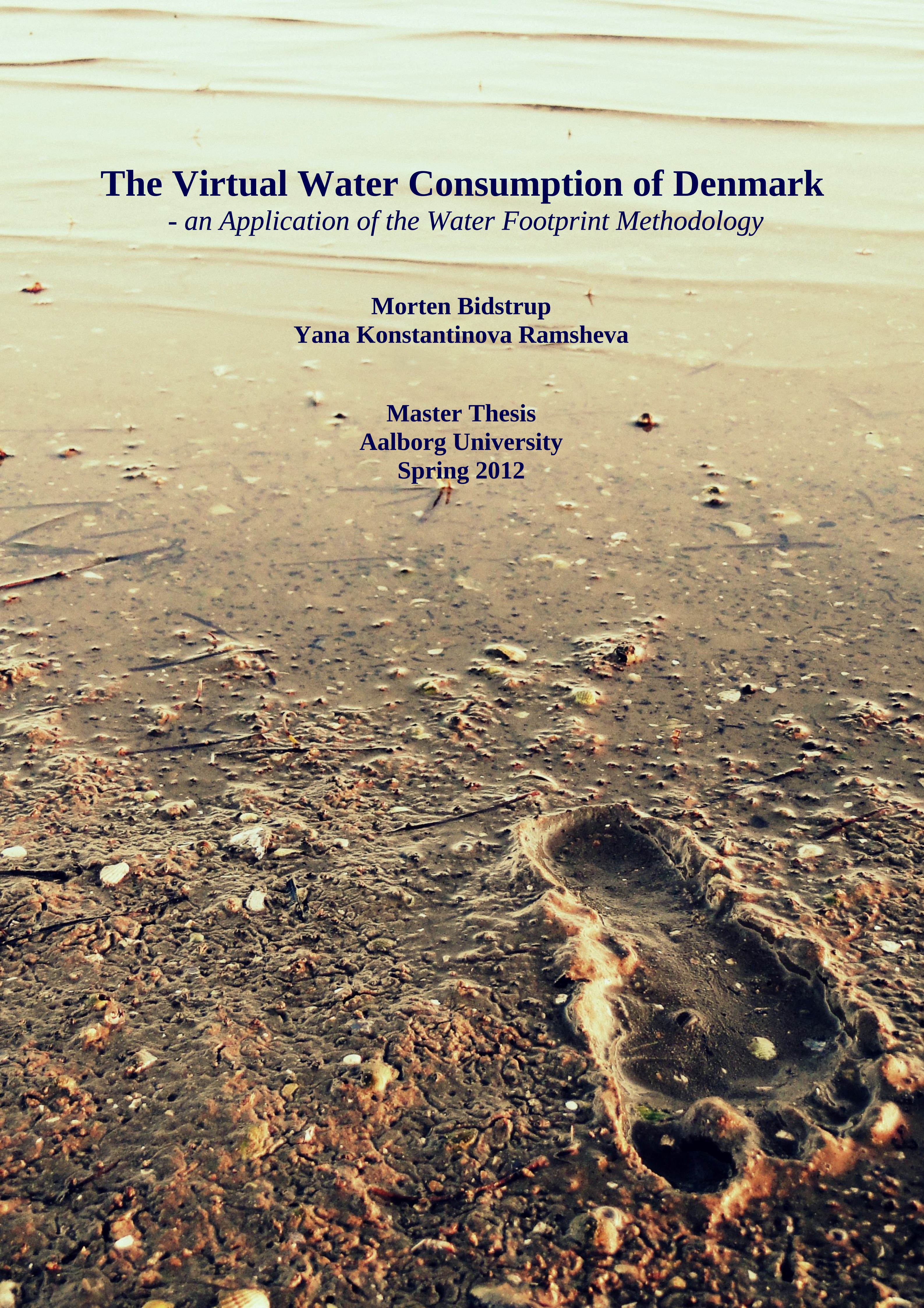

The Virtual Water Consumption of Denmark

- an Application of the Water Footprint Methodology

Morten Bidstrup
Yana Konstantinova Ramsheva

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I. Title Page

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Supervisor:	Per Christensen Professor Department of Development and Planning, Aalborg University The Danish Centre of Environmental Assessment
Co-supervisor:	Dr. Ludwig Tent Wastewater Management and Water Protection, Technische Universität Hamburg - Harburg
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Writers:	

