,9	3,8	3,6	3,9	3,8	3,1	3,6
Afwasmachine	0,9	1,9	2,4	3,0	3,0	3,0	2,0

Voedselbereiding	2,0	1,7	1,6	1,8	1,7	1,4	1,0
Koffie/thee	1,5	1,1	1,0	1,0	1,2	1,2	0,6
Water drinken		0,5	0,5	0,6	0,6	0,6	0,4
Overig keukenkraan	6,7	6,1	6,7	6,4	5,3	5,3	3,4
Total	**137,1**	**131,9**	**130,7**	**123,8**	**127,5**	**120,1**	**118,9**

2.4.4 Comments on the Dutch water use data

On a first note, when it comes to the data pertaining to total Dutch water abstraction and use. When one considers literature and data on which the Dutch Environmental Data compendium is based on. What comes to mind is the fact that these figures don't show the true total appropriation of water of the Netherlands. In fact, the Dutch government utilizes the System of Environmental-Economic Accounting (SEEA) as a framework for estimating their environmental accounts (including the accounting for water resources) (7, 25). However, this framework does not consider the global nature of the economic system and the effects of the local economic system on the global environment. Instead it approaches "environmental-economic" accounting only from a national (local) perspective (8). For example, in the fiscal year of 2017 the GDP of the Netherlands grew with around 3.2 %. According to CBS, this growth in GDP was largely attributed to export (26). Out of the total export and import that took place in that fiscal year. 19,4 and 15,2 % was attributed to export and import, respectively, of agricultural products (27). The problem here is, that the virtual water associated with these import and some of the export products are not accounted for in the total water appropriation of the country.

Secondly, when it comes to the data on water consumption attributed to a Dutch consumer. Consumption is only approached from a local perspective since indirect and direct water consumption is not regarded in the local assessments of consumer water appropriation. Therefore it is safe to assume that the current estimates of water consumption of a Dutch consumer is actually underestimated and underreported.

2.5 WATER FOOTPRINT OF THE DUTCH

Previous studies have estimated the total WF (attributed to industrial and agricultural goods) of Dutch consumers to be around 2300 m^3 cap^{-1} y^{-1} (period 1996 - 2005). Out of this WF, 67% is attributed to agricultural products, 31% is attributed to industrial goods and 2% is attributed to domestic water use (see Figure 9) (6, 14).

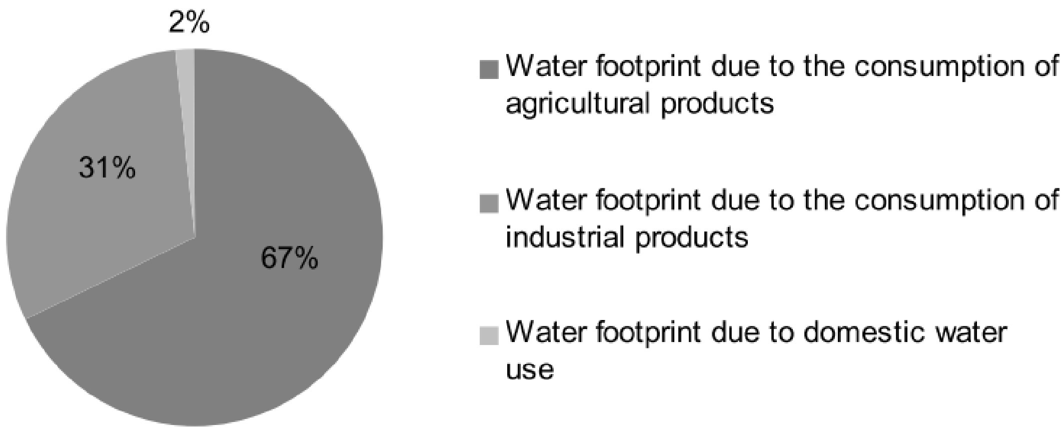

Figure 9 Total water footprint of a Dutch consumer (6)

When you take a closer look at the WF from agricultural products, what can be observed is that 46% of it is attributed to livestock products. Furthermore, 17 % is attributed to oil crops, 12% is from the consumption of tea, coffee, tobacco, cacao. Also, cereals and beer (made from barley) contributes around 8%. Finally, cotton products 6%, fruit 5% and other agricultural products 6% (see Figure 10)(6).

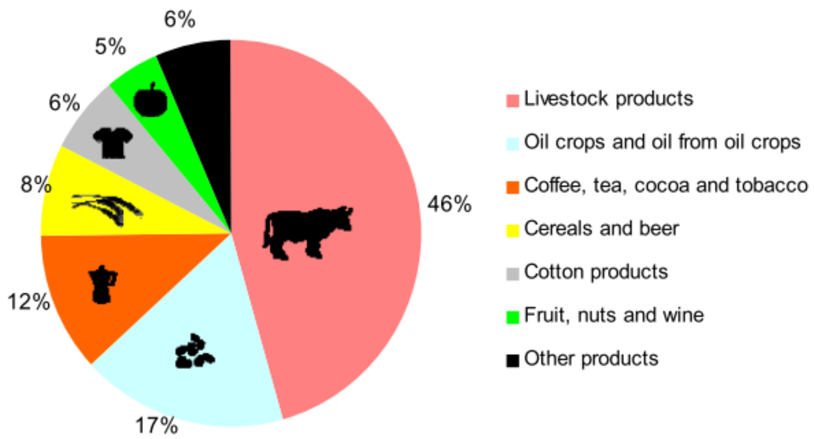

Figure 10 Composition of the Dutch total water footprint attributed to agricultural products (6)

2.5.1 Internal and external water footprint of the Dutch society

When looking at WF at the national level, there are several perspectives that need to be considered e.g. Internal and External WF. On one side, the Internal WF refers to the total volume of water that is consumed within the boundaries of a nation. Conversely, the external WF refers to the volume of water used in other countries to produce goods and services consumed by the inhabitants of the country in question (19).

In the case of the WF of the Dutch society, about 89% is external and 11% internal. In terms of agriculture products, 97% of the WF is external. Moreover, 48% of this external WF is located in Europe (e.g. Germany, Belgium, France), 20% in Latin America (e.g. Brazil and Argentina), 14% in Asia, 9% in North America, 8% in Africa and 1 % in Oceana. Half of the WF for industrial products is within Europe and, 33% from Asia and the rest of the WF originates from Latin America, Africa and Oceania (see Figure 11) (7).

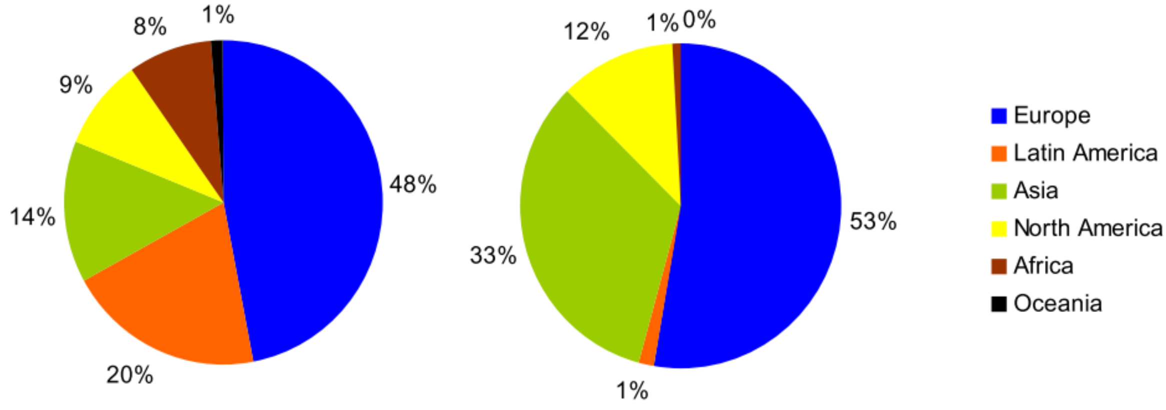

Figure 11 Global distribution of Dutch water footprint (industrial goods left, agricultural goods right) (6)

Next, when it comes to the external WF of the Netherlands, largest percentage (40%) is attributed to oil crops and oil from oil crops[2]. Furthermore, 22 % is attributed to meat, 13% to cereals and beer, 7% to coffee, tea, cocoa and tobacco, 7% to cotton products, 4% to fruits nuts and wine and 7% to other agricultural products (see Figure 12) (6).

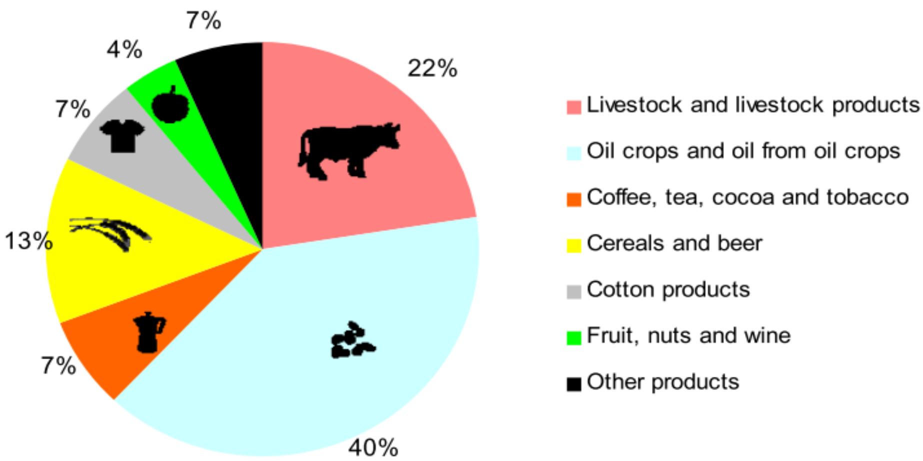

Figure 12 Composition of Dutch external water footprint attributed to agricultural products (6)

[2] Note: these crops include animal feed

2.5.2 Impacts related to Dutch water consumption

When thinking about the water consumption attributed to agricultural and economic practices (in the context of food trade) of the Netherlands certain aspects (e.g. social, economic and environmental) have to be considered.

First of all, since the biggest portion out of the total WF of the Netherlands is external, it can be concluded that the Netherlands has a high level of water dependency. In fact, it has been estimated that the Netherlands is about 80 % dependent on freshwater resources. Also, since the large part of the Dutch economy consists of imports (agricultural and industrial) that are then re-exported. This level of water dependency can put the Dutch's economic security and food security at risk (28).

Secondly, A 2008 study on the external WF of the Netherlands showed that a large percentage of the imported (water-intensive) agricultural and industrial goods are from countries that experience some level of water scarcity (e.g. China, India, Spain, Turkey, Pakistan, Sudan, South Africa, and Mexico)(see Figure 13). What this means is that a lot of pressure is put on the freshwater resources that are necessary for ensuring some level of water security in those regions. Furthermore, conflict over water is considered more prevalent in the near future. This further puts pressure on food security in the Netherlands (5, 6).

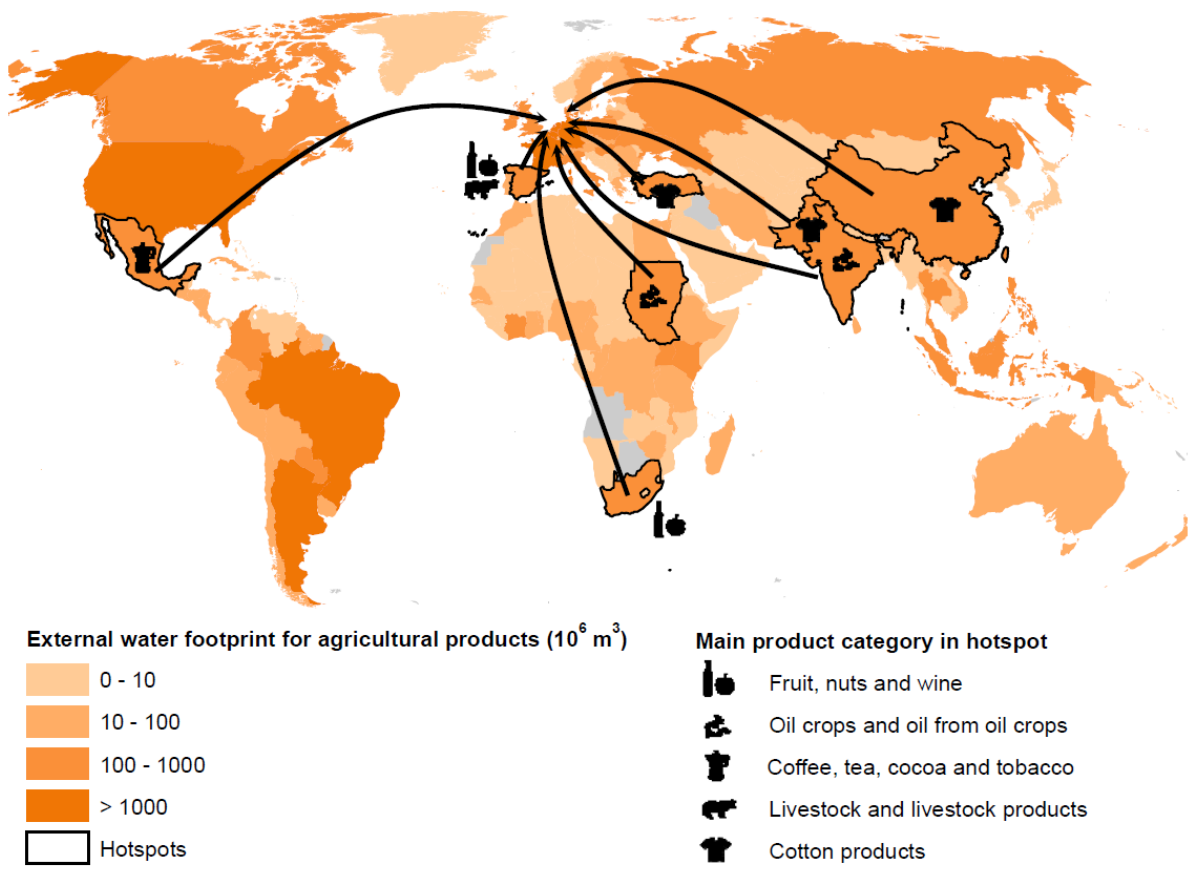

Figure 13 The external water footprint for consumed agricultural products in the Netherlands and countries considered as hotspots (6)

Finally, pollution also seems to be a problem when it comes to the production and consumption of agricultural and industrial goods. Not only in countries in which water-intensive products are produced for import, but also locally. According to the Dutch environmental data compendium, most of the surface waters (around 60%) in the Netherlands do not meet the water quality standards as set by the European framework directive. The chemical quality of in most of most of the surface water is insufficient. Also, the ecological quality in a most of the surface waters ranges from moderate to poor. It has been stated that overfertilization with nitrogen and phosphorus are amongst the causes for the current state of the water bodies in the Netherlands[3] (29).

2.6 THE FOOD CONSUMPTION PATTERN OF DUTCH CITIZENS

According to a national survey done by the Dutch National Institute for Public Health and the Environment, a typical Dutch person consumes around 3.1 kg of food (including drinks) per day. About 60 % of this falls in the category of 'alcoholic' and 'non-alcoholic' beverages (e.g. water, tea, coffee, juice, and soda). Next, about 41% of the remaining food and drinks is animal based (see Table 5). Furthermore, other food groups that constitute a high portion of the food intake include: dairy (products), cereal (products), vegetables, fruit, nuts and olives and potatoes (30).

Table 5 The consumption pattern of a Dutch citizen

						On consumption days			
Food groups based on GloboDiet classification	**Mean g/day**	**P5 g/day**	**Median g/day**	**P95 g/day**	**% Consumption days**	**Mean g/day**	**P5 g/day**	**Median g/day**	**P95 g/day**
01. Potatoes and other tubers	73	0	61	210	49	148	40	140	308
02. Vegetables	127	10	112	299	86	147	23	124	352
03. Legumes	4	0	0	37	4	103	18	96	225
04. Fruits, nuts and seeds, olives	122	0	87	352	66	184	18	151	448
05. Dairy products and substitutes	355	33	316	818	94	378	36	329	887
06. Cereals and cereal products	192	60	178	369	98	196	50	175	415
07. Meat, meat products and substitutes	101	11	90	223	90	112	19	95	274
08. Fish, shellfish and amphibians	15	0	0	87	13	114	13	96	280
09. Eggs and egg products	12	0	0	50	24	51	6	50	131
10. Fats and oils	22	3	19	53	94	24	3	20	58
11. Sugar and confectionery	38	0	27	113	76	50	5	36	143
12. Cakes and sweet biscuits	39	0	30	122	63	63	10	47	176
13. Non-alcoholic beverages	1,725	603	1,626	3,148	100	1,729	542	1,580	3,370
14. Alcoholic beverages	152	0	0	750	30	513	45	330	1,830
15. Condiments, spices, sauces and yeast	37	0	27	109	74	50	4	35	150
16. Soups and stocks	24	0	0	141	13	192	34	180	433
17. Miscellaneous	4	0	0	0	2	258	19	258	515
18. Savoury snacks	20	0	0	88	30	67	10	51	175
19. Ready meals	0	0	0	0	0	234	190	250	250

As can be observed in Table 5 the average intake for the following food categories are:

- Vegetables: 127 g/day
- Fruits nuts and olives : 122 g/day
- Dairy (products): 355 g/day (208 g concern milk and milk beverages, and 33 g cheese
- Cereal (products): 192 g
- Bread (products): 126 g
- Nonalcoholic beverages: 1.7 liter (¾ liter concerns coffee and tea, ~½ liter concerns water and 350 g concerns soft drinks and fruit and vegetable juices)

When it comes to the caloric and energy intake of the Dutch, the United Nations has estimated it to be around 3000 kcal day^{-1} and 105 g protein day^{-1} respectively (31, 32).

[3] Note: Nitrogen and Phosphorus are the main elements that are used in fertilizers for agriculture

2.7 ALTERNATIVE FARMING SYSTEMS

2.7.1 Aquaponics

As a solution to the problems that conventional farming poses (e.g. climate change, pollution, animal disease etc.) there exists the concept of recirculating aquaculture systems (i.e. aquaponics).

Aquaponics is a soilless food production system which combines elements of other food production systems like hydroponics and aquaculture. These type of systems appeared in the 1970's and are currently applied in many urban areas around the globe as a potential response towards unsustainable food production practices. In comparison to conventional food production systems (i.e. agriculture) nutrients are recovered and recycled back into the system. Also, water loss is minimized only to evaporation and spillage. Furthermore, the productivity of the aquaponics system is much higher compared to the conventional agriculture farming because for the same amount of water much more food is produced. Generally, this is how an aquaponics system work (see Figure 14):

1. Food (fish feed) is fed to basins containing fish (aquaculture component)
2. Nutrients (e.g. Phosphorus and Nitrogen) are excreted by the fish (aquaculture component)
3. Aquaculture effluent bacterial component of the system so that the nutrients are ionized through nitrification (biologic), denitrification
4. Finally the effluent containing ionized forms of nitrogen are then assimilated by the plants.