Morten Bidstrup
JEMES student

Yana Konstantinova Ramsheva
EMSS student

II. Preface

This report is the master thesis of Morten Bidstrup and Yana Ramsheva, written in the spring of 2012 at Aalborg University, Denmark. The study consists of 70 pages, including formalia, bibliography list, two appendices and eight Microsoft Excel files on a CD-ROM. It is primary addressed to the supervisors, the examiner and the public. Our research is a pilot project and it is based on the methodology proposed by the Water Footprint Network. It provides new insights on the water consumption patterns of Denmark. We hope our work will contribute to further research on the topic and that it will be the first step towards fully understanding how Danes influence the global fresh water resource.

As authors of this report, we would like to thank the Water Footprint Network team for developing a detailed manual for conducting water footprint assessments, as well as freely available water footprint product-specific databases without which this research would not have been possible to conduct.

We would also like to acknowledge the devoted efforts of both of our supervisors; however, especially Per Christensen for the guidance and support from the initial to the final level of our research.

III. Abstracts

English

Clean fresh water is a valuable natural resource, but it is under continuous threat due to an anticipated global increase in both consumption and pollution. The objective of the study is to investigate whether water footprint assessments can provide new knowledge for the Danish water management – thus clearing the way for a more holistic management approach. The study provides a wider perspective on how water is consumed or polluted by Danish activities.

The water footprint methodology divides water use into three categories; namely, blue water, water abstracted from surface waters or groundwaters; green water, water biologically abstracted from the soil matrix; grey water, the water needed to assimilate pollutants. The notion of the "footprint" implies that all products have a virtual water volume assigned; a unit equivalent to all the water consumed and polluted along the chain of production. The methodology provides a conceptual change in modern water management, since water consumption is both assigned to the consumer and the producer, respectively defined as the direct water footprint and the virtual water footprint.

The study is conducted exclusively on a national level, and it includes water from households, public institutions, agriculture and industry. Virtual water bodies are assigned to the trade of 377 agricultural products, whereas industrial water trade is calculated for those 55 countries that account for 98% of all Danish imports.

The Danish water footprint is 35% higher than the world average, and this value has remained rather constant for the last 20 years despite significant lowering of the direct domestic water footprint. The virtual water footprint proves to be 14% lower than the direct water footprint due to export of animal products; an export of virtual water equivalent to almost 2/3 of all water used in Denmark. When looking at an average Dane, his actual blue water use increases from 123 l/day to 480 l/day by following the water footprint methodology. His daily coffee consumption surpasses all water used for bathing, cleaning, cooking and drinking, and he can greatly impact his personal water footprint by making smarter product choices.

The conducted research is built on well-tested and well-documented principles, but it is completely new in a Danish context. It opens up for much further academic extrapolation; however, the main result is that the water footprint methodology <u>can</u> provide new knowledge for the Danish water management.

Dansk (Danish)

Rent ferskvand er en forudsætning for alt liv, men stigende global efterspørgsel på vand og stigende forurening af vand bringer ressourcen i fare. Formålet med denne rapport er, at undersøge om vandfodsporsanalyser kan bidrage med ny viden, og derved bane vejen for en mere holistisk dansk vandforvaltning. Rapporten giver et bredere perspektiv på, hvordan vand forbruges og forurenes af Danmark og den danske livsstil.

Vandfodsporsteorien inddeler vandforbrug i tre kategorier. ”Blåt vand” refererer til alt indvundet overfladevand eller grundvand, ”grønt vand” refererer til alt biologisk indvundet vand fra jorden, og ”gråt vand” refererer til det nødvendige vandvolumen for at fortynde en forureningsmængde. ”Fodspor”-definitionen implicerer, at alle produkter vil have et virtuelt vandvolumen tilknyttet, og dette er defineret som summen af alt vandforbrug og vandforurening tilknyttet fremstillingen af produktet. Teorien resulterer i en konceptuel ændring af den traditionelle vandforvaltning, eftersom enhver vandpåvirkning tildeles både forbrugeren og producenten. Dette er defineret som henholdsvis det direkte vandfodspor og det virtuelle vandfodspor.