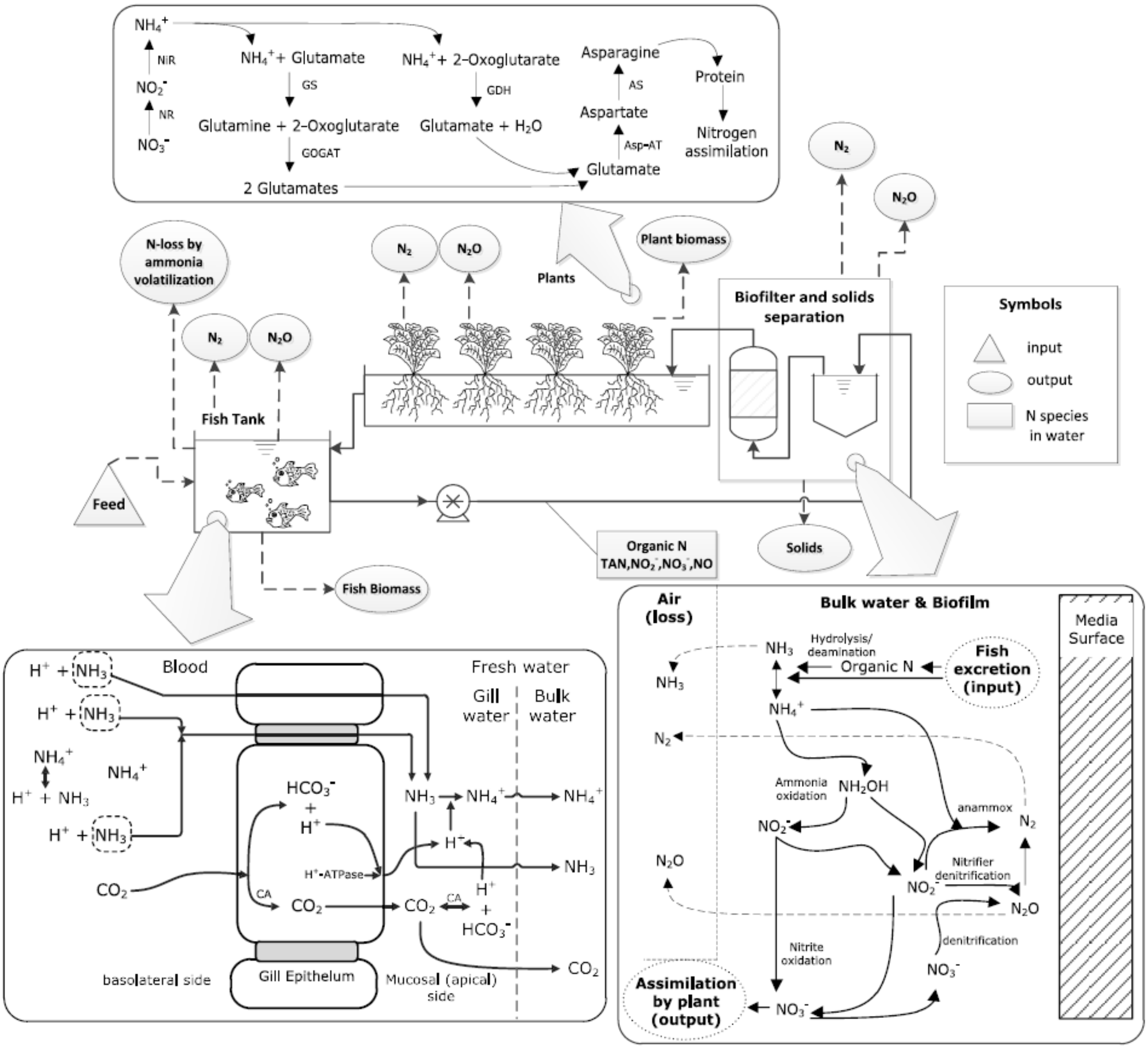

Figure 14 Diagram of a aquaponic system, its underlying components and the subsequent nutrient transformations that take place within the system (33)

In total there exists three types of aquaponics techniques, which are based on the types of growing beds that are used these include: Nutrient Film Technique (NFT), Floating-raft and media-filled systems (see Figure 15)(33, 34).

Generally NFT delivers high levels of oxygen to the plant roots and thus facilitates a high vegetable yield. however, this technique is more suitable for smaller plants, since the grow beds cannot support high root density, since this can block recirculating flow. Amongst all of the different types of aquaponic systems, the floating raft systems is most commonly used. This is because these types of systems allow for the free absorption of nutrients without actually clogging the water channel. Both NFT and floating-raft systems require a biofilter and a sedimentation tank for nitrification and the removal of solids, respectively. In media-filled systems however, biofilters are not required. Because these systems generally contain media (e.g. pumice stones and clay beads) in the growing bed that facilitate nitrification. Although, a siphon is required for the drainage and for the supply of water, so that oxygen can be supplied to plant roots. Also, in media-filled systems, clogging and insufficient oxygen levels commonly occur in long-term operation of aquaponic systems (33).

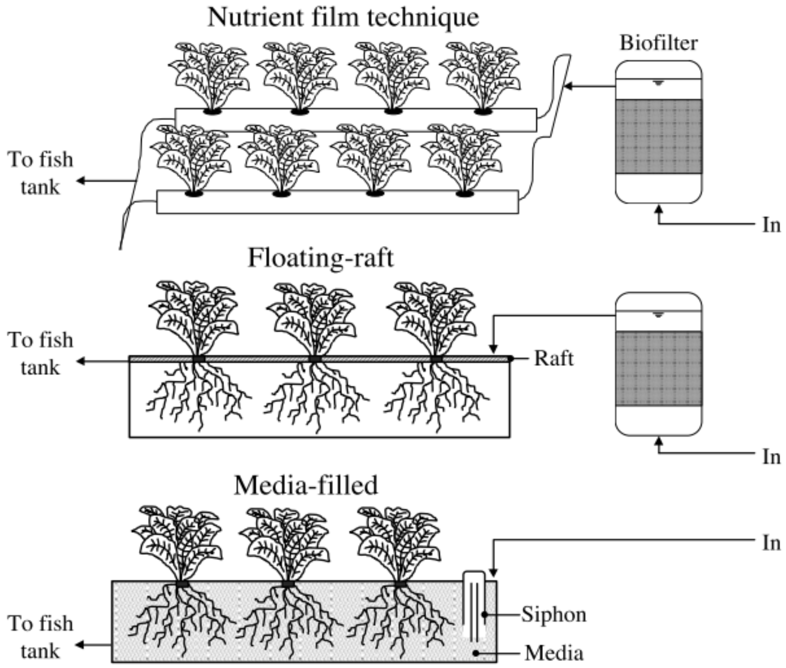

Figure 15 different types of growing beds in aquaponic systems (33)

2.7.2 Insect farming

A recent trend that has been taken place in the realm of food production is the concept of (edible) insect farming. This has come in the wake of global population growth and with that an increasing pressure on food production systems for producing high value proteins. However, conventional protein production also puts a lot of pressure on the global water, energy and carbon resources because of the resource intensity that is required.

Insect farming provides an alternative solution for the production of high value protein because of its perceived low impact. For example, mealworms (*tenebrio molitor)* require significantly less water and food for producing the same quality of proteins, conventionally resourced from animal products (35, 36).

3 METHOD AND DATA

3.1 DATA GATHERING

One of the components of the research project was to gather information about the stakeholders involved in the research project and about their productions systems. This was achieved through multiple company visits and interviews with the stakeholders involved.

3.1.1 FRE2SH

FRE2SH is a subsidiary of Stad van Morgen (S.T.I.R.), which is an institute that recognizes the socio-economic, and environmental challenges that societies (particularly the Netherlands) are facing today. It acknowledges the fact that we need to move away from a society driven by infinite economic growth to a society driven by human and natural values.

The foundation was initiated by Jean Paul close, whom, after becoming aware of the serious vulnerabilities of our human existence decided to do something about it. Therefore he defined two criteria for achieving human sustainable progress: Core human values and shared responsibility. The core human values need to be respected in order to achieve harmony with our surroundings and the way to respect these core values is to have a shared perspective in the context of responsibility, when it comes to interaction between hierarchies of government, business and society. These five core human values include: health, safety, shared resilience, awareness and the fulfillment of human basic needs.

The Food sector is amongst the sectors in which S.T.I.R. operates. S.T.I.R. believes that by producing and consuming food locally many of the problems associated with food production will be reduced. FRE2SH is simply an organic outgrowth out of this premise, it is just a network of likeminded individuals whom all want to contribute in solving the issues related with food. It consists of many individuals, amongst them is Duurzame Kost and Wurmpie Wurmpie. For the sake of the theme of this research, the focus was only on the circular system that the latter stakeholders built.

3.1.2 Duurzame Kost

Duurzame Kost is an institution that applies indoor farming (aquaponics), and was started by Jos Hakkennes. He has a history in agriculture, particularly (intensive) livestock farming, where he was selling infrastructure for maintaining live stock (e.g. ventilation systems, feeding systems, drinking water systems). After working for around 15 years within agriculture he decided to do something else because he saw that farming in the western world (e.g. the Netherlands) was getting more destructive by the day. He saw that agricultural practices where putting pressure on the environment, human health and animal welfare. Farmers generally have to abide to the different market prices when they go about doing their business, this is one of the many wrong incentives that exist today in agribusiness. This is a problem, because a consumer wants to eat, however he does not know where his food comes from. And If a farmer is going to produce food as cheap as possible so that he can compete in the market, the quality of the food will be negatively affected. Furthermore, there are many intermediaries in the food supply chain, each of which are siphoning profit. This puts even more pressure on the farmer, the quality of the product and finally environmental, animal and human health. This is because in order to stay competitive (price wise) farmer utilize many chemicals (e.g. fertilizers, pesticides and herbicides) that in the long run are a detriment to the environment. Also, animals are kept in unsanitary conditions and fed with chemicals as to increase the grow rate of the animal. These chemicals pose risks to human health, not to mention the diseases that spread because of the way the animals are kept. After working for around 2 decades in the care sector working on reintegrating people with disabilities in the job sector, he then started Duurzame Kost. Now he is the director of Duurzame Kost, in which is combining the experiences he had in the agriculture and care sector. By working with people with disabilities so that they can also have work.

3.1.2.1 The Duurzame Kost aquaponics system

According to Jos, aquaponics has the potential form intensive farming, because one can control the growing conditions for plants. Also by producing fish and plants at the same time while considerable reducing the inputs required to produce these things.

Jos system is based on aquaponics which utilizes the floating raft technique. With this system Jos produces vegetables (mainly lettuces) and fish (trout). The system is comprised of the following components:

- 4 basins of 22,5m^3 – these are the basins in which the fish are left to become matured (see Figure 16)
- 1 nursery basin 15m^3– in this basin, new fish are born and nurtured (see Figure 16)
- 3 Biofilters which houses bacteria, used for nitrifying the nitrogen that comes out of the fish thank (see Figure 17)
- 4 grow-out basins 5 m^3 – in these basins the plants (mostly lettuces) (see Figure 18)
- Processing unit – in this unit harvested vegetables are washed and packaged (see Figure 19)
- Storage units – refrigerators used for storing the final products (see Figure 20)

Figure 16 Nursery basins at Duurzame Kost aquaponics system

Figure 17 Biofilters at Duurzame Kost aquaponics system

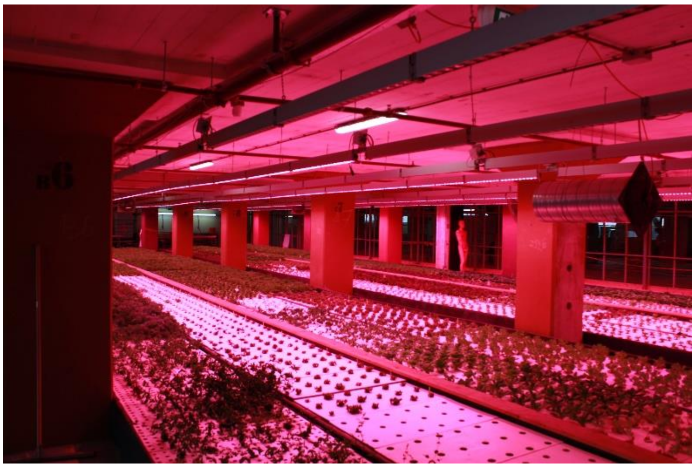

Figure 18 Grow out basins at Duurzame Kost aquaponics system

Figure 19 Processing Unit at Duurzame Kost

Figure 20 refrigeration unit (storage) at Duurzame Kost

3.1.3 Wurmpie Wurmpie

Wurmpie Wurmpie is a commercial venture started by Shasco Laugs that focuses on the production of edible insects, particularly mealworms (*tenebrio molitor*). He got interested into growing worms after he got exposed to this idea through a kickstarter project. When he started to read on the subject he got really interested into growing worms as an alternative source for protein.

He then got in touch with Jean Paul (S.T.I.R. FRE2SH), and then got into contact with the other members of FRE2SH (e.g. Jos Duurzame Kost). They then all put in the resources together to create the area that was going to be used for growing for the worm farming. However, they soon encountered some problems in terms of the leasing the building in which the food production system takes place, so the development of the production system was put on hold for some time. But now things seem a little bit clearer with regard to leasing of the building, so he hopes that they can continue with the work.

Shasco's system consists of the following components:

- Breading unit – in this component the worms are bred and kept until they reach the right age for harvesting (see Figure 21)
- Storage unit – after the worms have reached the age for harvesting, they are stored in a refrigerator (see Figure 22)

Figure 21 Breading unit at Wurmpie Wurmpie worm farm


Figure 22 Storage unit (refrigerator) at Wurmpie Wurmpie worm farm

3.2 Flow Diagram

Out of the data that was gathered by from the two stakeholders, a systems diagram was created in order to illustrate the interconnectivity between the two food production systems (see Figure 23)

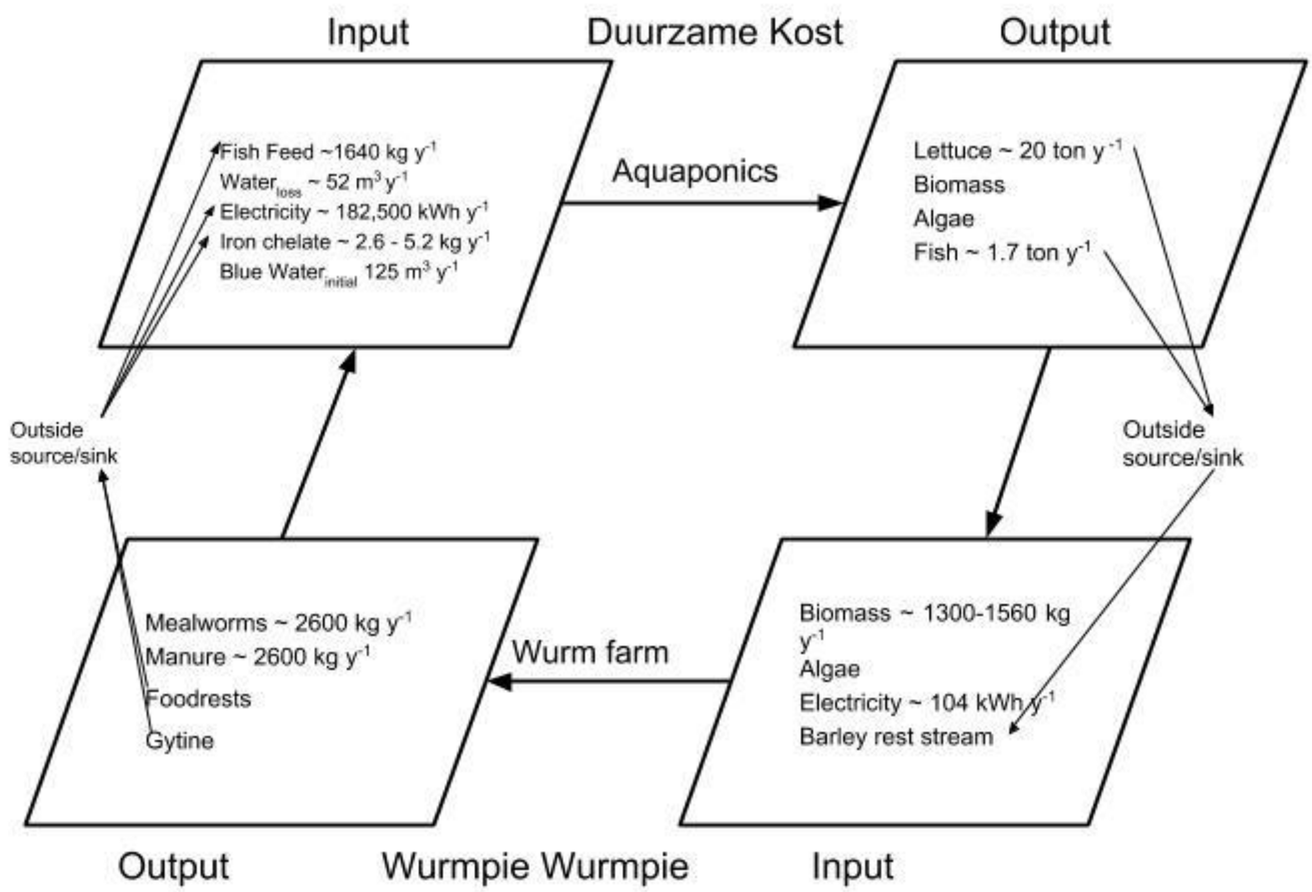

Figure 23 Flow diagram of the aquaponic system and the worm farm

First of all, for the aquaponics system, around: **1640 kg y^{-1}**, **52m^3 w^{-1}** and around **182.5 MWh y^{-1}** of fish feed, added blue water (blue water abstraction) and electricity respectively, enters the system as input. Also, Iron chelate (**2.6-5.2 kg y^{-1}**) is added as a trace element whenever yellow coloring is observed on the leaf of the crops. Iron chelate is generally added as a micronutrient for the plant if deficiencies of iron within the plant occurs.

Second of all, for the worm farm, around **1.3-1.56 ton y^{-1}**, **104 kWh y^{-1}** of biomass and electricity respectively, enter the system as input. Other inputs include algae (waste stream from the aquaponics system) and used barley (waste stream from nearby beer brewery).

Furthermore, the aquaponics system produces around 20 ton y^{-1} of salads and around **1.7 ton y^{-1}** of trout. Next, under optimum conditions the worm farm can produce around **2.6 ton y^{-1}** of mealworms and around **2.6 kg of manure**. The manure consists of undigested and finely composted food rests. Another output of the mealworm farm is the skin of the worm itself (gytine).

3.2.1 Circularity between the two systems

The system as a whole is circular in that the outputs of the aquaponics system e.g. unused biomass (roots of vegetables) are used as input for the worm farm. Conversely, the outputs e.g. worms will be recirculated as input for the aquaponic system. It is important to note that only part of output of the aquaponic system is used as input for the worm farm. However, all of the inputs (excl. electricity) for the worm farm are rest streams from e.g. Duurzame kost or rest streams from other systems (e.g. used barley).

3.2.2 System parameters and boundaries

Based on the availability of data, some boundaries and conditions were considered in order to get a more detailed outcome of the WF for the production process as a whole.

3.2.2.1 System parameters

First of all for the both the aquaponics system and the worm farm, thee parameters were considered. The first one being a parameter under which energy is not accounted for in the accounting of WF. The reason for doing this is to maintain homogeneity in WF accounting between the FRE2SH food production system and the conventional food production system which this study utilizes (6). Next, the second parameter is one under which the energy consumption is accounted for, and it is assumed that the energy is coal based (37). This is because, according to the WF assessment method, all the WF of all inputs have to be accounted for, and in the FRE2SH system electricity is a major source. Furthermore, the majority of energy that is consumed within the produced within the Netherlands (around 80%) is sourced from fossil fuels (37). The final parameter is one under which the energy source accounted for is sourced from a renewable energy source (wind). In the context of sustainability, it is interesting to see what will happen to the WF of FRE2SH is sourced from a renewable energy source.

Second of all, two other parameters were attributed to the output of the worm farm namely conservative and optimum. Under the conservative parameter the ratio between the worms and manure was considered to be 1:1 (output) and in the optimum condition the ratio was considered to be 3:2. What this means is that under the conservative parameter, the output is considered to be 50% mealworms and 50% manure. Conversely, under the optimum parameter, the output is considered to be 60% mealworms and 40% manure. Also, energy consumption is 0.08 kwh kg^{-1} w^{-1} in the conservative condition and 0.1 kwh kg^{-1} w^{-1} in the optimum condition. These assumptions are based on operational conditions of the worm farm itself and where estimated by the founder.

3.2.2.2 System boundaries

The inputs and outputs that were considered are displayed in Table 6. On one side, when looking at the aquaponics system (Duurzame Kost) the following inputs were considered: fish feed, energy (in the form of electricity), blue water abstraction and blue water loss. Blue water abstraction referrers to the initial volume of water that is obtained from the grid in order to start the project. Also, blue water loss refers to the water that is lost as a result of spillage. This water needs to be refilled every week and is thus abstracted from the grid. Conversely, the outputs considered were fish and lettuce. On the other side, when looking at the worm farm (Wurmpie Wurmpie) the inputs and outputs that were considered included energy (electricity) and mealworms respectively.

One compound that is also used in the aquaponic system is Iron chelate. This was not taken into account because next to it being only used in trace amounts (between 50-100 g w^{-1} or between 0.0025-0.05 g kg^{-1} of lettuce). There was no sufficient data available in the literature on the WF of chemicals like iron chelate. Generally, iron chelate is utilized as a nutrient source for iron and is only added when/if the crops start to turn yellow. Therefore, leaving iron chelate out of the equation will have miniscule to no effect on the total WF because of the fact that is only used in trace amounts. Furthermore, leaving this compound out of the equation will not have an influence when comparing the WF of FRE2SH to that of the conventional system. Because Iron as a trace element was not considered in the WF assessment of conventional agriculture In the Netherlands (6).

Next, only fish and lettuce were considered as output components for the calculation of the WF. This because first of all, the number of algae that is reused is not known by the system managers because it's about very small units of mass. Second of all, according to the literature in systems that reuse their waste streams (6). The WF (e.g. blue, grey and green) of the reused waste streams should not be counted in, this to prevent double accounting when analyzing the WF account. Therefore, the WF of the reused outputs (e.g. biomass, barley and algae) of the aquaponics systems are not considered during the process of WF accounting (19).

Table 6 Inputs and outputs of the FRE2SH food production network

Duurzame Kost	
Inputs	Value (unit)
Fish feed	1640 kg y^{-1}
Energy (electricity, coal/wind)	182.5 MWh y^{-1}
Blue water abstraction (blue water loss)	52 m^3 y^{-1}
Blue water abstraction (initial)	125 m^3 y^{-1}
Outputs	
Fish (Rainbow Trout, *Oncorhynchus mykiss*)	1.7 ton y^{-1}
Lettuce	20 ton y^{-1}
Wurmpie Wurmpie	
Inputs	Value (unit)
Energy (electricity, coal/wind)	104 kWh y^{-1}
Outputs	
Mealworms (*Tenebrio molitor*, conservative)	1.3 ton y^{-1}
Mealworms (*Tenebrio molitor*, optimum)	1,56 ton y^{-1}

3.3 WATER FOOTPRINT ACCOUNTS

In order to determine the WF of a crop (e.g. lettuce), a product (e.g. mealworms and trout) or a system (e.g. FRE2SH production process) certain methods of WF accounting were considered. There are different types of contexts when it comes to WF accounting. The ones that have been considered in this study are the following:

- WF of a process (e.g. evaporation, evapotranspiration and blue water abstraction and blue water incorporation) – this points out to the WF of the process or processes of growing lettuce crops.
- WF of a product - this refers to the WF of the different products that are produced in the system as whole (e.g. lettuce, fish and mealworms). Usually this is estimated by summing up the individual WF of the processes that were considered in the production cycle of a crop or product.
- WF of FRE2SH food production process - this refers to total WF of the FRE2SH food production process. Basically, what this presents is the summation of the total WF of all of the products produced in the FRE2SH food production process
- WF of a consumer - Generally, this is estimated by summing up the WF of all of the products consumed by an individual.

3.3.1 Scenarios and boundaries

Based on the availability of data and the goals of the project. The following scenarios and parameters were considered in order to convey results of the WF from different perspectives.

3.3.1.1 Scenarios

Two scenarios were created, and these were based on the goals of the research project. Each scenario also had the same system parameters (e.g. aquaponics and worm farm), mentioned in paragraph 3.2.2, attributed to them.

Firstly, one scenario, denoted by S1 was created based on the research question: what will happen to the total WF of the Dutch consumer if all of the vegetables (e.g. lettuce) and fish that they consume, were to be replaced by fish and vegetables (lettuce) produced by FRE2SH? Furthermore, S1 was split into nine (sub) scenarios (e.g. S1P1-S1P9) based on the system parameters discussed in (section 3.2.2) (see Table 7). Next to the system parameters, three other parameters where considered e.g. accounted, halved and unaccounted. These parameters were not based on system processes, instead they were based on WF accounting. Since the system is circular in the sense that the worms are partly used to feed the fish. It becomes imperative to test what will happen to the total WF of the production system if all, half or none of the fish feed were to be replaced with worms. Therefore, in order to test this, the parameters (e.g. accounted, halved and unaccounted) for WF accounting were considered. The "accounted" parameter refers to a situation in which all of the WF of the fish feed is being accounted for. Next, the "halved" parameter refers to a situation in which 50 % of the WF is accounted for. Also, the "unaccounted" parameter refers to a situation in which the WF of the fish feed is completely excluded from the WF account.

Secondly, the second scenario (S2) was based on the research question; what would happen to the total WF of a Dutch consumer if they source their total energy intake (kcal cap^{-1} y^{-1}) and total protein intake (g protein cap^{-1} y^{-1}) was replaced with FRE2SH products? Just like how S1 was subdivided into in nine (sub) scenarios. Scenario 2 was also subdivided into nine (sub) scenarios. Next to applying the same parameters for S2 as was done in S1, two additional parameters were considered (e.g. conservative, optimum) , based on the system parameters discussed in the second paragraph of (section 3.2.2) (see Table 7).

Table 7 Scenarios and parameters that were considered for the estimation of the water footprint

1. What would happen to the WF of a Dutch consumer if all the fish and vegetables he/she consumes is sourced from the products produced by FRE2SH?		
Scenario	Parameters	Description
S1P1	Coal Accounted	Energy is coal based, fish feed is completely taken into WF account
S1P2	Coal Halved	Energy is coal based, half of fish feed is taken into WF account
S1P3	Coal, Unaccounted	Energy is coal based, fish feed is not taken into WF account
S1P4	Wind Accounted	Energy is wind based, fish feed is completely taken into WF account
S1P5	Wind Halved	Energy is wind based, half of fish feed is taken into WF account
S1P6	Wind, Unaccounted	Energy is wind based, fish feed is not taken into WF account
S1P7	None Accounted	Energy is not taken into WF account, fish feed is completely taken into WF account
S1P8	None Halved	Energy is not taken into WF account, half of fish feed is taken into account
S1P9	None, Unaccounted	Energy is not taken into WF account, fish feed is not taken into account
What would happen to the WF of a Dutch consumer if the calories and protein he/she consumes per day were to be completely sourced by FRE2SH?		
S2P1	Coal, Conservative, Accounted	Energy is coal based, conservative worm farm conditions, fish feed is completely taken into WF account
S2P2	Coal, Conservative, Halved	Energy is coal based, conservative worm farm conditions, half of fish feed is taken into WF account
S2P3	Coal, Conservative, Unaccounted	Energy is coal based, conservative worm farm conditions, fish feed is not taken into WF account

S2P4	Wind, Conservative, Accounted	Energy is wind based, conservative worm farm conditions, fish feed is completely accounted for in WF account
S2P5	Wind, Conservative, Halved	Energy is wind based, conservative worm farm conditions, half of fish feed is taken into WF account
S2P6	Wind, Conservative, Unaccounted	Energy is wind based, conservative worm farm conditions, fish feed is not taken into WF account
S2P7	None, Conservative, Accounted	Energy is not taken into WF account, conservative worm farm conditions, fish feed is completely accounted for in WF account
S2P8	None, Conservative, Halved	Energy is not taken into WF account, conservative worm farm conditions, half of fish feed is taken into WF account
S2P9	None, Conservative, Unaccounted	Energy is not taken into WF account, conservative worm farm conditions, fish feed is not taken into WF account
S2P10	Coal, Optimum, Accounted	Energy is coal based, optimum worm farm conditions, fish feed is completely taken into WF account
S2P11	Coal, Optimum, Halved	Energy is coal based, optimum worm farm conditions, half of fish feed is taken into WF account
S2P12	Coal, Optimum, Unaccounted	Energy is coal based, optimum worm farm conditions, fish feed is not taken into WF account
S2P13	Wind, Optimum, Accounted	Energy is wind based, optimum worm farm conditions, fish feed is completely accounted for in WF account
S2P14	Wind, Optimum, Halved	Energy is wind based, optimum worm farm conditions, half of fish feed is taken into WF account
S2P15	Wind, Optimum, Unaccounted	Energy is wind based, optimum worm farm conditions, fish feed is not taken into WF account
S2P16	None, Optimum, Accounted	Energy is not taken into WF account, optimum worm farm conditions, fish feed is completely accounted for in WF account
S2P17	None, Optimum, Halved	Energy is not taken into WF account, optimum worm farm conditions, half of fish feed is taken into WF account

S2P18	None, Optimum, Unaccounted	Energy is not taken into WF account, optimum worm farm conditions, fish feed is not taken into WF account

3.3.1.2 Boundaries

First of all, the total WF of the Dutch consumer was not calculated rather it was retrieved from the literature and used as a reference value (see Table 9)(see 3.5.2). Past studies have determined the internal and the external WF of a Dutch consumers and as well the WF of crops like lettuce and the production of energy (6, 38, 39). Data on the consumption patterns was also based on literature findings (30). Third, data on total energy intake were based on literature findings from the same period as the data on the total WF of Dutch consumer.

3.4 WATER FOOTPRINT QUANTIFICATION

The calculations of all of the water footprints in the FRE2SH were estimated by applying the calculation framework, the WFN method (see 2.2.5) developed by Prof. Arjen Y. Hoekstra and his colleagues (19). It was decided to use the WFN method for the calculation of the WF because of the goal of the project. The goal of the project is to estimate the WF of the FRE2SH food production system so that this could be used for further analysis of the Dutch WF. In order to achieve this goal, the WF only needs to be calculated and no new impact assessment needs to be done to achieve this, not on global level and definitely on the local level. Therefore, it does not matter if the WF calculation method of the WFN or the WF calculation method of the LCA community was to be utilized. If the goal was to do an impact assessment on a local level with regard to the WF of the Dutch citizen, the LCA method would be more applicable. However, this was not the case. Plus, a W assessment was already undergone in the study utilized for this research project (19). This study also applied the WFN method, and thus it's only fitting to also use the same method to calculate the WF of the FRE2SH, so that homogeneity can be maintained when undergoing the comparative analysis.

3.4.1 Calculating the water footprint

For estimating the WF of the different products (e.g. lettuce, trout and mealworms) that are produced in the FRE2SH food production network. There are general equations that were repeatedly applied in the process of calculating the WF for each of the products. These equations are need for calculating the following; the WF of the growing process of a crop (e.g. evapotranspiration), the WF of product, the water incorporated into a product or crop, the WF related to energy consumption (e.g. electricity) and finally blue water abstraction.

Firstly, there is the WF of the growing process of a crop. Usually this refers to the evapotranspiration that took place during the growth of the crop. For calculating the evapotranspiration of a crop, the following equation is used:

$$WF_{proc} = WF_{proc,\,green} + WFproc_{,\,blue} + WF_{proc,\,grey} \quad [\text{volume/mass}] \qquad (1)$$

WF_{proc} (m^3/ton) refers to the total WF of the process (evapotranspiration) of a growing crop. Next, the $WF_{proc,\,green}$,$WF_{proc,\,blue}$ and $WF_{proc,\,grey}$ refers to the green, blue and grey component of the total WF. According to the A.Y. Hoekstra, the grey and green WF should not be considered if there is no use of green water taking place and if there is treatment and reuse of wastewater taking place (19). This is exactly in the case of the FRE2SH system, therefore the total WF of a process of a growing crop becomes $WF_{proc} = WF_{proc,\,blue}$.

$$WF_{proc,\,blue} = CWU_{blue} / Y \quad [\text{volume/mass}] \qquad (2)$$

The blue component of the WF of the process of a growing crop or tree is computed by dividing the crop water use (CWU_{blue}, m³/ha) by the yield (Y, kg/Ha) of that crop. Furthermore, the crop water use is calculated as the accumulation of the daily evapotranspiration over the complete growing period see the following equation.

$$CWU_{blue} = 10 \text{ x } \sum_{d=1}^{lgp} ET_{blue} \text{ [volume/area]} \quad (3)$$

In equation 3, CWU_{blue} (m³/ha) refers to the total irrigation water that has evaporated from the field. ET_{blue} (mm/day) represents the blue water evapotranspiration and the factor 10 is used to convert the water depth in mm into volume per land surface area (m³/ha). The summation is done from the day of plating (d=1) to the day of harvest. Thus, lgp stands for the length of the growing period. Evapotranspiration can either be measured or estimated by using a model that is based on empirical formulas. Usually measuring is more costly, but there also exist models (e.g. CROPWAT, EPIC) that can be used to generate accurate estimates of evapotranspiration. These models use data on climate, soil properties and crop characteristics as input for estimating evapotranspiration.

In this research, ET_{blue} was estimated using CROPWAT and the CLIMWAT model created by the FAO (25, 26). There are different options that can be used on the model for e.g. "the crop water requirement option" (CWR) and "the irrigation schedule option". The former option assumes that the conditions in which the crop in question is grown (temperature, humidity etc.) are optimal. While, this option requires less is easier to apply, it is less accurate in that it does not include (dynamic) data in soil water balance. Conversely, "the irrigation schedule" option allows for the inclusion of the data mentioned beforehand. Thus, it allows for more accurate estimates for both optimal and non-optimal conditions. However this option has a higher difficulty level in terms using it since it requires more data as input. For this research the CWR option was chosen with the data in Table 8. K_c refers to a coefficient that incorporates the crop characteristics that distinguish field crops from grass. This crop coefficient varies over the length of the growing period of the crop. Thus K_c ini refers to the crop coefficient at the initial stage of the crop, K_c mid, the mid stage and K_c end the final growing stage of the crop. The data on rain was acquired from the FAO website, the crop parameters where taken gathered from the literature (14). Also, data on climate was obtained from the ClIMWAT climate database (40). Basically, CLIMWAT is a database of meteorological stations that store climate data from measured in many regions of the world.

Table 8 crop parameters that were used in the CROPWAT model

Crop	Crop parameters							
	Kc ini	Kc mid	Kc end	Initial stage	Dev stage	Mid Stage	Late stage	Planting date
Lettuce	0.70	1.00	0.95	35.00	50.00	45.00	10.00	15-Feb

CWR option was chosen because it was more relevant for this particular situation. For example, Duurzame Kost uses Led lighting in order to mimic an optimum (constant) growing environment for crops. Therefore, choosing this option will probably produce more conservative results. Because the bio-physiological characteristics are optimum, since the growing medium is water and the roots of the plant are more frequently exposed to the nutrients in the water. Furthermore, there is a constant and consistent water level maintained in the aquaponic system. These conditions rarely occur in a constant or consistent manner in the natural environment.

The CWR options estimates the crop evapotranspiration (ET_c) by applying the following equation:

$$ET_c = K_c \times ET_0 \text{ [length/time]} \quad (4)$$

here K_c refers to the crop coefficient, which incorporates characteristics of the crop and the averaged effect of evaporation from the soil. ET_0 refers to the reference evapotranspiration conveyed from a hypothetical grass reference crop that is not short of water. Et $_{blue}$ was calculated by adding the (model) output of the equation 4 over the periods in which the ET_c is estimated.

Secondly, for the estimation of the WF of the products that are produced in in FRE2SH (e.g. lettuce, trout and mealworms). The chain summation approach, developed by A. Y. Hoestra and Mekonnen was used (6). In this approach, the WF of the input products that were necessary in the last processing step for producing that product and the addition of the process WF for that processing step. This chain summation approach is expressed with the following equation:

$$WF_{prod}[p] = \left(WF_{prod}[p] + \sum_{i=1}^{y} \frac{WF_{prod[i]}}{f_{p[p,i]}}\right) \text{ [volume/mass]} \quad (5)$$

In this equation WF_{prod} [p] refers to total WF of output product [p]. The WF_{prod}[i] refers to the WF of the input product *i*. Furthermore, WF_{proc}[p] is the WF of the processing step that transforms y input products into *z* output products. Next, f_p[p,i] refers to the so called product fraction while parameter f_v[p,i] refers to the value fraction. Essentially the parameter f_v[p,i] (mass/mass) is the product fraction of an output product *p* that is processed from an input product *i*. It is defined as the quantity of the output product (w[p], mass) that is acquired per amount of input (w[i], mass) (see equation 6).

$$f_p[p,i] = \frac{W[p]}{W[i]} \text{ [-]} \quad (6)$$

The value fraction is obtained almost the same way as the product fraction however the only thing that changes is that the quantity of the output and input products is multiplied by their respective monetary value.

Thirdly, Incorporation refers water content of the product (virtual water) and was acquired by multiplying the water content of the product in question with its total yield.

Next, the WF of the amount of energy that is consumed refers to the amount of water that is required producing a unit of energy. This was estimated by taking a reference value for the total water consumption for a unit energy produced in Europe. Afterwards, this value was be multiplied with the total energy used for each process in the production facility and divided by the total amount of products produced for in that particular process.

Finally there is blue water abstraction, this is defined as the amount of water that enters the aquaponic system to make up for the loss of water through evaporation. In this particular case the total blue water abstraction is around $1 m^3 w^{-1}$. The share of the water that enters the aquaponic system is calculated by multiplying the share of the product group with water abstraction value.