Rapporten er udelukkende udarbejdet på et nationalt niveau, og den inkluderer vand til husholdninger, institutioner, landbrug og industri. Der er tilknyttet virtuelle vandvoluminer til den nationale handel med 377 forskellige landbrugsprodukter, og den industrielle virtuelle vandhandel er beregnet for de 55 lande, der står for 98% af den danske import.

Det danske vandfodspor er 35% højere end verdensgennemsnittet, og værdien har været relativ konstant over de seneste 20 år, på trods af en betydelig optimering af det direkte nationale vandforbrug. Det virtuelle vandfodspor er 14% lavere end det direkte vandfodspor, og dette skyldes den virtuelle vandeksport af svinekød, hvis omfang er på størrelse med 2/3 af alt vand forbrugt i Danmark. Vandfodsporsteorien betyder desuden, at det direkte blå vandforbrug for en gennemsnitsdansker stiger fra 123 l/dag til 480 l/dag, og vandfodsporet af hans daglige kaffeforbrug er f.eks. større end vandforbruget forbundet med bad, tøjvask, opvask og madlavning. Rapporten understreger, at enhver dansker kan sænke dit vandfodspor ved at vælge forbrugsgoder med omhu.

Forskningen i denne rapport er velafprøvet og veldokumenteret, men tankegangen er ny i en dansk sammenhæng. Den åbner op for fremtidig akademisk ekstrapolering, men det overordnede resultat er, at vandfodsporsteorien kan bidrage med ny viden.

Български (Bulgarian)

Чистата и свежа вода е ценен природен ресурс, който е под постоянна заплаха поради вероятното глобално увеличаване на консумацията на продукти и замърсаването на околоната среда. Целта на това проучване е да проследи дали изследването на водния отпечатък' ("water footprint assessment") може да допринесе нова информация за ръководството на водните ресурси в Дания, подпомагайки по такъв начин за изграждането на холистичен подход на управление. Проучването също така дава една по-различна перспектива за дейностите извършени в Дания, които водят до използването и замърсяването на водните ресурси.

Следвайки методологията на 'водния отпечатък' ("water footprint"), водният ресурс се дели на три категории – синя вода, извлечена от повърхностните- или подземни- води; зелена вода, биологично извечена от почвата; сива вода, необходима за асимилация на замърсителните вещества. Понятието 'отпечатък' ("footprint") означава, че всички продукти притежават тъй наречения 'виртуален воден обем', който се равнява на количеството вода изпозвана във всички стъпки на процеса на производство. Методологията също така предоставя възможността за промяна на фокуса на ръководство на водните ресурси, тъй като воданото потребление е приписано както на потребителя, така и на производителя на консумираните изделия. Това водно потребление се дефинира респективно като 'пряко ' и 'виртуално' изпозлване на водния ресурс.

Проучването е извършено на национално ниво и вкючва както водата, използвана от домакинствата, така и тази използвана от селското стопанство и индустриите. 'Виртуални' водни единици са възложени на 377 търговски стопански продукта. Търговската дейност с индустриални продукти (окачествена като 'воден ресурс' в $м^3$) е изчислена за 55 страни, представляващи 98% от водното количество на внос в Дания.

'Водният отпечатък' ("the water footprint") на Дания е 35% по-висок от средния за всички страни в света, и тази стойност е постоянна за последните 20 години, въпреки значителното намаляване на водата за домакински нужди. 'Виртуалнитят воден отпечатък' ("the virtual water footprint") е 14% по-нисък от 'директния воден отпечатък' ("the direct water footprint"), което се дължи на износа на животиниски продукти. Това е износ на 'виртуална' вода равняващ се на почти 2/3 от целия воден ресурс, използван от Дания. Следвайки методологията на 'водния отпечтък' ("the water footprint methodology"), консумацията на синя вода на средния датски потребител се увеличава от 123 литра/ден до 480 литра/ден. Неговата дневна консумация на кафе надминава количеството вода използвана за къпане, чистене, готвене и пиене. Заключението е, че потребителят може значително да повлияе на персоналния си 'воден отпечатък' като разумно подбира продуктите си за консумация.