3.4.1.1 Boundaries

In estimating CWU_{blue} the area was converted from ha to m^2 by looking at the total area of the growing space in FRE2SH. This was a conservative choice since the actual growing space of just the aquaponics system is much smaller than the total area of the floor in which the growing space resides. The component $f_{v,}[p]$ in equation 5 was not utilized since this study does not focus on the economic aspect of the system.

3.4.2 Water footprint lettuce

First of all, for estimating the WF of lettuce the following formula was used:

$$WF_{lettuce} = WF_{lettuce,evaporation} + WF_{incorporation} + WF_{lettuce,energy} + WF_{bwa,lettuce} \quad (7)$$

$WF_{lettuce}$ (l/kg^{-1}) refers to the total WF that is attributed to the growth of a kilogram of lettuce in the aquaponics system. With $WF_{lettuce,\ evaporation}$ ($l\ kg^{-1}$) representing the process WF that is attributed to growing a kilogram of lettuce, $WF_{incorporation}$ ($l\ kg^{-1}$) referring to the water that is incorporated into the lettuce. Furthermore, $WF_{lettuce,energy}$ (l/kg^{-1}) the total WF of the energy that is required to produce a kilogram of lettuce. Finally, $WF_{lettuce,\ abstraction}$ (l/kg^{-1}) refers to the share of the total blue water that is abstracted so that one kilogram can be used. $WF_{lettuce,\ abstraction}$ was calculated by multiplying the total blue water that is abstracted in a whole year, with a factor that represents the share of lettuce in the context of the total food supply (lettuce and fish).

Secondly, alongside just the WF of lettuce, the WF per unit of nutritional value (e.g. kilocalories and protein) was also calculated. This was achieved by dividing the estimated WF of the crop with the nutrient content (e.g. kcal kg^{-1} and g kg^{-1} protein) pertaining to lettuce.

3.4.2.1 Boundaries

Nutrient content values were retrieved from the literature (see Table 9).

3.4.3 Water footprint of trout

In the case of the fish that is produced in the aquaponic system, the following equation was applied for calculating the WF of the fish:

$$WF_{trout} = \left(WF_{trout,\ evapotranspiration} + \frac{WF_{fishfeed}}{F_p}\right) + WF_{trout,\ energy} + WF_{bwa,\ trout} \quad (8)$$

With WF_{trout} ($l\ kg^{-1}$) referring to the total WF that is attributed to the production of one kilogram of trout. Next, $WF_{trout,\ evaporation}$ ($l\ kg^{-1}$) refers to the share of water evaporation that is attributed to producing one kilogram of trout. Also, $WF_{fish\ feed}$ ($l\ kg^{-1}$) pertains to the WF of the feed that is consumed in order to produce one kilogram of trout. Furthermore, WF_{energy} ($l\ kg^{-1}$) pertains to the WF of the energy that is required to produce one kilogram of fish. Finally, $WF_{bwa,\ trout}$ ($l\ kg^{-1}$) refers to the share of the blue water abstraction that is attributed to the production of one kilogram of fish.

3.4.3.1 Boundaries

The share of water evaporation attributed to producing trout is based on the mass percentage of trout within the context of all food produced. Since there are no measuring devices for measuring the evaporation that occurs on the growing basins of the fish.

3.4.4 Water footprint of mealworms

For calculating the WF of the mealworms equation (9) was used. In this equation

$$WF_{mealwoms} = WF_{mealworm,\ incorporation} + WF_{mealworm,\ energy} \quad (9)$$

$WF_{mealworms}$ ($l\ kg^{-1}$) refers to the total WF that is attributed to the production of one kilogram of mealworm. $WF_{mealwrom,\ incorporation}$ pertain to the water content of a mealworm ($l\ kg^{-1}$). Also, $WF_{mealworm,\ energy}$ refers to the WF that is attributed to the energy that is required to produce one kilogram of mealworms.

3.5 COMPARATIVE ANALYSIS

After the calculation of the WF of the FRE2SH production system was done, a comparative analysis was done in order to see what would happen to the WF of the Dutch if they would source their food or energy intake from the FRE2SH food production system. Also, the WF of lettuce produced by FRE2SH was compared to the WF produced in conventional farming. Furthermore, the WF of the most common animal products (e.g. beef, chicken, egg and milk) unit of nutritional value (l g protein^{-1}) was compared with the WF of all of products (e.g. fish, mealworms, lettuce) per unit of nutritional value (l g protein^{-1}).

First of all, in order to complete the comparison of the first research question; *What would happen to the WF of a Dutch consumer if all the fish and vegetables he/she consumes is sourced from the products produced by FRE2SH?* the following steps were taken:

1. Determine the WF of fish and vegetables of the Dutch using the reference value found in the literature (see Table 9). The reference value of the WF of the Dutch was taken from the study on the external WF of the Dutch (6).
2. Replace WF of fish and vegetables (m^3/cap/y), estimated from the reference (WF) value and based on the diet pattern of the Dutch, with the WF of fish and lettuce produced by FRE2SH.
3. Calculate the difference in total WF (m^3/cap/y) that occurs.

Secondly, for completing the second research question; *What would happen to the WF of a Dutch consumer if the calories and protein he/she consumes per day were to be completely sourced by FRE2SH?* the following steps were taken.

1. Convert the reference value for the Dutch dietary energy and protein intake (e.g. kcal cap^{-1} y^{-1} , g protein cap^{-1} y^{-1}) into WF per unit of nutritional value calories and protein respectively (e.g. l kcal^{-1}, l g protein^{-1}) (see Table 9). This was achieved by dividing the reference WF of the Dutch (e.g. m^3/cap/y) by the reference dietary and protein intake of the Dutch and then conveying in liters instead of cubic meters (see Appendix I).
2. Calculate the difference of by subtracting the calculated WF per nutritional value calories and protein in step 1, from the WF calculated in the quantification process in each of the scenarios displayed in Table 7

Finally, for comparing the WF of the lettuce produced in the conventional system with the WF produced within the FRE2SH production system. The WF of FRE2SH lettuce was taken as a division of the WF of lettuce produced in the conventional system. Furthermore, the latter was repeated, in the case of comparing the WF per unit of nutritional value protein of animal products from the conventional system with the WF per unit of nutritional value protein from FRE2SH products.

3.5.1 Boundaries

- The reference values that were used in the answering the research questions and in comparing the WF of lettuce and WF per unit value of protein were based on literature findings (see Table 9).
- It was assumed that food categories vegetables and fish and amphibians of the Dutch diet were just comprised of lettuce and trout (rainbow trout) respectively.

Table 9 Reference values used for further calculations

Parameter	Value (unit)	Reference
Average water content of Mealworms	5.00 %	(41)
Average water content of trout	77.82 %	(43)
Average water content of lettuce	95.63 %	(42)
Mass fraction of Trout	7.83 %	Interview data
Mass fraction of Lettuce	92.17 %	Interview data
WF lettuce	240 l kg^{-1}	(38)
Total WF Trout feed	1500 m^3 ton^{-1}	(44)
WF of energy production in Europe (Coal)	2100 m^3 Tje^{-1}	(39)
WF of energy production in Europe (Wind)	12 m^3 Tje^{-1}	(39)
Calorific value of Lettuce	150 kcal kg^{-1}	(45)
Calorific Value of Mealworms	2230 kcal kg^{-1}	(46)
Calorific Value of Trout	1410 kcal kg^{-1}	(47)
Nutrient Value of Lettuce	14 g protein kg^{-1}	(45)
Nutrient Value of Mealworms	530 g protein kg^{-1}	(46)
Nutrient Value of Trout	209 g protein kg^{-1}	(47)
Total WF Dutch consumer	1541 m^3 cap^{-1} d^{-1}	(6)
Average daily caloric intake Dutch consumer	3000 kcal cap^{-1} d^{-1}	(32)
Average daily protein intake Dutch consumer	105 g protein cap^{-1} d^{-1}	(31)

3.5.2 Comments on boundaries between conventional food production system and FRE2SH

As part of the comparative analysis, in which the two research questions will be answered, a study has been chosen as a background, a frame of reference so to speak. This study was chosen based on the availability of data with regards to the WF of a Dutch consumer (6). For the sake of the comparative analysis there has to be a level of homogeneity with regards to parameters of considered in both the FRE2SH food production system and the system utilizing conventional agriculture. It is in this light that the boundaries and method of the chosen study is analyzed in this section.

Method and boundaries for determining the water footprint of the Netherlands

The study mentioned above was amongst the first and only studies out there that quantified the actual (total) external WF of the Netherlands. Furthermore, the 2008 study, was based on methodology of a 2005 study. Which was one of the first studies quantified the real water appropriation of major economic powers of the world (incl. the Netherlands). Continuing, the method used for estimating the water footprints in the 2005 study, was based on the first ever method developed for calculating WF, which was applied in a 2002 study done by the same authors. Also, the objective of this study was:

> *"To quantify the virtual water trade flows between nations in the period 1995 – 1999 and to put the virtual water trade balances of nations within the context of national water needs and water availability."*

Firs of all, in the approach of this 2002 study the international crop trade flows (ton y^{-1}) were multiplied by their associated virtual water content (m^3 ton^{-1}). The data on crop trade was obtained from the United nations statistic division in New York. Furthermore, the data on virtual water content of the different crops that are traded was based on FAO databases (CropWat, ClimWat, FAOSTAT). Also, there was no mention of boundaries that were considered in the light of what type of agriculture was used (28).

Secondly in the 2005 study, the method used in the 2002 was worked out further and concepts like virtual water flow (virtual water import, virtual water export) and virtual water content where evolved into concepts of WF (e.g. internal, external). The Major difference between the two studies was the research period. Hence, data was utilized from the period between 1997 – 2001. Furthermore some insights were given on the scope in terms of agricultural water use. This included both part of irritation water used effectively for crop production and effective rainfall. Also, they did not include water lost in irrigation, instead the assumption was made that water lost in irrigation returned to the resource, thus it could be reused. Next, the data they used for domestic water use was retrieved from FAO's AQUASTAT (14).

Finally, the 2008 study is one of the most recent in terms of determining the external WF of the Netherlands. Even though this report was based on the same methodological principals that were applied and expanded upon from the 2002 and 2005 study, there were still some differences. One of which was the period of study, it was chosen to focus on a 10 year period (1995-2005) based on the available date. Another difference was that instead of just using one method of calculation (the top-down approach) another one was also applied mainly the bottom-up approach in WF accounting. The final outcome of the WF, in the top-down approach, depends on the quality of trade data. While the outcome of the WF, in the bottom-up approach depends on the quality of consumption data. Generally, both approaches will yield the same outcome. However, if there are slight errors in either of respective data bases (e.g. water consumption data and trade data), the final outcomes of the approaches will be affected. Both approaches where used to calculate the WF for agricultural and industrial products. However, only the results of the bottom-up approach where used for further assessment. Another major difference was that the study included impact assessment, which also was one of the first ones of its time. When it came to data sources, most of the data was from United Nations institutions (see Table 10) (6).

Table 10 Sources of input variables in the 2008 study

Input variable	Source
Agricultural water use	
• Crop water requirement per crop per country	Hoekstra & Chapagain (2008)
• Agricultural yield per crop per country	FAOSTAT (FAO, 2007b)
• Livestock feed composition in the Netherlands	CBS (2007), Elferink et al. (2007), LEI (2007) PDV (2005)
• Livestock feed composition in other countries	Hoekstra & Chapagain (2008)
• Consumption per product	FAO's food balance sheets, which are part of FAOSTAT (FAO, 2007b); data available for 1996-2003; average for this period assumed for 2004-05.
• Agricultural production	FAO PRODSTAT (FAO, 2007b)
• Use of fertilizer for important crops in hotspots	FAO FERTISTAT (FAO, 2007c)
Domestic water use	
• Domestic water withdrawal in the Netherlands	AQUASTAT (FAO, 2007a); Vitens (2008)
Industrial water use	
• Industrial water withdrawal per country	AQUASTAT (FAO, 2007a)
• Added value in the industrial sector per country	UN Statistic Division (2007)
Import and export of agricultural and industrial products	ITC (2006)
Precipitation and renewable water resources per country	AQUASTAT (FAO, 2007a)

4 Results

4.1 Water footprint FRESH products

4.1.1 Water footprint of lettuce

First of all results showed that lettuce had a WF of roughly 16.54 l kg^{-1} un the parameter in which coal was the main source of energy (see Figure 24). For the situation in which wind energy was the main source of energy, the WF was around 16.51 l kg^{-1} (see Figure 24). Furthermore, in the situation in which the WF attributed to energy consumption was not accounted at all, the situation results remained relatively unchanged (see Figure 24).

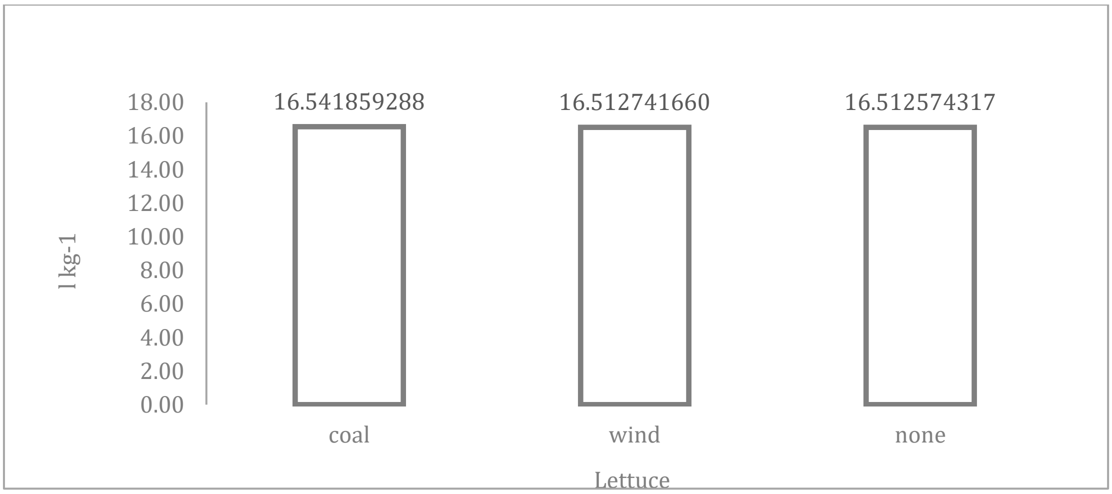

Figure 24 Water footprint FRE2SH lettuce

Secondly, in the case of the WF per unit of nutritional value calories, the results showed that under the parameter in which coal was the main source of energy, the WF amounted to around 0.11 l $kcal^{-1}$ (see Figure 25). In the case 'wind' and 'none' parameter, the outcome for the WF was around the same. However a very small difference between WF results of the two parameters was observed (see Figure 25).

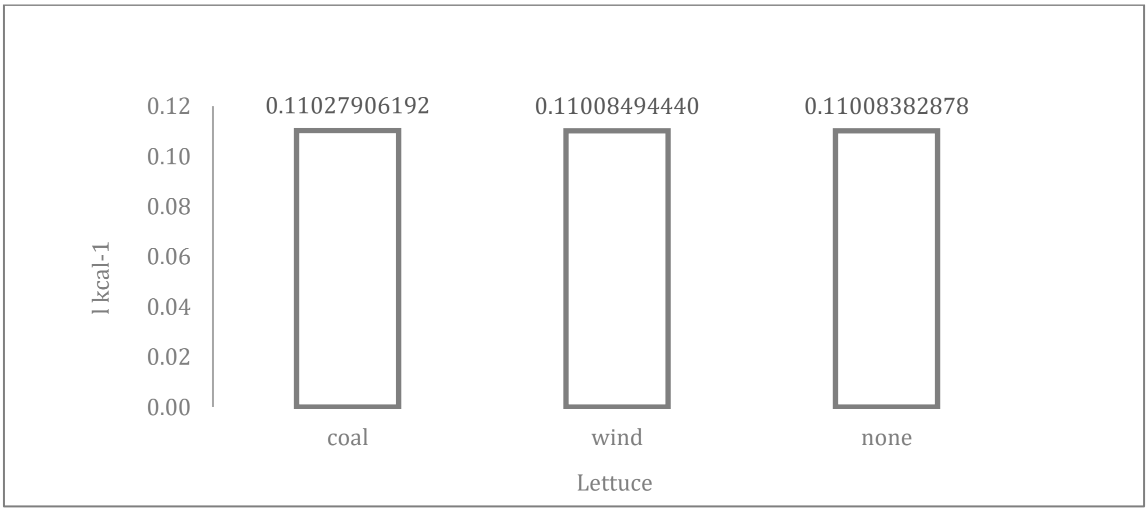

Figure 25 Water footprint per unit of nutritional value calorie FRE2SH lettuce

Finally, in the case of the WF per unit of nutritional value protein. The results showed that the WF was around 1.18 l g $protein^{-1}$, under the coal parameter (see Figure 26). Under the 'wind' parameter, the WF was also around 1.18 l g protein^{-1} when rounded off to the 2nd decimal point (see Figure 26). Furthermore, the same is to be said about the WF of lettuce under the 'none' parameter.

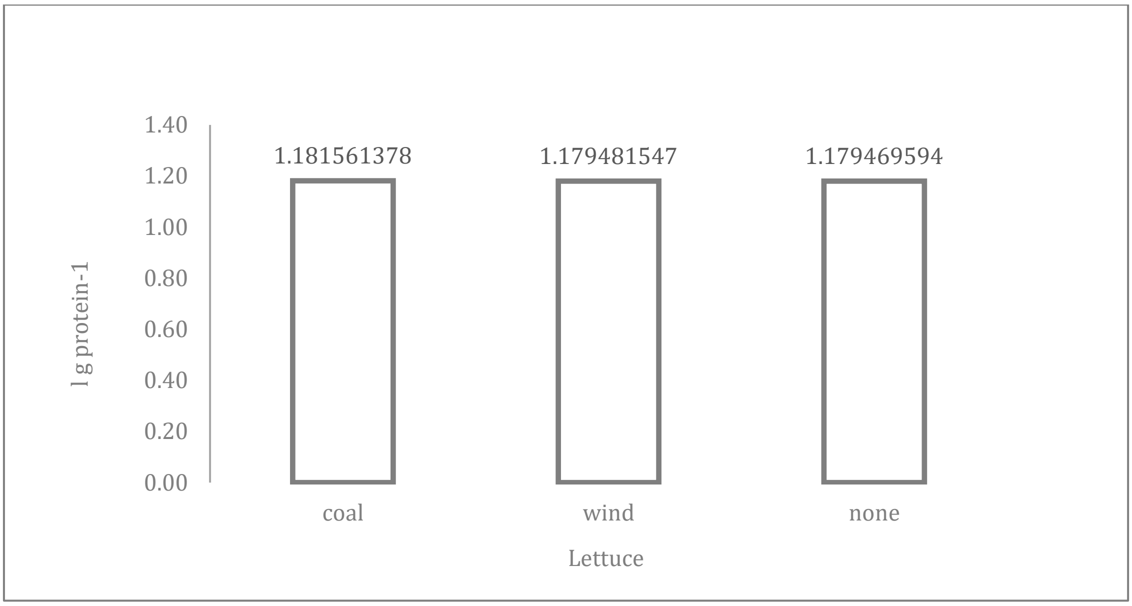

Figure 26 Water footprint per unit of nutritional value protein FRE2SH lettuce

4.1.2 Water footprint trout

First of all, for the WF of trout, under the parameter in which the total WF of the fish feed was accounted for, the WF was roughly 1552 l kg^{-1} (see Figure 27). Furthermore, very minute differences where in observed in the WF between the 'coal', 'wind' and 'none' parameters. These differences where so small that they did not have any effect on the final number, when rounded off. Under the 'halved' parameter, the WF of trout was calculated to be around 827 l kg^{-1} (see Figure 27). Also, very small differences were observed between the three energy related parameters. Next, in the case of the 'unaccounted' parameter, the WF was observed to be around 102 l kg^{-1} (see Figure 27). The same arguments of indifference in the WF are to be applied when looking at the three energy related parameters.