Проведеното проучване е базирано на добре изпитани и документирани принципи, но то е напълно новаторско в контекста на Дания. То отваря врати за по-нататъчно проучване на академично ниво.

Въпреки това, основният получен резултат е, че методологията на 'водния отпечатък' може да допринесе нова информация за ръководството на водните ресурси в Дания.

Table of Contents

1. Opening

Water is a precondition for all life on Earth and therefore among the most precious global resources. Humanity is dependent on the availability of clean freshwater and has thus, through time and evolution, come to both consume and pollute vast quantities of it every year. Though freshwater re-generates continuously in the hydrological circuit, one must not take the resource for granted, and water management is thus gaining ever more importance nationally as well as internationally.

Human needs of water have evolved - from meeting basic necessities for survival, to numerous applications of water in the daily activities. Water has become a precondition for urban life and it is used for sanitation, cooking, cooling and heating. It is furthermore used for agricultural irrigation and industrial purposes such as mining and manufacturing. All these activities have dramatically increased the water consumption and this tendency can be exemplified by the fact that an industrialised country like USA uses around 2.5 times more water per capita than India, [AQUASTAT 2010, (c)], [AQUASTAT 2010, (d)].

Water pollution is also a global environmental concern. Mining activities can cause massive groundwater pollution, while industries such as paper mills, petroleum refineries and other chemical plants generate hazardous wastewater. About 20% of the global water withdrawal is used for industries and energy production, and this water is often returned to the source in a contaminated state without prior treatment. Additionally, much industrial and public wastewater is treated inadequately even after reaching designated sanitary systems. Last but not least, agricultural activities cause pollution by realising pesticides, nitrogen, phosphorous and other substances, into ground- and surface- waters. [UNEP 2010]

Water-related problems are both local and global issues. Every nation shares a part of the responsibility, either directly or through the demands created by trade. It is vital to realise that all activities, industrial or not, are directly on indirectly related to a certain amount of both water consumption and water pollution; hence, a water footprint can be assigned. The collective and individual choices we make all hold such footprints; however, this fact has previously been given little attention, [Hoekstra, et al. 2011].

For example, whenever one buys an orange, one also buys a certain fraction of all the water, nutrients, and pesticides used in order to cultivate an orange tree in Southern Spain. Whenever one buys a new mobile phone, one also buys a fraction of all the water used in the production process, as well as a fraction of all the water pollution assigned to the precious metal components. Whenever one buys a new T-shirt on sale, one also buys a fraction of the water pollution assigned to textile production in poor corners of the world. The list goes on.

In a world with free market forces, the individual must further realise that every bought product changes the demands for the market, and it is thus crucial to make smart and thought-through decisions. The methodology of life cycle assessments (LCA) has for some years now aimed at identifying consumption and pollution along the production and supply chain, [Kørnøv, et al. 2007]; however, that has until recently not been a big focus area within the science and practice of water management, [Hoekstra, et al. 2011].

This present study will investigate whether the methodology of the water footprint can create new knowledge for the water management of Denmark, and thereby facilitate a broader and better-informed national management of the global fresh water resource.

2. The Water Footprint Methodology

This chapter serves the purpose of introducing the water footprint methodology. Firstly, all concepts and definitions will be presented in a clear and coherent manner, thereby creating a foundation for the later analysis in this very paper. Lastly, a discussion is made in relation to the similarities and differences of the water footprint, the carbon footprint and the ecological footprint. It is included in order to avoid misunderstandings related to these 3 management tools that have a rather similar name, as well as to create a foundation for future comparison of research papers that deal with one of these concepts.

2.1 The current state of standardisation

The International Organization for Standardization (ISO) is currently in the process of developing a new standard 'ISO 14046 Water footprint – Requirements and guidelines', which will provide an internationally standardised approach for calculating water footprints. It is not yet decided whether ISO 14046 will include a methodology for calculating the offsets or compensation, but it will serve the purpose of assisting the reduction of the water footprint, by complementing other already existing standards on life cycle assessment (LCA). [ISO 2011]

Due to the lack of international standards in the area of water consumption and savings, organizations apply diverse criteria when reporting their water use. The Water Footprint Network (WFN) is an association that strives to create an accurate methodology and tools for a more coherent estimation of the water footprint of governments, companies, and other public organizations. The WFN is a non-profit foundation under the Dutch law. It is an international network, working with diverse stakeholders, non-profit organizations, universities, businesses and other international corporations. [WFN 2012]

The WFN has a board with two directors, Mrs. Ruth Mathews (executive director) and Prof. Arjen Y. Hoekstra (scientific director and also creator of the water footprint concept). There exists also a supervisory- and advisory council, and other partners who have either contributed to the establishment of the network and/or worked as advisory bodies by providing feed back experiences to improve the tools of the network. The function of the WFN is to assist governments on formulating policies regarding water resources, share knowledge with the academia on open forums of debates, and offer global standards and tools for carrying out a Water Footprint Assessment. [WFN 2012]

The organisation published the first standard for water footprint assessments in 2009; however, the newest publication is "The Water Footprint Assessment Manual – Setting the Global Standard" from 2011, [Hoekstra, et al. 2011]. The methodology from this publication shapes the foundation of the theory applied in this paper. It will be referred to as reference [Hoekstra, et al. 2011].

The organization also conducts various research and reports on estimating the water footprint of diverse agricultural and animal products, as well as country-specific water footprint accounts that can be used for benchmarking, [International Footprint Network 2012]. Examples of such papers are:

- "Research Report Series No. 47
  - The green, blue and grey water footprint of crops and derived crop products",
  [Hoekstra and Mekonnen 2010, (a)]
- "Research Report Series No 50
  - National water footprint accounts:
  The green, blue and grey water footprint of production and consumption",
  [Hoekstra and Mekonnen 2011]

2.2 The constituents of a water footprint

The water footprint is a comprehensive indicator of freshwater resource appropriation that can be perceived as a supplement to a more traditional water management. It is a measure for the amounts of freshwater used or polluted along the supply chain of a product or an activity, and it is divided into three subcategories that sum up to the total water footprint.

The three categories are: Blue water, Green water and Grey water. [Hoekstra, et al. 2011].

- Blue water refers to the consumption of groundwater or surface water.
- Green water refers to the consumption of natural rainwater.
- Grey water refers to the volume of ambient water needed to assimilate a pollution load from an activity.

"Consumption" is defined as any water body lost from the catchments area it was taken from. The term can be discussed, since water will never be lost – it will merely change its chemical structure. "Consumption" therefore refers to an application of water to a process, after which it is no longer available for other applications at that same location. That will for instance be the case if water is evaporated or if is has been transported to a wastewater treatment plant in sewage pipes. [Hoekstra, et al. 2011]

"Assimilation" refers to uptake of the pollutant by dilution in receiving water bodies. Any pollution load can in theory be diluted to a state where the water quality complies with ambient quality limits; however, the water needed for this dilution should, from a normative perspective, be assigned to the polluter. The water volume needed for such assimilation depends on the pollution load, the ambient concentration and the ambient water quality standard. [Hoekstra, et al. 2011]

2.3 Water footprint of a product - EXAMPLE: Potato production

Agricultural products are among the most water intensive, and section 2.3 will therefore serve the purpose of presenting how such a water footprint can be calculated – see figure 2.1. The potato plant is chosen as the subject of the example since it is well known in both Denmark and in the rest of the world.