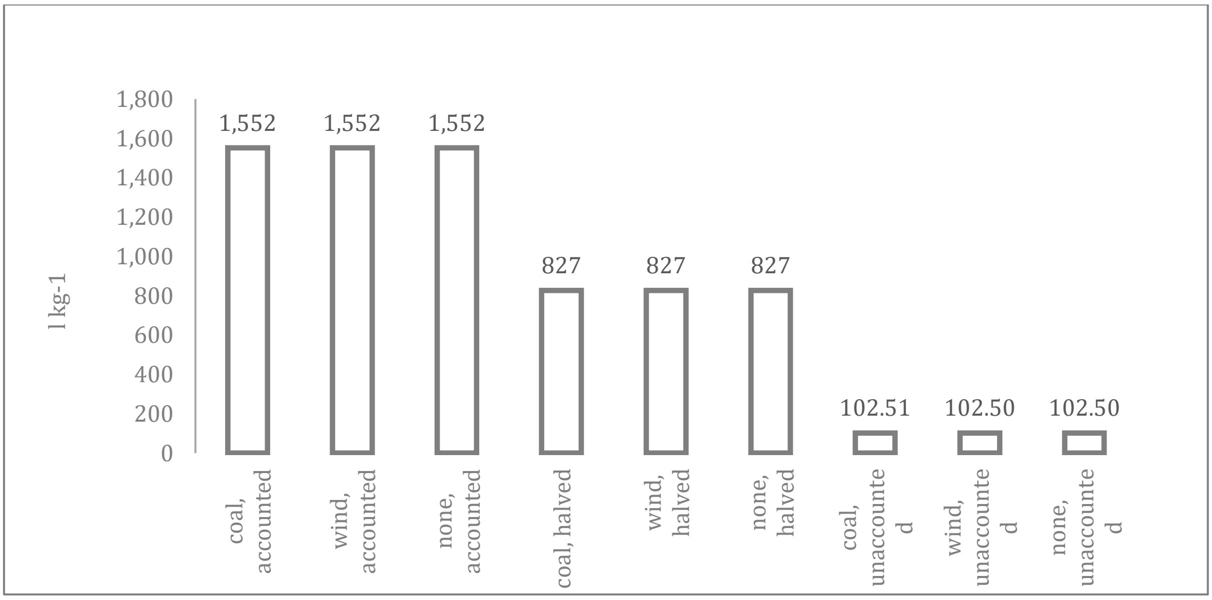

Figure 27 Water footprint FRE2SH trout

Secondly, when it comes to the WF per unit of nutritional value calories of trout. The WF was calculated to be around 1.10 l $kcal^{-1}$ under the accounted parameters (see Figure 28). No significant difference were observed between the energy related parameters. In the case of the halved parameter, the WF per unit of nutritional value was calculated to be around 0.59 l $kcal^{-1}$ (see Figure 28). In this case also no significant differences were observed in the WF of per unit of nutritional value calories was observed between the energy parameters. Next, under the unaccounted parameter, the WF per unit of nutritional value calories of FRE2SH trout was calculated to be around 0.07 l g $kcal^{-1}$ (see Figure 28). Also in under this parameter, very miniscule differences were observed in the WF per unit of nutritional value between the energy related parameters.

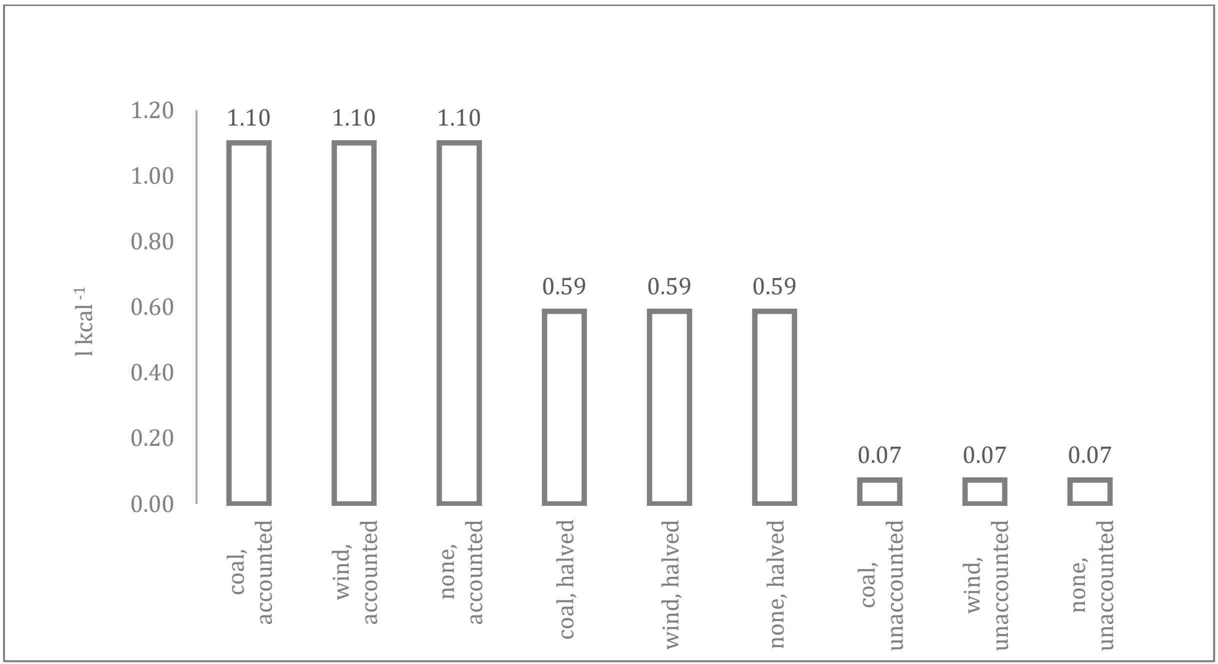

Figure 28 Water footprint per unit of nutritional value calorie FRE2SH trout

Finally, in the case of the WF per unit of nutritional value protein of trout, the WF was calculated to be around 7.42 l g $protein^{-1}$ for FRE2SH trout under the 'accounted' parameter (see Figure 29). No significant differences in WF were observed between the energy related parameters. Next, Under the halved parameter, the WF of FRE2SH trout was calculated to be around 3.96 l g $protein^{-1}$ (see Figure 29). Furthermore, just as in the previous case, no significant differences were observed in the final outcome. Also, in the case of the 'unaccounted' parameter the WF per unit of nutritional value protein was calculated to be around 0.49 l g $protein^{-1}$ (see Figure 29). Similarly just as in the previous case, no significant difference was observed in the WF between the energy related parameters.

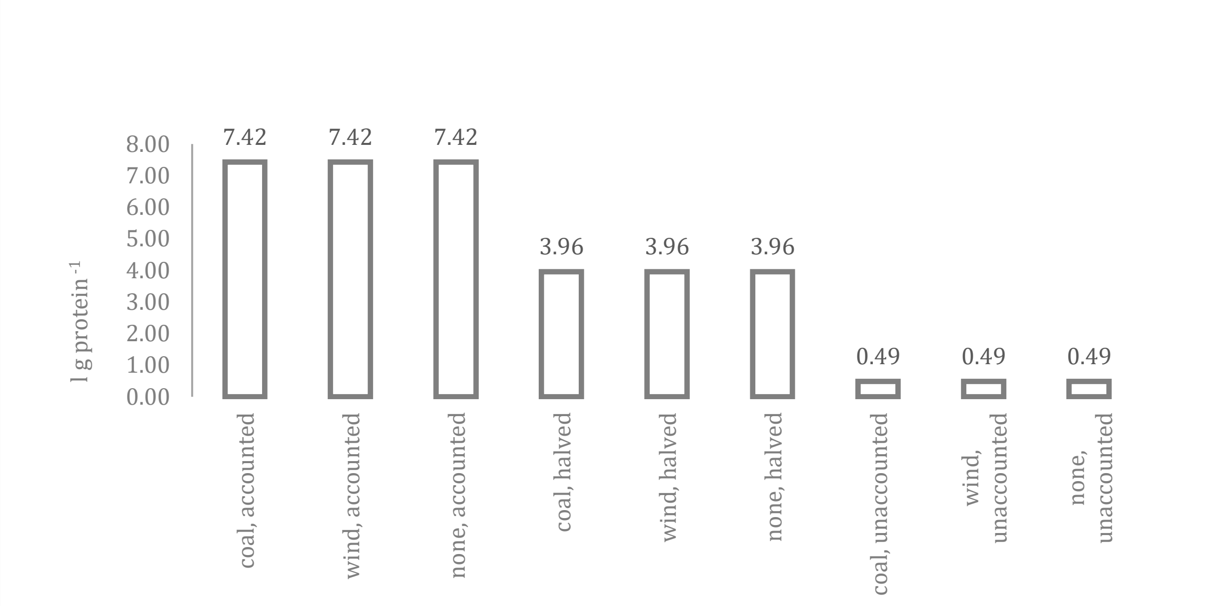

Figure 29 Water footprint per unit of nutritional value protein FRE2SH trout

4.1.3 Water footprint worms

First of all, in the case of the WF of the FRE2SH meal worms, under the 'coal, conservative', the WF was calculated to be around 0.097 l kg^{-1} (see Figure 30). Under the 'wind, conservative' and the 'none, conservative' parameter, the WF was calculated to be around 0.05 l kg^{-1} (see Figure 30). Next, under the 'optimal, coal' parameter, the WF of FRE2SH meal worms was calculated to be around 0.11 l kg^{-1} (see Figure 30). In the case of the 'optimal, wind' and the 'optimal, none' parameter, the WF was calculated to be around 0.05 l kg^{-1} (see Figure 30). It is important to note that since the parameters 'conservative' and optimal are based on the output of the worm farm. Differences of WF will not be visible when looking at the WF per kilogram of worm. The differences however are clearly visible when looking at the total WF (summation over the year) of the meal worms. By doing that it was found that the WF under the 'coal, conservative' and the 'coal, optimal' were calculated to be around 125 l kg^{-1} and 169 l kg^{-} respectively. In the case of the 'wind, conservative' and 'none, conservative' the total WF was calculated to be around 65 l kg^{-1}.

Also in the case of the parameters 'wind, optimal' and 'none, optimal', the WF was calculated to be around 78 l kg^{-1}.

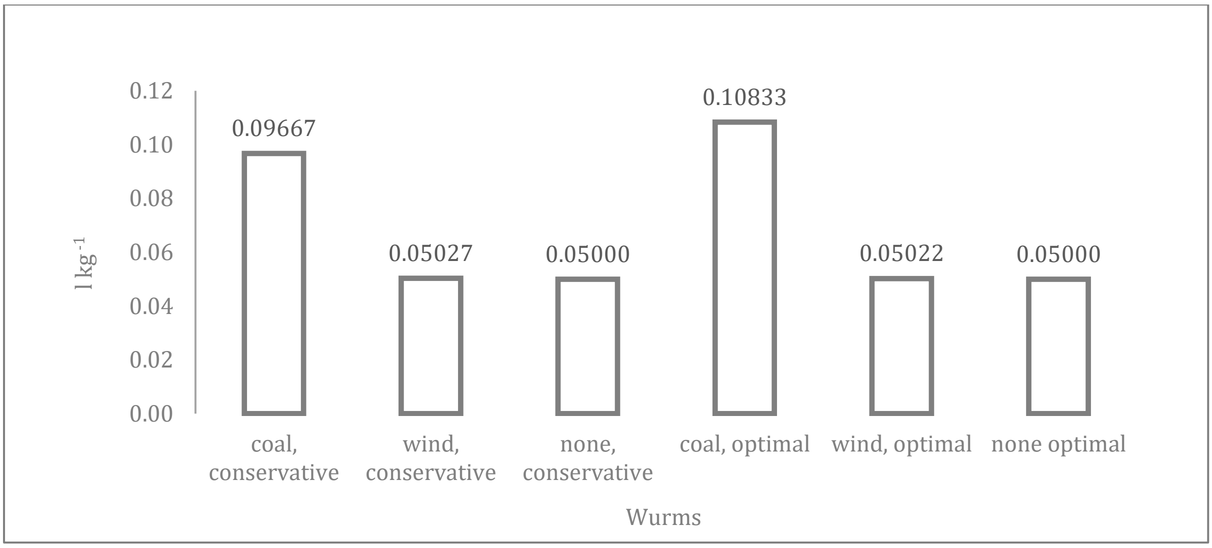

Figure 30 Water footprint FRE2SH worms

Secondly, when it comes to the WF per unit of nutritional value calories of FRE2SH meal worms, under the parameter 'coal conservative' and 'coal, optimal', the WF is calculated to be at around 4.33E^{-05} l $kcal^{-1}$ and 4.86E^{-05} l $kcal^{-1}$ respectively (see Figure 31). In the case of the parameters 'wind, conservative' and 'none, conservative', the WF per unit of nutritional value calories is calculated to be around 2.25E^{-5} l $kcal^{-1}$ and 2.24E^{-5} l $kcal^{-1}$ (see Figure 31). Furthermore, in the case of the parameters 'wind, optimal' and 'none, optimal' the WF was calculated to be around the same as was calculated in the latter parameters. On another note, just as in the previous chapter, the difference in WF per unit of nutritional value calories can only be observed when taking the total WF per unit of nutritional value. When considering the latter, the total WF per unit of nutritional value calories becomes 5.64E^{-02} l $kcal^{-1}$ and 7.58E^{-02} l $kcal^{-1}$ for the parameters 'coal, conservative' and 'coal, optimal' respectively. With regard to the parameters 'wind, conservative' and 'none, conservative', the total WF per unit of nutritional value calories becomes 2.93 l $kcal^{-1}$ and 2.91 l $kcal^{-1}$ respectively. Conversely, under the parameters 'wind, optimal' and 'none, optimal' the WF per unit of nutritional value calories becomes 3.51 l $kcal^{-1}$ and 3.50 l $kcal^{-1}$ respectively.

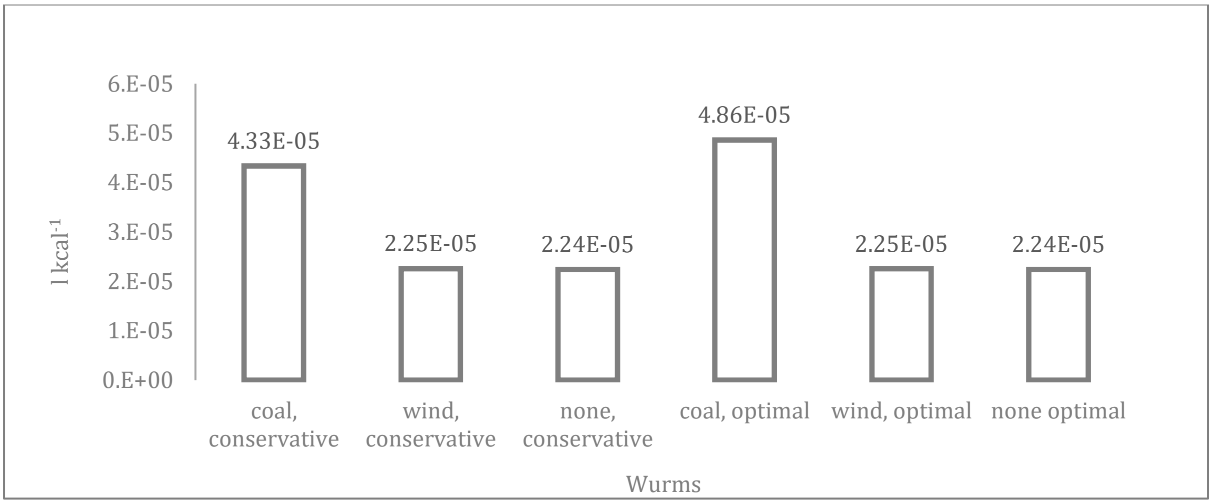

Figure 31 Water footprint per unit of nutritional value calorie FRE2SH worms

Finally, when looking at the WF per unit of nutritional value protein of FRE2SH worms. Under the parameters 'coal, conservative' and 'coal, optimal', the WF is calculated to be 1.82E^{-04} l g protein^{-1} and 2.04E^{-04} l g protein^{-1} respectively (see Figure 32). On the other hand, when looking at the total WF per unit of nutritional value protein, the total WF per unit of nutritional value for both parameters becomes 0.24 l g protein^{-1} and 0.32 l g protein^{-1} respectively (see Figure 32). Furthermore, when considering the parameters 'wind, conservative' and 'none, conservative' the WF per unit of nutritional value protein becomes 9.48E^{-05} l g protein^{-1} and 9.43E^{-05} l g protein^{-1} respectively (see Figure 32). Conversely, when considering the parameters 'wind, optimal' and 'none, optimal' the same values as in the conservative parameters were calculated. From the perspective of the total WF per unit of nutritional value protein. The 'wind, conservative' and 'none, conservative' both produced a total WF 0.12 l g protein^{-1}. Similarly, when considering the 'wind, optimal' and 'none, optimal' parameters, the total WF for both parameters was calculated to be 0.15 l g protein^{-1} .

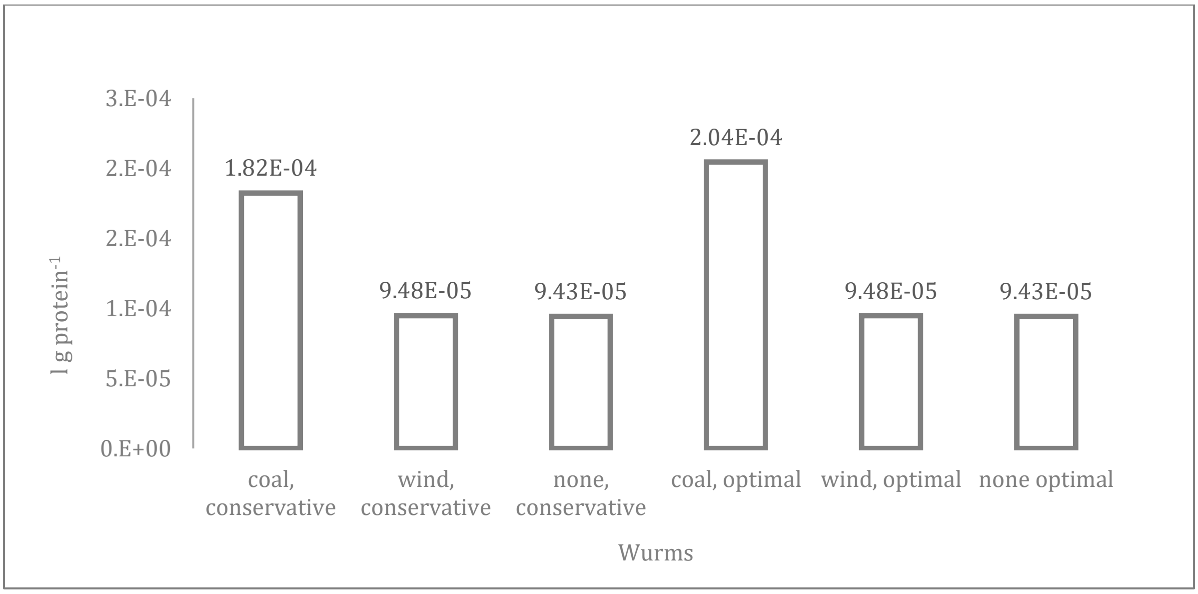

Figure 32 Water footprint per unit of nutritional value protein FRE2SH worms

4.2 WATER FOOTPRINT FRESH PRODUCTION SYSTEM

First of all, with regard to the WF of the FRE2SH food production system (i.e. the combined WF of all of the products produced within FRE2SH). The results showed that for all of the 'accounted' parameters, regardless of the energy related or worm farm related parameters, the WF was calculated to be 1568 l kg^{-1} (see Figure 33). In the case of the 'halved' parameter, the WF was calculated to be 844 l kg^{-1} (see Figure 33). Also, in the case of the 'unaccounted' parameter, the WF was calculated at 119 l kg^{-1} (see Figure 33).

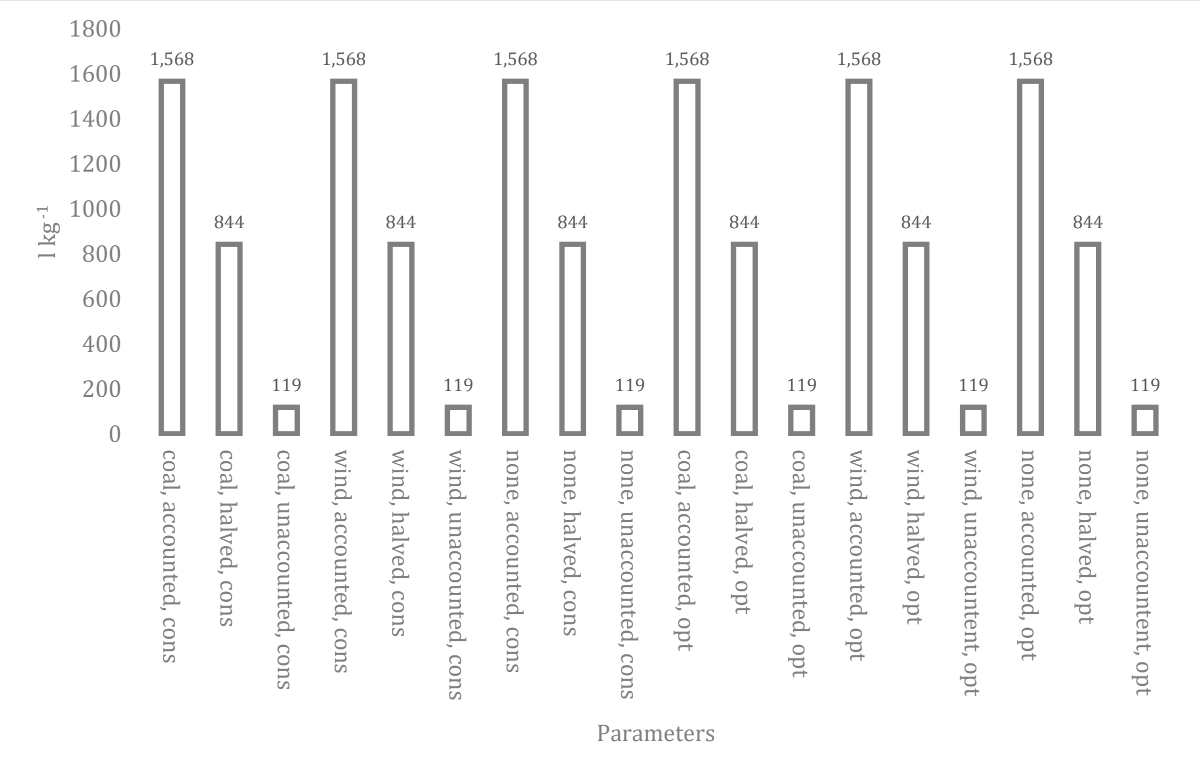

Figure 33 WF of FRESH food production system

Secondly, with regard to the WF per unit of nutritional value calorie of the FRE2SH production system. The results showed that for all of the 'accounted' parameters, regardless of the energy or worm farm related parameters. The WF per unit of nutritional value calorie was around 1.21 l $kcal^{-1}$ (see Figure 34). Next, in the case of all of the 'halved' parameters the results showed a calculated WF per unit of nutritional value calorie of around 0.697 l $kcal^{-1}$ (see Figure 34). Also, in the case of all of the 'unaccounted' parameters the results pointed towards a WF per unit of nutritonal value calorie of around 0.183 l $kcal^{-1}$ (see Figure 34).

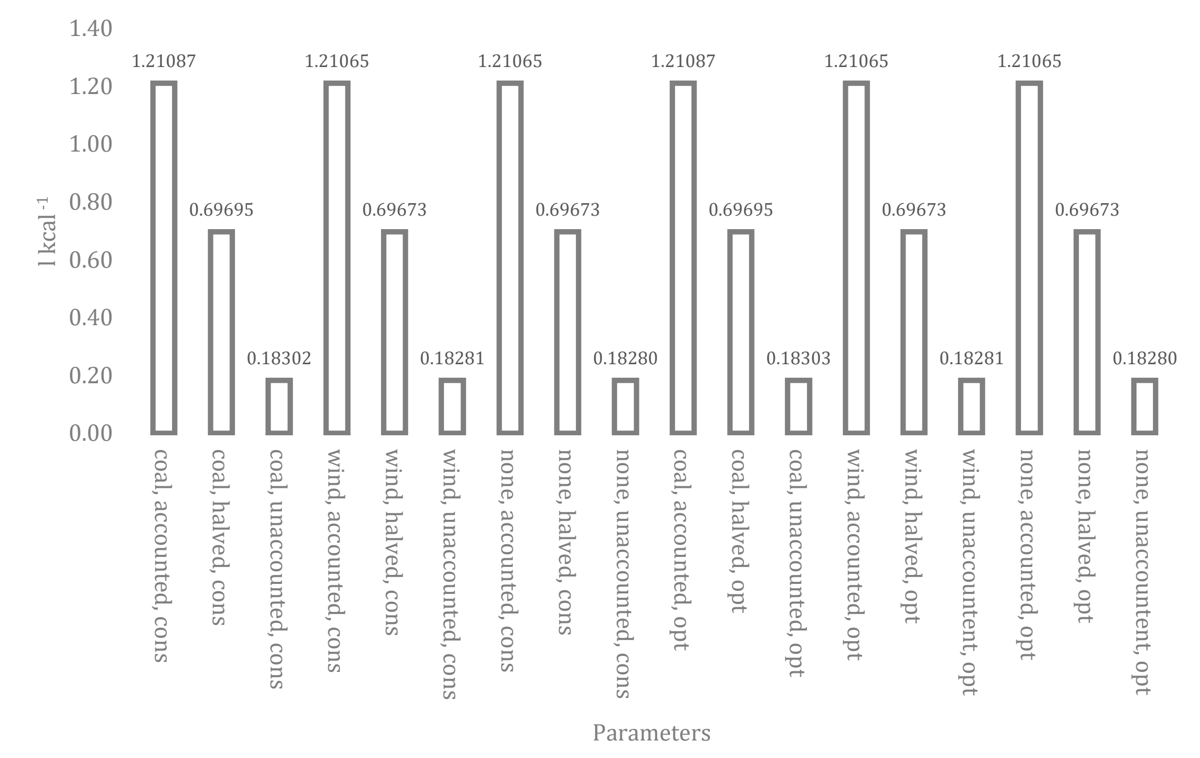

Figure 34 WF per unit of nutritional value calorie FRE2SH

Finally, when it comes to the WF per unit of nutritional value protein of the FRE2SH food production system. The results showed that for all of the 'accounted' parameters regardless of the energy or worm farm related parameter, the WF per unit of nutritional value protein was around 8.6 l g protein^{-1} (see Figure 35). In the case of the 'halved' parameter, the WF per unit of nutritional value protein was calculated to be around 5.14 l g protein^{-1} (see Figure 35). Furthermore, in the case of the 'unaccounted' parameter, the WF per unit of nutritional value protein was calculated to be around 1.67 l g protein^{-1}.

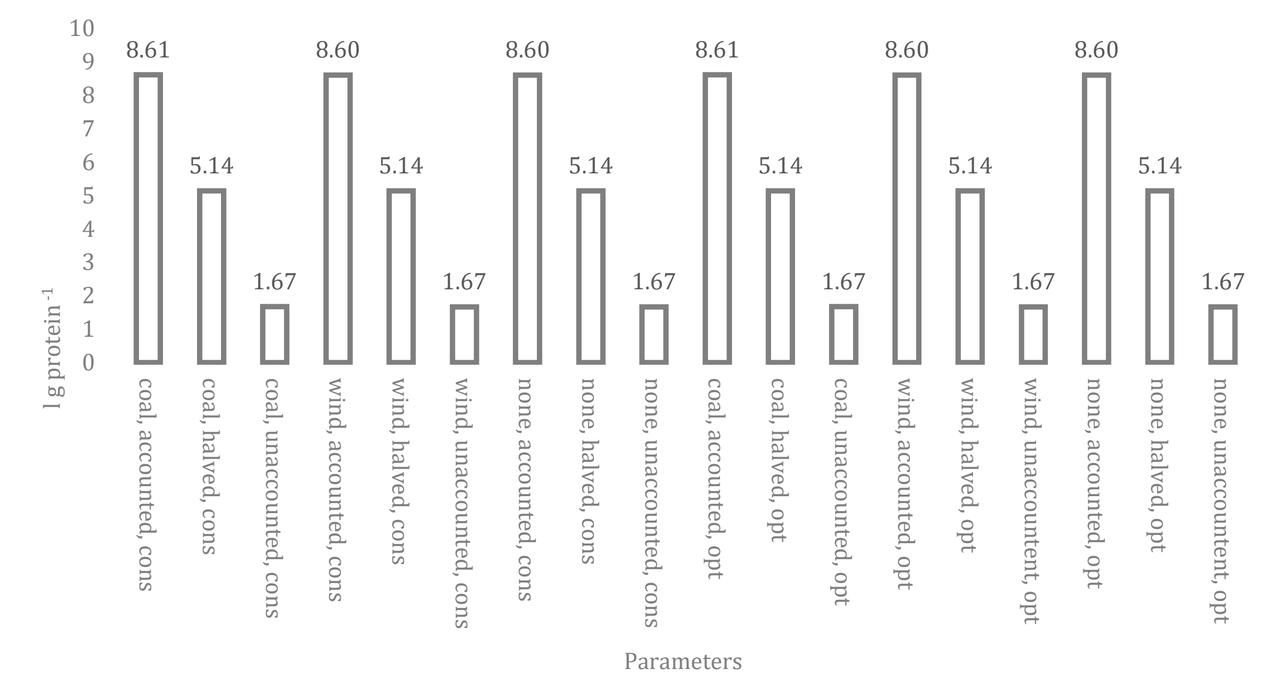

Figure 35 WF per unit of nutritional value protein FRE2SH

4.3 COMPARATIVE ANALYSIS

First of all, answering the first research question; what would happen to the WF of the Dutch if all of the fish and vegetables he/she consumes were to be sourced from FRE2SH? The results showed that in scenario's S1P1, S1P4 and S1P7 the WF of the Dutch would be reduced to 1479 m^3 cap^{-1} y^{-1}, which is a reduction of around 4.04 % (see Figure 36 and Figure 37). Next, scenario's S1P2, S1P5 and S1P8 showed a reduction of the total WF to around 1475 m^3 cap^{-1} y^{-1}, which is a reduction of around 4.29 % (see Figure 36 and Figure 37). Also, scenario's S1P3, S1P6 and S1P9 show a reduction of the Dutch WF to around 1471 m^3 cap^{-1} y^{-1}, which is around 4.55 % (see Figure 36 and Figure 37).

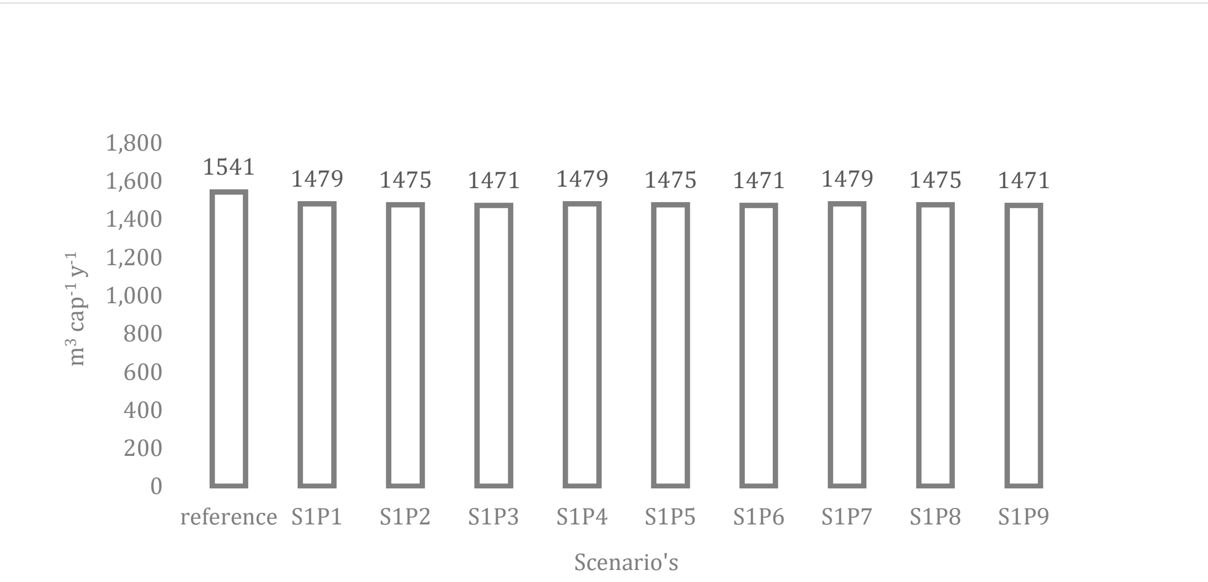

Figure 36 WF Duch citizen reference vs FRE2SH scenario 1

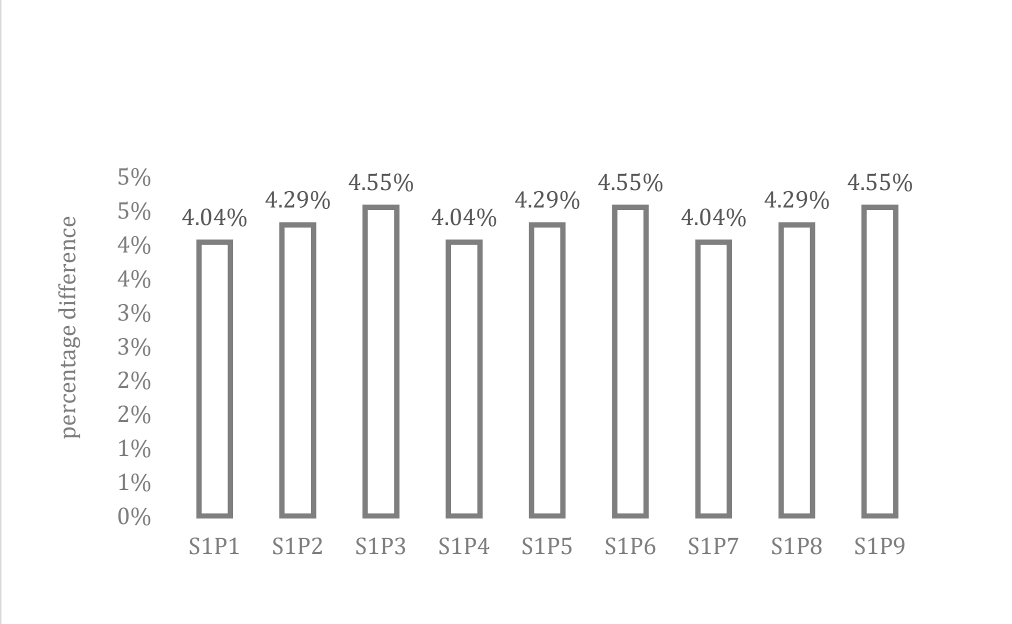

Figure 37 Percentage difference WF Dutch citizen reference vs FRE2SH scenario 1

Second of all, when considering the research question; what would happen to the WF of the Dutch if all of the calories he/she consumes were to be replaced with calories sourced from FRE2SH? The results showed that in scenario's S2P1, S2P4, S2P7, S2P10, S2P13 and S2P16 the total WF of a Dutch citizen was reduced to around 1326 m^3 cap^{-1} y^{-1}, which is around 14 % (see Figure 38 and Figure 39). Next, in the case of scenario's S2P2, S2P5, S2P8, S2P11, S2P14 and S2P17 the total WF of the Dutch was reduced to around 763 m^3 cap^{-1} y^{-1}, which is around 50% (see Figure 38 and Figure 39). Also, when it comes to scenario's S2P3, S2P6, S2P9, S2P12, S2P15 and S2P18, the results show a decrease to around 200 m^3 cap^{-1} y^{-1} in the total WF of the Dutch, which amounts to around 87 % (see Figure 38 and Figure 39).