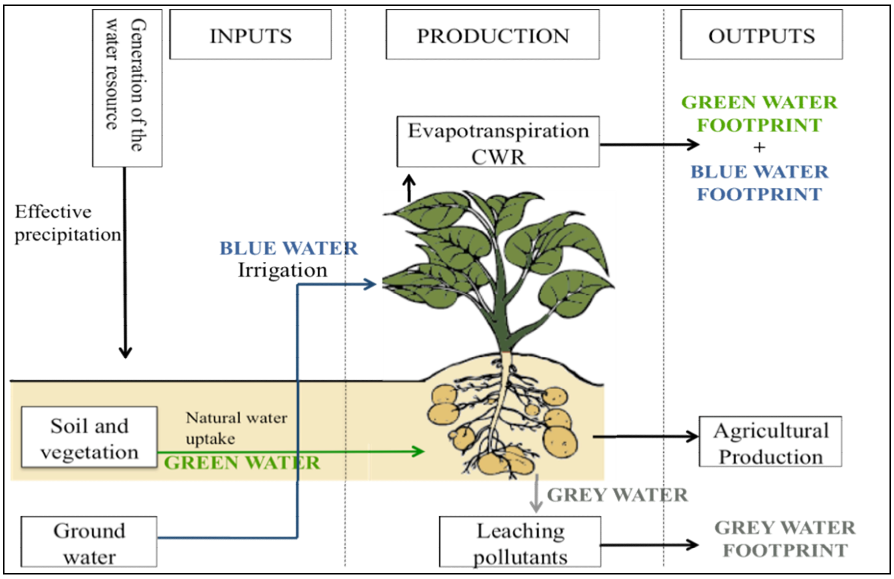

Figure 2.1: The water footprint of potato production
The potato drawing derives from [Potato plant picture n.d.]

A potato plant will during its stages of growth have a certain Crop Water Requirement (CWR) in order to produce maximum yield, or in extreme cases in order to survive. The CWR is dependant on both plant characteristics and on climatic factors, since high temperatures, direct radiation and low humidity will increase the evapotranspiration and thus also the water requirements of the plant. The CWR will be uptaken from the soil matrix, and it can, in theory, be supplied from 2 different sources – natural precipitation and man-made irrigation. [FAO 1998]

The consumption of water available in the soil matrix will be assigned green water whereas the usage of surface water or groundwater for irrigation will be assigned blue water. The water volume will be noted as "consumed" since the water is either lost by evapotranspiration or moved to another catchment area as the small fraction of water actually stored in the potato crop. Figure 2.1 shows that a certain load of pollutants will leach and thus re-enter the hydrological circuit due to bad agricultural management. This load needs to be assimilated in the recipient; hence, a grey water footprint can be assigned.

The potato plant from figure 2.1 will in the end produce a yield in the form of potatoes that can be sold. The demands for those potatoes have caused a water use matching the sum of the blue, green and grey water use during the growth period. This water usage can be expressed in relation to profit, yield or land use. By doing so, it is possible to compare potato production with, for instance, wheat production in relation to which crop choice that will generate most profit for the local community or most biomass for the production of food or energy; hence respectively the units [m^3/DKK profit], [m3/ton yield] or [m^3/kcal]. The present research will solely deal with the production of biomass for consumer good; hence equation 2.1.

$$WF_{crop} = \sum WF \,/\, \text{potato yield}, \; [m^3/\text{ton}]$$

Eq. 2.1: Calculation of a potato water footprint, [Hoekstra, et al. 2011]

When conducting any sort of life cycle assessment, it is important to carefully consider how allocation of impact is conducted in the case of a production process with multiple outputs. The Water Footprint Network proposes that such matters are dealt with in regards to both the mass and value fraction of the product when, [Hoekstra, et al. 2011].

Returning to the example of the potato plant, such considerations are necessary when studying potato flour production. Potato flour production is normally combined with the production of potato protein, and these two processes have are residues respectively potato pulp and potato juice. Potato pulp has a value as animal fodder, and the potato juices can be used as fertiliser; hence, 4 products ultimately exist – see figure 2.2. [AKS 2012]

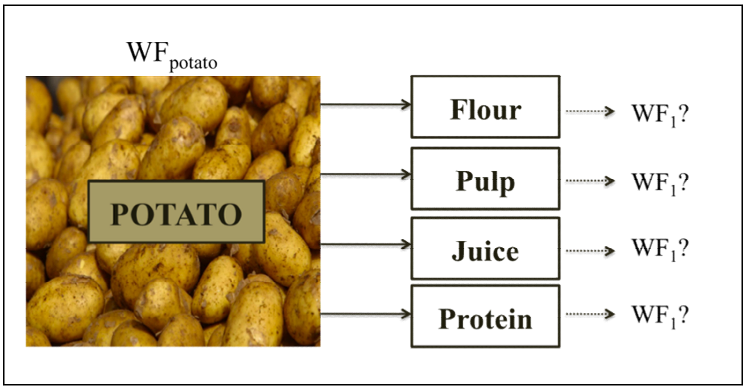

Figure 2.2: The outputs of potato flour production
[The potato picture derives from [Potato image, n.d.]