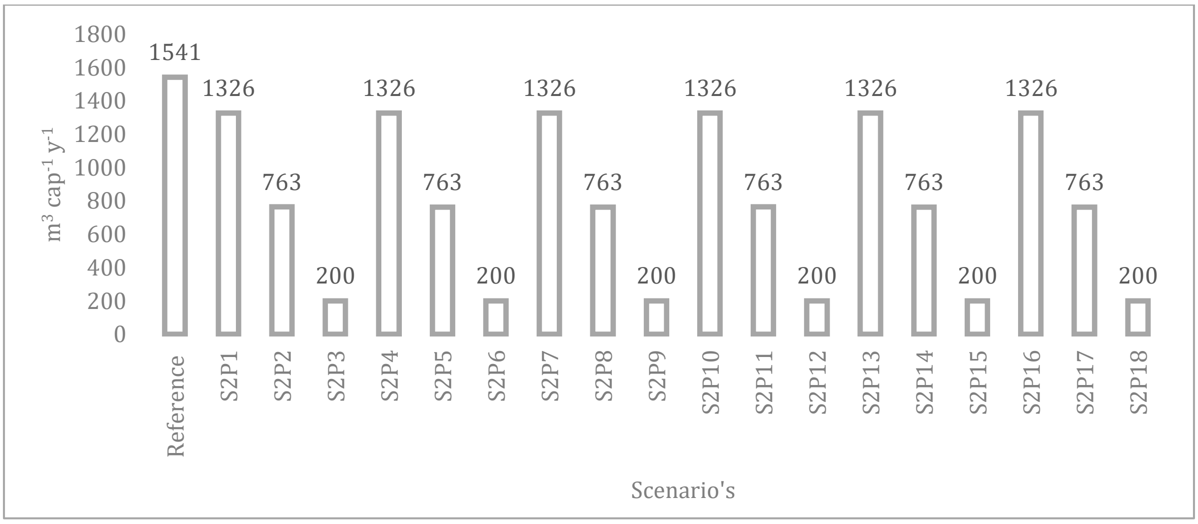

Figure 38 WF unit of Dutch citizen reference vs FRE2SH scenario 2 (calories)

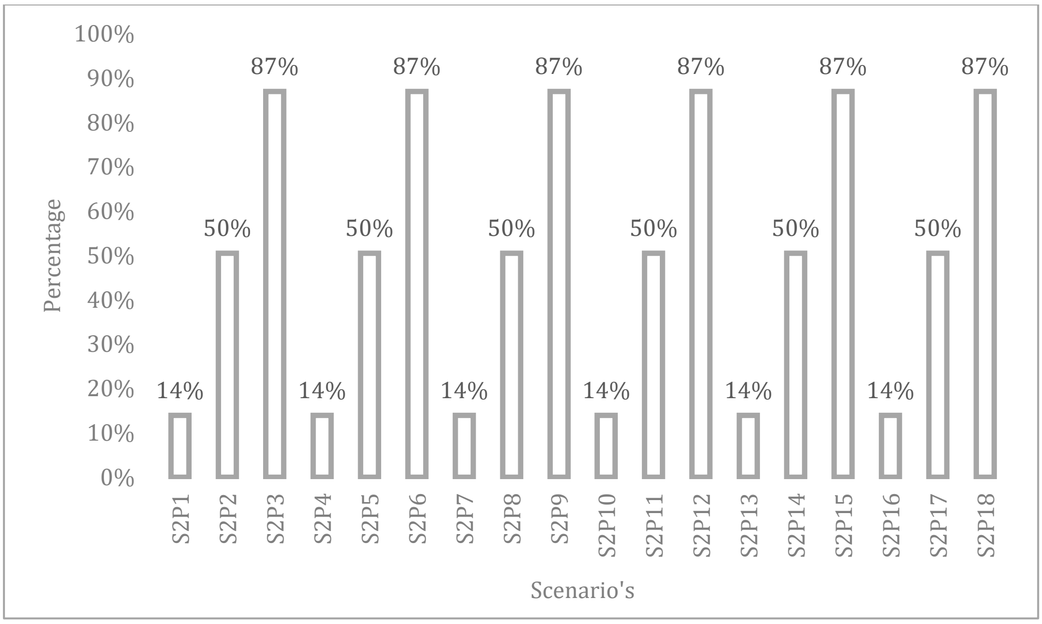

Figure 39 Percentage difference WF unit of Dutch citizen reference vs FRE2SH scenario 2 (calories)

Thirdly , when considering the research question; what would happen to the WF of the Dutch if all of the protein he/she consumes were to be replaced with protein sourced from FRE2SH? The results showed that in scenario's S2P1, S2P4, S2P7, S2P10, S2P13 and S2P16 the total WF of a Dutch citizen was reduced to around 330 m^3 cap^{-1} y^{-1}, which is around 79 % (see Figure 40 and Figure 41). Next, in the case of scenario's S2P2, S2P5, S2P8, S2P11, S2P14 and S2P17 the total WF of the Dutch was reduced to around 197 m^3 cap^{-1} y^{-1}, which is around 87 % (see Figure 40 and Figure 41). Also, when it comes to scenario's S2P3, S2P6, S2P9, S2P12, S2P15 and S2P18, the results show a decrease to around 64 m^3 cap^{-1} y^{-1} in the total W of the Dutch, which amounts to around 96 % (see Figure 40 and Figure 41).

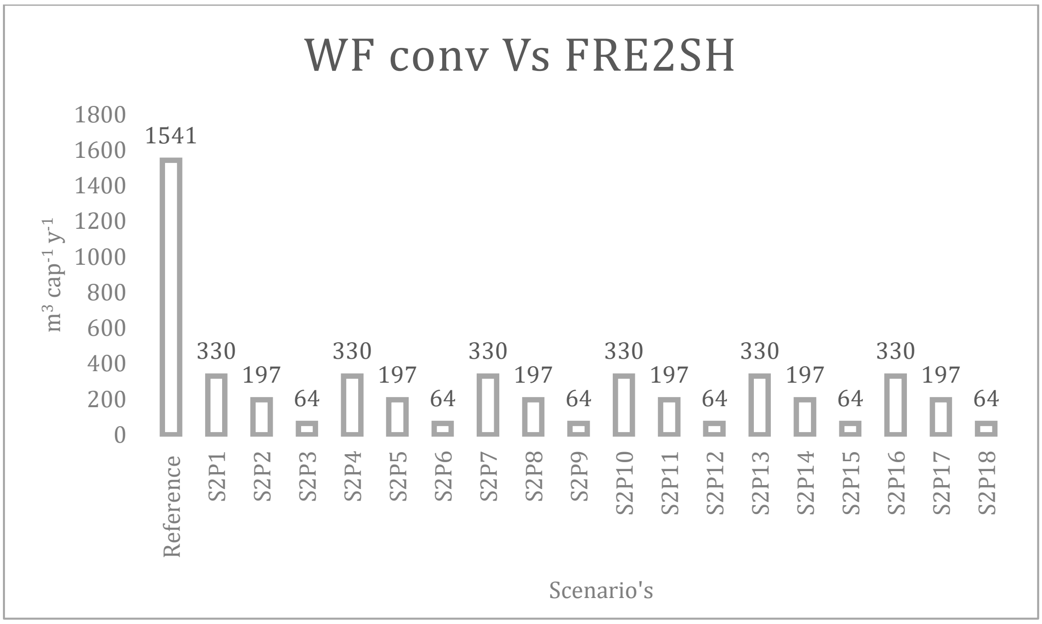

Figure 40 WF unit of Dutch citizen reference vs FRE2SH scenario 2 (proteins)

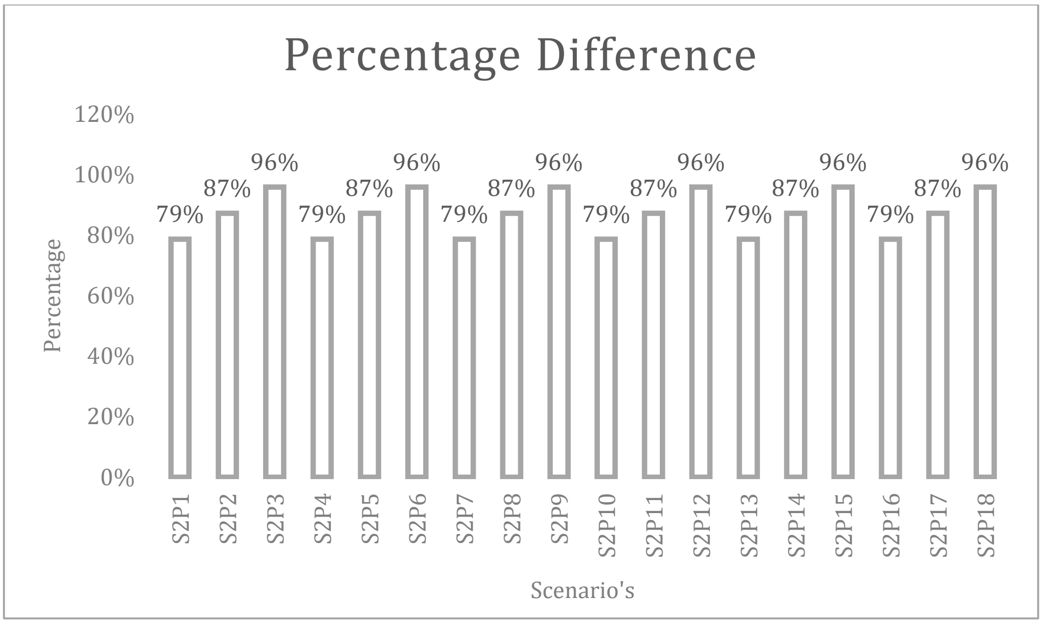

Figure 41 Percentage difference WF unit of Dutch citizen reference vs FRE2SH scenario 2 (proteins)

Finally when comparing the WF of lettuce produced in the conventional food production system with that of FRE2SH lettuce. The results show that lettuce produced in FRE2SH is around 14 times more efficient in water consumption. What this means is that the FRE2SH lettuce consumes around 14 times less water that conventional lettuce (see Figure 42). In the case of proteins, the results show that FRE2SH protein consumes around 13 times less water for each gram of protein produced (see Figure 42).

Group	product	WF		
		Conventional	FRE2SH	
		l/kg		
Vegetables (lettuce)	lettuce	237	16.54	
Animal Protein		l/g protein		
	beef	47.19	all products of fresh combined 'none, accounted, conservative'	all products of fresh combined 'none, accounted, optimal'
	pig	42.18		
	chicken	14.07		
	Egg	12.08		
	milk	16		
	Total	115.53	8.60	8.60

Figure 42 WF lettuce and animal proteins conventional vs FRE2SH

5 Discussions Conclusions and Recommendations

5.1 Discussion

5.1.1 Methods and data

Given the goal of the project it was chosen to use the WF assessment method, created by the WF network (WFN)(19). Since, the goal of the project was not to assess the impact of the WF but rather do a comparative analysis in which the WF of Dutch citizen was analyzed. It was only required to use the quantification and accounting methods as proposed by WFN e.g. WF

Assessment (WFA). Furthermore, as previous studies have shown, both the WFA method and that of the LCA community show similar results in the quantification and accounting phase of the WF (48). Therefore, for this research it would not matter if the WFA method or the LCA method was used. However, in order to maintain homogeneity between the reference study that was used in this research, it made more sense to utilize the WFA method, since the reference study also utilized said method. Also, if the goal of the project was to assess the impacts of the WF, then the method for WF assessment would have to be considered carefully. Because, the WFA method gives a different approach and therefore a different interpretation of the results, compared to the LCA method.

When it comes to the boundaries of the study that was utilized as a reference for the WF of the Dutch. Assessment of the boundaries of that study showed that the study focused on a 10 year period in terms of water consumption and virtual water trade data. Also, another boundary that was considered in the reference study was the method of calculation. In the reference study both approaches (e.g. bottom-up and top-bottom) where utilized to calculate the WF, however only the results of the bottom up approach were utilized for the impact assessment of the WF. Also, the data sources for the reference study were either data used from previous studies by the same author or data supplied by the United Nations (FAO). Thus in this study, the reference WF of the Dutch was based on the same 10 year period. However, the literature research also focused on the current water consumption data. Which revealed that in current governmental data on the water consumption of the Dutch is incomplete. Since, the focus is only on local consumption of water, even though there is a global perspective when it comes to water management. This is because many products consumed within the Netherlands have virtual water attached to it. Meaning that the production of the products consumed in the Netherlands, require water consumed outside of the boundaries of the Netherlands. It was for these reasons that the reference WF based on that 10 year period was utilized instead of current data on water consumption. Next, the bottom-up approach was utilized for the calculation of the WF of the different products produced by FRE2SH in order to maintain homogeneity in the quantification and accounting methods.

5.1.2 Water footprint lettuce

First of all with regard to the methods to the method that was used for estimating the blue water evaporation. Since in the CROPWAT method, the crop water requirement option assumes general optimal conditions in which topographical characteristics related to soil is also taken into account in the calculation. The value for blue water evaporation of lettuce can be much lower than is actually measured in the FRE2SH growing environment. Thus the final WF of FRE2SH could also be lower.

Secondly, with regard to the WF of FRE2SH lettuce, what could be observed is that amongst the three energy parameters (e.g. 'coal', 'wind' and 'none') very miniscule difference were observed in the outcome. The reason for this is that the water consumption that is required for energy production is really small. So small that overall it has a very small influence on the accumulated WF.

5.1.3 Water footprint trout

On a first note, when considering the water footprint of trout. The same phenomena was observed in the WF outcome of lettuce. Hence, very miniscule difference were observed in the outcome of the WF of trout between the three energy related parameters. Similarly, the reason for this was that the a change in energy source had a relatively small effect on the total water footprint of trout.

Secondly, the it is between the parameters 'accounted', 'halved' and 'unaccounted' that the highest largest differences were observed. This is because of the fact that the water footprint of trout was largely attributed to the water footprint of the fish feed. The fish feed is comprised of high intensive agricultural products (e.g. crops).

5.1.4 Water footprint mealworms

When it comes to the water footprint of the mealworms, very small differences were observed between the outcomes of the 'conservative' and the 'optimal' parameters. One explanation for this is that the 'conservative' and 'optimal' parameters are effected by the output of the worm farm. Thus differences where much better observed when looking at the total water footprint (e.g. over the whole year).

Next, when looking at the energy related parameters, the most significant differences that took place were amongst the energy related parameters. One reason for this is that unlike the WF for trout or lettuce, the water foot print of the worms are relatively small. Meaning that the small changes in water footprint that take place when changing the energy source, would more easily show in the final footprint.

5.1.5 Water footprint of FRE2SH

With regard to the water footprint of the FRE2SH production system, the largest differences in water footprint were observed between the 'accounted', 'halved' and 'unaccounted' parameters. This is because out of all the products, trout had the highest water footprint attributed to it. Since, the largest part of the water footprint was attributed to the fish feed.

5.1.6 Comparative analysis

With regard to research question 1, the scenarios S1P7 and S1P8 are considered to be the most reliable outcomes. Firstly, this is because in both of the scenarios the energy is not considered. And since, in the reference study there is no mention about energy being considered or not this outcome shows to be the most reliable because of the homogeneity in the quantification and accounting process between the conventional and FRE2SH food production system. Secondly, because in S1P1 and S1P7 the most the water footprint of the fish feed is completely accounted for and in the other case accounted for half. This is the most realistic case, since the FRE2SH food production system has not managed to replace all of its fish feed with meal worms yet.

Next, with regard to research question 2, the scenarios S2P7 and S2P8 seem to the most reliable. The exact reasons apply as is discussed in the previous paragraph. Furthermore, what also needs to be considered is the fact that the scenarios that assume the 'conservative' parameters are more reliable than the 'optimal' scenario. Because in the 'optimal' scenarios, optimal outcomes are considered in terms of out of the worm farm. While, this is not the case, since the worm farm has not reached that state yet. However, theoretically it is calculated to be possible and is likely to be achieved in the future.

Also, when considering the impacts related to the water footprint of the Dutch (mentioned in reference study). By sourcing fish and vegetables consumption from FRE2SH, the Dutch can manage to reduce their water footprint by about 4-4,3 %. This helps already in reducing the existing pressures on fresh water reserves in the so-called 'hot spots' countries from which the Dutch import some of their products, given that it is fish and vegetables that is also imported from these countries.

On a final note, when comparing the WF of lettuce produced within conventional agriculture with the WF of FRE2SH lettuce. It was observed that FRE2SH lettuce consumed 13 times less water for each kilogram of lettuce produced. This is fairly consistent with what has been found in the literature (49). In the case of proteins, it was observed that FRE2SH consumes around 14 times less water than the water that is consumed to produced one gram of protein through conventional agriculture (e.g. livestock). Also, the water footprint is representative for the sustainability of fresh water use and freshwater resources (depending on what perspective is chosen). It does not give a complete representation of environmental sustainability, which generally includes all the three environmental subjects air, water, soil. In order to get a complete view of the environmental sustainability, then alongside of the water footprint, also a carbon footprint and a ecological footprint would be needed.

5.2 Conclusions

First of all the WF and WF per unit nutritional value (e.g. calorie and protein) of the products (e.g. lettuce, rainbow trout and mealworms) produced in an alternative food production network FRE2SH were determined. Next, the WFN method was used to quantify the WF of said products and said food production system. Within the WFN method, the bottom-up accounting approach was utilized for the quantification and the accounting process of WF.

Second, it was found that the water footprint of lettuce ranged between 16.51-16.54 l kg^{-1}. That of trout was determined to range between 827-1552 l kg^{-1} and that of the mealworms ranged between 0.05 - 0.11 l kg^{-1}. Also, the total water footprint and the water footprint per unit of nutritional value for all of the products together were estimated. Which ranged between 119-1568 l kg^{-1}, 0.18-1.21 l $kcal^{-1}$ and 1.67-8.61 l g*$protein^{-1}$, respectively.

Third a comparative analysis was conducted in which the water footprint of a Dutch consumers was analyzed in two scenarios (e.g. S1 and S2) based on the following questions:

- What will happen to the total water footprint of a Dutch consumer if the fish and vegetables he consumes where sourced from FRE2SH?
- What will happen to the total water footprint of a Dutch consumer is his daily caloric and protein intake was sourced from the calories and proteins produced by FRE2SH

Depending on the parameters considered in the aquaponics system and the worm farm, the Dutch WF ranged between 4-4.3% if all of the fish and vegetables of the Dutch diet were to be produced by FRE2SH. Furthermore, the water footprint of a Dutch citizen showed a reduction by 14-50 % (considering outcomes of the most reliable scenario S1P7 and S1P8) and by 79-87 % if all of the calories and proteins (respectively) were to be sourced from FRE2SH products. However, higher efficiencies can be reached when the aquaponics system (Duurzame Kost) uses the Mealworms (Wurmpie Wurmpie) as input. Furthermore, production of one kilogram of lettuce produced by FRE2SH showed to consume 13 times less water than lettuce produced in conventional farming. Also, the production of one kilogram of protein produced by FRE2SH showed to consume 14 times less water the animal based protein produced in conventional agriculture.

5.3 Recommendations

For future research, the exact water footprint of all of the different food products the Dutch diet is comprised of can be calculated individually. So that the value for the water footprint of the Dutch a Dutch citizen is more specific. The same applies for the water footprint per unit of nutritional value. Future research can also include the carbon footprint and ecological of the system in order to get a more holistic view of the impacts of the system.

It is important to note that the improvements in water productivity do not have anything to do with the production of food at walking distance, rather it is the result of the system being circular.

However, in the context of the impacts related to the water footprint of the Netherlands, it can be logically derived and reasoned from the findings that these impacts can be mitigated when producing internalizing the WF of the Dutch.

With regard to the production system itself, from the findings it can be concluded that the production system can become much more efficient if the inputs of the aquaponics system are at least for a small part replaced with the outputs of the worm farm.