Each of these products will represent a fraction of both the mass of the original potatoes input, $\mathbf{f_m}$, and a fraction of the value generated, $\mathbf{f_v}$. Moreover, the processing of the potato may also require some operational water.

Following this methodology, the water footprint of any product can be determined by the use of equation 2.2.

$$WF_{product} = WF_{operation} + (WF_{input} * f_m / f_m)$$

Eq. 2.2: Calculation of a potato water footprint, [Hoekstra, et al. 2011]

2.4 Water footprint in relation to area specific water management

It is also possible to conduct water footprint assessments on delimited areas such as river basins, municipalities and nations. These can be used for identifying environmental hotspots in relation to water consumption and water pollution, and therefore integrate planning in regards to water abstraction permits, wastewater discharges, agricultural leaching, area use, nature preservation, etc. [Hoekstra, et al. 2011]

The principle is illustrated as figure 2.3.

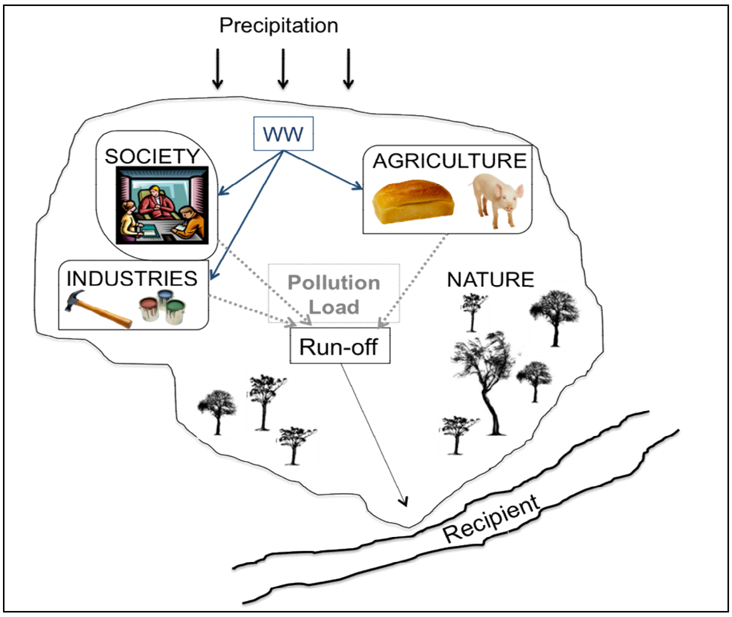

Figure 2.3: A sketch of the water usage in a delimited area.
The pictures derive from [Picture, n.d.] ***and*** [Pictures, n.d.]

Effective precipitation is the main input of the water balance. This volume would then in pristine conditions either be lost through evapotranspiration of natural vegetation, or run off the catchment area as either groundwater or surface water. However, society has modified the environment by societal activities, agricultural activities and industrial activities, and these modifications require water from the local waterworks. These water quantities will then be consumed, after which some load of pollution will be released to the environment.

The activities from figure 2.3 can be expressed as a water footprint by the very same principles as in figure 2.1. This extrapolation is presented in figure 2.4 in relation to the water balance of a delimited area. The total resource is defined by the effective precipitation, after which some volume will be lost by non-production related evapotranspiration – i.e. evaporation from surfaces or consumption from nature. Industrial biological water uptake from the soil matrix will be accounted as green water, whereas water abstracted from groundwater reservoirs will be accounted for as blue water. The remaining fraction of water will run-off. Assimilating the pollution load from society will generate a grey water footprint that represents the flow of run-off water needed in order to assimilate the pollution expelled from the societal activities.