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APPENDICES

APPENDIX I

All data from data sheets that was utilized in the calculation of the water footprint[4]

Duurzame Kost			
Inputs		Outputs	
Feed (kg/y)	1642.5	Lettuce (kg/y)	20,000
bluewater loss (m3/y)	365	Fish (kg/y)	1,700
Initial blue water cost (m3/y)	125		
Energy (kwh)	109500		
Dimensions of growing area (m2)	1182		

Wurmpie Wurmpie							
Conservative				Optimal			
Inputs		Outputs		Inputs		Outputs	
Biomass (kg/y)	208	Worms (kg/y)	1300	Feed (kg/y)	624	Worms (kg/y)	1560
Barley (kg/y)	832	Manure (kg/y)	1300	Barley (kg/y)	936		
Energy (kwh)	104			Energy (kwh)	156		

Crop parameters								
Crop	Kc ini	Kc mid	Kc end	Initial stage	Dev stage	Mid Stage	Late stage	Planitng/green up date
Lettuce	0.70	1.00	0.95	35.00	50.00	45.00	10.00	15-Feb

PLanting date	15-02
Harvest date	04/07
Etblue (mm/d)	0.002490107

[4] This data can be retrieved in its original form from the following link: https://docs.google.com/spreadsheets/d/1w0UTJdMsEykow_bKYGEDujdfP3QAmQQ7UD8ilURudvA/edit?usp=sharing

Dutch consumption patterns				Data Analysis Scenario1								
Food group	Mean kg/cap/y	%	Reference water footprint (m3/cap/y)	Total WF S1P1 (m3/cap/y)	Total WF S1P2 (m3/cap/y)	Total WF S1P3 (m3/cap/y)	Total WF S1P4 (m3/cap/y)	Total WF S1P5 (m3/cap/y)	Total WF S1P6 (m3/cap/y)	Total WF S1P7 (m3/cap/y)	Total WF S1P8 (m3/cap/y)	Total WF S1P9 (m3/cap/y)
Potatoes and other tubers	26.645	2.38%	37	37	37	37	37	37	37	37	37	37
Vegetables	46.355	4.15%	64	0.766797887	0.766797887	0.766797887	0.76544814	0.76544814	0.76544814	0.765440382	0.765440382	0.765440382
Legumes	1.46	0.13%	2	2	2	2	2	2	2	2	2	2
Fruits, nuts and seeds, olives	44.53	3.98%	61	61	61	61	61	61	61	61	61	61
Dairy products and substitutes	129.575	11.59%	179	179	179	179	179	179	179	179	179	179
Cereals and cereal products	70.08	6.27%	97	97	97	97	97	97	97	97	97	97
Meat, meat products and substitutes	36.865	3.30%	51	51	51	51	51	51	51	51	51	51
Fish, shellfish and amphibians	5.475	0.49%	8	8.49594588	4.528583747	0.561221615	8.495932329	4.528570197	0.561208064	8.495932251	4.528570119	0.561207986
Eggs and egg products	4.38	0.39%	6	6	6	6	6	6	6	6	6	6
Fats and oils	8.03	0.72%	11	11	11	11	11	11	11	11	11	11
Sugar and conectionery	13.87	1.24%	19	19	19	19	19	19	19	19	19	19
Cakes and sweet biscuits	14.235	1.27%	20	20	20	20	20	20	20	20	20	20
Non-alcolic beverages	629.625	56.34%	868	868	868	868	868	868	868	868	868	868
Alcoholic Beverages	55.48	4.96%	76	76	76	76	76	76	76	76	76	76
condiments, spices, sauces and yeast	13.505	1.21%	19	19	19	19	19	19	19	19	19	19
Soups and stocks	8.76	0.78%	12	12	12	12	12	12	12	12	12	12
Miscellaneous	1.46	0.13%	2	2	2	2	2	2	2	2	2	2
Savoury snacks	7.3	0.65%	10	10	10	10	10	10	10	10	10	10
Ready meals	0	0.00%	0	0	0	0	0	0	0	0	0	0
Total	1117.63	100.00%	1541	1479	1475	1471	1479	1475	1471	1479	1475	1471
Difference				4.04%	4.29%	4.55%	4.04%	4.29%	4.55%	4.04%	4.29%	4.55%

WF processes					
Overal process		Sub process (WF proc, Blue)		sub process (CWU, green) (m3/ha)(evapotranspiration)	
	(m3/kg)	CWU (m3/m2)	0.000908889	ETblue (mm/day)	0.002490107

WF(proc)total	5.37E-05	Y (kg/m2)	17	milimeter converter	10
WF(proc, blue)	5.37E-05	Sub process (WF proc, Blue)		growth period (day)	365
WF(proc, green)	0.00	BWL (m3/y)	52		
WF(proc, grey)	0.00	BWA INIT (m3/y)	125		
		Sub process (WF proc, Green) N.A.			
		CWU (m3/ha)	0		
		Y (kg), (ton)	0		
		Sub process (WF proc, Grey) N.A.			
		α			
		AR (kg/ha)			
		c(nat) (kg/m3)			
		c(nat) (kg/m3)	1		
		Y (ton, ha)	1		

Lettuce					
Water footprint of lettuce		WF process		product fraction	
WF[plants] (m3/kg) coal	0.0165419	Evapotranspiration (m3/kg)	4.95E-05	fp[qlettuce,qnutrition]	0
WF[plants] (m3/kg) wind	0.0165127	Incorporation (m3/kg)	0.0009563	w[lettuce] (kg)	0
WF[plants] (m3/kg) none	0.0165126	BWA (m3/kg)	0.016	w[nutrition-->feed] (kg)	0
WF(proc)[p] (m3/kg) coal	0.0165419	Energy Coal (m3/kg)	2.9285E-05		
WF(proc)[p] (m3/kg) wind	0.0165127	Energy Wind (m3/kg)	1.67343E-07		
WF(proc)[p] (m3/kg) none	0.0165126				
WFprod[i] (N.A.)	0				
fp[p,i] (N.A.)	0				
fv[p] (N.A.)	0				
Total (m3/y) coal	330.8371858				
Total (m3/d) coal	0.906403249				
Total (m3/y) wind	330.2548332				
Total (m3/d) wind	0.904807762				

Total (m3/y) none	330.2514863
Total (m3/d) none	0.904798593

WF Products					
FISH					
Water footprint of fish		WF processes		product fraction	
WF[fish] (m3/kg) (accounted, coal)	1.551770937	Evaporation (m3/kg)	4.21E-06	fp[qfish,qfeed]	1.035
WF[fish] (m3/kg) (accounted, wind)	1.551768462	Incorporation (m3/kg)	0.0007782	w[fish] (kg)	1,700.000
WF[fish] (m3/kg) (accounted, none)	1.551768448	BWA (m3/kg)	0.101721334	w[feed] (kg)	1,642.500
WF[fish] (m3/kg) (halved, coal)	0.827138584	Energy Coal (m3/kg)	2.48922E-06		
WF[fish] (m3/kg) (halved, wind)	0.827136109	Energy Wind (m3/kg)	1.42241E-08		
WF[fish] (m3/kg) (halved, none)	0.827136095				
WF(proc)[p] (m3/kg) (unaccounted, coal)	0.102506231				
WF(proc)[p] (m3/kg) (unaccounted, wind)	0.102503756				
WF(proc)[p] (m3/kg) (unaccounted, none)	0.102503742				
WFprod[i] (m3/kg)	1.50				
fp[p,i]	1.035				
Total (m3/y) (accounted, coal)	2,638.01059				
Total (m3/d) (accounted, coal)	7.22743				
Total (m3/y) (accounted, wind)	2,638.00639				
Total (m3/d) (accounted, wind)	7.22741				
Total (m3/y) (accounted, none)	2,638.00636				
Total (m3/d) (accounted, none)	7.22741				
Total (m3/y) (halved, coal)	1,406.13559				
Total (m3/d) (halved, coal)	3.85243				
Total (m3/y) (halved, wind)	1,406.13139				
Total (m3/d) (halved, wind)	3.85241				
Total (m3/y) (halved, none)	1,406.13136				
Total (m3/d) (halved, none)	3.85241				
Total (m3/y) (unaccounted, coal)	174.26059				
Total (m3/d) (unaccounted, coal)	0.47743				
Total (m3/y) (unaccounted, wind)	174.25639				
Total (m3/d) (unaccounted, wind)	0.47741				

Total (m3/y) (unaccounted, none)	174.25636
Total (m3/d) (unaccounted, none)	0.47741

Wurms					
Conservative					
Water footprint of lettuce		WF process		product fraction	
WF[wurms] (m3/kg) coal	9.66667E-05	Evaporation (m3/kg)	0	fp[qworms, qbarley]	1.5625
WF[wurms] (m3/kg) wind	5.02667E-05	Incorporation (m3/kg)	0.00005	w[wurms] (kg)	1300
WF[wurms] (m3/kg) none	0.00005	Energy (m3/kg) coal	4.66667E-05	w[barley] (kg)	832
WF(proc)[p] (m3/kg) coal	9.66667E-05	Energy (m3/kg) wind	2.66667E-07		
WF(proc)[p] (m3/kg) wind	5.02667E-05				
WF(proc)[p] (m3/kg) none	0.00005				
fp[p,i]	1.5625				
fv[p] N.A.					
Total (m3/y) coal	0.125666667				
Total (m3/d) coal	0.000344292				
Total (m3/y) wind	0.065346667				
Total (m3/d) wind	0.000179032				
Total (m3/y) none	0.065				
Total (m3/d) none	0.000178082				

Optimal					
Water footprint of lettuce		WF process		product fraction	
WF[wurms] (m3/kg) coal	0.000108333	Evaporation (m3/kg)	0	fp[qworms,qbarley]	1.666666667
WF[wurms] (m3/kg) wind	5.02222E-05	Incorporation (m3/kg)	0.00005	w[wurms] (kg)	1560
WF[wurms] (m3/kg) none	0.00005	Electricity (m3/kg) coal	5.83333E-05	w[barley] (kg)	936
WF(proc)[p] (m3/kg) coal	0.000108333	Electricity (m3/kg) wind	2.22222E-07		
WF(proc)[p] (m3/kg) wind	5.02222E-05				
WF(proc)[p] (m3/kg) none	0.00005				
WFprod[barley] (m3/kg)	N.A.P.				
fp[p,i]	1.666666667				
fv[p] N.A.					

Total (m3/y) coal	0.169
Total (m3/d) coal	0.000469444
Total (m3/y) wind	0.078346667
Total (m3/d) wind	0.000214648
Total (m3/y) none	0.078
Total (m3/d) none	0.000213699

Water footprints of products within FRE2SH									
				WF per unit of nutritonnal value kcal		WF per unit of nutritonnal value protein		WF lettuce	
Product	parameter	m3/kg	l/kg	m3/kcal	l/kcal	m3/gprotein	l/gprotein	m3/d	m3/y
Lettuce	coal	0.016541859	16.54	1.10E-04	0.11	1.18E-03	1.18	0.91	331
	wind	0.016512742	16.51	1.10E-04	0.11	1.18E-03	1.18	0.90	330
	none	0.016512574	16.51	1.10E-04	0.11	1.18E-03	1.18	0.90	330
Trout	coal, accounted	1.551770937	1,552	1.10E-03	1.10	7.42E-03	7.42	7.23	2638
	wind, accounted	1.551768462	1,552	1.10E-03	1.10	7.42E-03	7.42	7.23	2638
	none, accounted	1.551768448	1,552	1.10E-03	1.10	7.42E-03	7.42	7.23	2638
	coal, halved	0.827138584	827	5.87E-04	0.59	3.96E-03	3.96	3.85	1406
	wind, halved	0.827136109	827	5.87E-04	0.59	3.96E-03	3.96	3.85	1406
	none, halved	0.827136095	827	5.87E-04	0.59	3.96E-03	3.96	3.85	1406
	coal, unaccounted	0.102506231	102.51	7.27E-05	0.07	4.90E-04	0.49	0.48	174
	wind, unaccounted	0.102503756	102.50	7.27E-05	0.07	4.90E-04	0.49	0.48	174
	none, unaccounted	0.102503742	102.50	7.27E-05	0.07	4.90E-04	0.49	0.48	174

Wurms	coal, conservative	0.000096667	0.09667	4.33E-08	4.33E-05	1.82E-07	1.82E-04	3.44E-04	1.26E-01
	wind, conservative	0.000050267	0.05027	2.25E-08	2.25E-05	9.48E-08	9.48E-05	1.79E-04	6.53E-02
	none, conservative	0.000050000	0.05000	2.24E-08	2.24E-05	9.43E-08	9.43E-05	1.78E-04	6.50E-02
	coal, optimal	0.000108333	0.10833	4.86E-08	4.86E-05	2.04E-07	2.04E-04	4.63E-04	1.69E-01
	wind, optimal	0.000050222	0.05022	2.25E-08	2.25E-05	9.48E-08	9.48E-05	2.15E-04	7.83E-02
	none optimal	0.00005	0.05000	2.24E-08	2.24E-05	9.43E-08	9.43E-05	2.14E-04	7.80E-02
WF production sytem		m3/kg	l/kg	m3/kcal	l/kcal	m3/gprotein	l/gprotein	m3/d	m3/y
WF FRESH	coal, accounted, cons	1.57	1,568	1.21E-03	1.21	8.61E-03	8.61	8.13	2,969
	coal, halved, cons	0.84	844	6.97E-04	0.70	5.14E-03	5.14	4.76	1,737
	coal, unaccounted, cons	0.12	119	1.83E-04	0.18	1.67E-03	1.67	1.38	505
	wind, accounted, cons	1.57	1,568	1.21E-03	1.21	8.60E-03	8.60	8.13	2,968
	wind, halved, cons	0.84	844	6.97E-04	0.70	5.14E-03	5.14	4.76	1,736
	wind, unaccounted, cons	0.12	119	1.83E-04	0.18	1.67E-03	1.67	1.38	505
	none, accounted, cons	1.57	1,568	1.21E-03	1.21	8.60E-03	8.60	8.13	2,968
	none, halved, cons	0.84	844	6.97E-04	0.70	5.14E-03	5.14	4.76	1,736
	none, unaccounted, cons	0.12	119	1.83E-04	0.18	1.67E-03	1.67	1.38	505
	coal, accounted, opt	1.57	1,568	1.21E-03	1.21	8.61E-03	8.61	8.13	2,969
	coal, halved, opt	0.84	844	6.97E-04	0.70	5.14E-03	5.14	4.76	1,737
	coal, unaccounted, opt	0.12	119	1.83E-04	0.18	1.67E-03	1.67	1.38	505
	wind, accounted, opt	1.57	1,568	1.21E-03	1.21	8.60E-03	8.60	8.13	2,968
	wind, halved, opt	0.84	844	6.97E-04	0.70	5.14E-03	5.14	4.76	1,736

	wind, unaccountent, opt	0.12	119	1.83E-04	0.18	1.67E-03	1.67	1.38	505
	none, accounted, opt	1.57	1,568	1.21E-03	1.21	8.60E-03	8.60	8.13	2,968
	none, halved, opt	0.84	844	6.97E-04	0.70	5.14E-03	5.14	4.76	1,736
	none, unaccountent, opt	0.12	119	1.83E-04	0.18	1.67E-03	1.67	1.38	505

Data analysis Scenario 2						
	Difference water footprint per unit of nutritional value Calories			Difference water footprint per unit of nutritional value Protein		
Scenario	difference (l/kcal)	percentage	m3/cap/y	difference (l/kcal)	percentage	m3/cap/y
S2P1	0.20	13.96%	215	31.6	78.60%	121
S2P2	0.7	50.48%	778	35.1	87.22%	134
S2P3	1.2	86.99%	1341	38.5	95.84%	147
S2P4	0.20	13.97%	215	31.6	78.60%	121
S2P5	0.7	50.49%	778	35.1	87.22%	134
S2P6	1.2	87.01%	1341	38.5	95.85%	147
S2P7	0.20	13.97%	215	31.6	78.60%	121
S2P8	0.7	50.49%	778	35.1	87.22%	134
S2P9	1.2	87.01%	1341	38.5	95.85%	147
S2P10	0.20	13.96%	215	31.6	78.60%	121
S2P11	0.7	50.48%	778	35.1	87.22%	134
S2P12	1.2	86.99%	1341	38.5	95.84%	147
S2P13	0.20	13.97%	215	31.6	78.60%	121
S2P14	0.7	50.49%	778	35.1	87.22%	134
S2P15	1.2	87.01%	1341	38.5	95.85%	147
S2P16	0.20	13.97%	215	31.6	78.60%	121
S2P17	0.7	50.49%	778	35.1	87.22%	134
S2P18	1.2	87.01%	1341	38.5	95.85%	147

water footprint per unit of nutritional value conventional system		
calories	m3/kcal	l/kcal

		0.001407306	1.407305936
	m3/gprotein	l/gprotein	
protein		0.040208741	40.20874103

REFERENCE VALUES	
Parameter	Value
Average water content of worms (dried)	5.00%
Average water content of trout	77.82%
Average water content of lettuce	95.63%
Mass fraction of Trout	7.83%
Mass fraction of Lettuce	92.17%
Global water footprint lettuce (l/kg)	240
Total WF Trout feed (m3/ton)	1500
WF per unit energy production in Europe (m3 /Tje) Coal	2100
WF per unit energy production in Europe (m3 /Tje) Wind	12
WF per unit of energy production in Europe (m3 /kwh) Coal	0.000583333
WF per unit of energy production in Europe (m3 /kwh) Wind	3.33333E-06
Calorfic value of Lettuce (Cal/kg)	150
Calorific Value of Wurms (Cal/kg)	2230
Calorific Value of Trout (Cal/kg)	1410
Nutrient Value of Lettuce (g*Protein/kg)	14
Nutrient Value of Wurms (g*Protein/kg)	530
Nutrient Value of Trout (g*Protein/kg)	209
Total WF of dutch consumer (m3/cap/y)	1541
Average Dutch dietary energy intake (kcal/cap/day)	3000
Average Dutch dietary energy intake (kcal/cap/yr)	1095000
Average Dutch protein intake (g/cap/d)	105
Average Dutch protein intake (g/cap/y)	38325

Total Dutch WF (m3/cap/yr)	2300
Average Dutch dietary energy intake (kcal/cap/day)	3000

WF common meats					
	WF conventional system		Nutritional Value protein	wf per unit of nutritional value protein	
	m3/ton	m3/kg	g / kg	m3/gprotein	l/gprotein
Beef	6513	6.513	138	0.047195652	47.19565217
Pig	4429	4.429	105	0.042180952	42.18095238
Chicken	1787	1.787	127	0.014070866	14.07086614
Egg	1341	1.341	111	0.012081081	12.08108108
Milk	528	0.528	33	0.016	16

Analysis meats and vegetables conventional vs FRE2SH				
		water footprint		
Group	product	Conventional	FRE2SH	
		l/kg		
Vegetables (lettuce)	lettuce	237	16.54	
		l/gprotein		
Animal Protein	beef	47.19565217		
	pig	42.18095238		
	chicken	14.07086614		
	Egg	12.08108108	all products of fresh combined cons	all products of fresh combined opt
	milk	16		
	Total	115.53	8.60	8.60