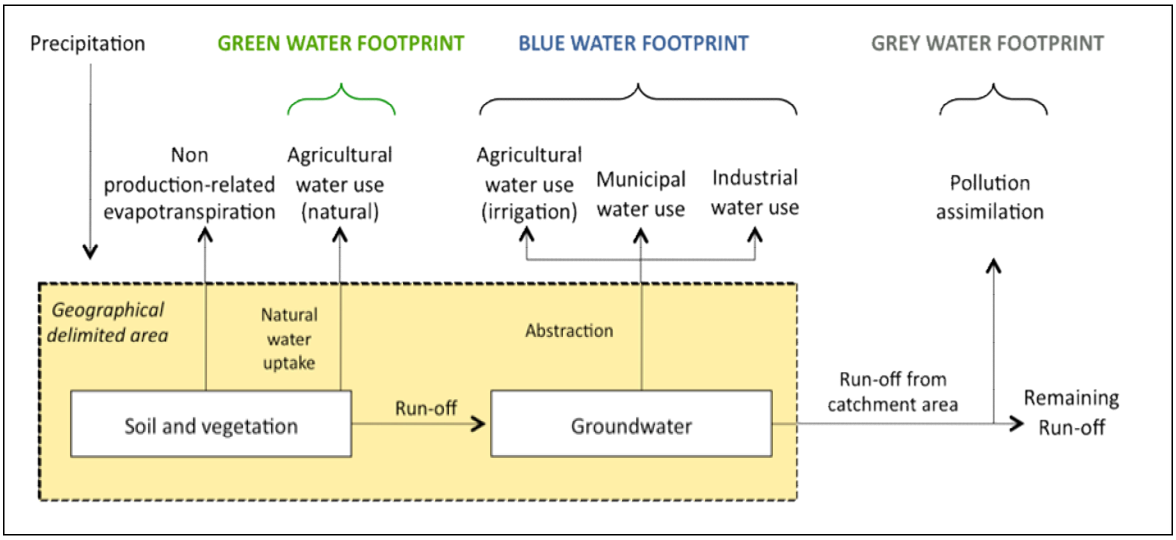

Figure 2.4: The water balance of a delimited area in relation to the water footprints [Hoekstra, et al. 2011] ***- modified]***

The principle is unique because it integrates matters of water use, area use and pollution on one common unit – volume of water used. It is possible to subdivide the overall footprint into colours and sectors in order to analyse specific areas of interest in relation to the local water resource. The water footprint could for instance be divided among the industries of the community, and it could thus be investigated which ones that are most efficient in relation to the profit they generate for the local community; hence [m3/DKK profit] or [m3/DKK salary paid]. The same principle could be used in regards to pollution by investigating which companies that generate large grey water footprints. [Hoekstra, et al. 2011]

2.5 Water footprint in relation to consumption

The water footprint methodology has until know only been presented as a way of integrating matters of water usage and water pollution into one unit that is rather easy to understand and to communicate - this approach is useful when managing quantitative water resources in a delimited area. However, the methodology of the water footprint is also strongly correlated to the theory of life cycle assessments (LCA), in the way that it strives at solving the global problem of freshwater scarcity by highlighting the demands for water intensive goods, [Hoekstra, et al. 2011]. LCA are gaining more and more importance within modern environmental management, and the international office for standardisation (ISO) describes the trend as:

"The increased awareness of the importance of environmental protection,
and the possible impacts associated with products, both manufactured and consumed,
has increased interest in the development of methods to better understand and address these impacts.",

[ISO 2006, (a)]

Every product consumed has resulted in a water use – blue, green and grey – along the chain of supply and production. LCA implementation to the water footprint concept is thus making it possible to assign water use to the consumer instead of the producer; hence, defining virtual water use. This is illustrated in figure 2.5 below. [Hoekstra, et al. 2011]

The consuming unit can be defined in many ways; however, figure 2.5 illustrates a human consumer. Such a unit will consume direct blue water from the local waterworks, and discharge waste which can be presented as a direct grey water use. Moreover, the unit will consume a variety of products which have all had a water usage during their life cycle, and this is defined as the virtual water footprint. Following this theory, it is evident that there are two different ways of perceiving the water use of the potato production from section 2.3. It can either be perceived as direct water footprint assigned to the process of growing the crop, or it can be assigned as a virtual water footprint of the consumer who buys the potatoes. The approach is dependent on the aim and scope of study; however, it is important to be consistent so that "double counting" is avoided, [Hoekstra, et al. 2011].

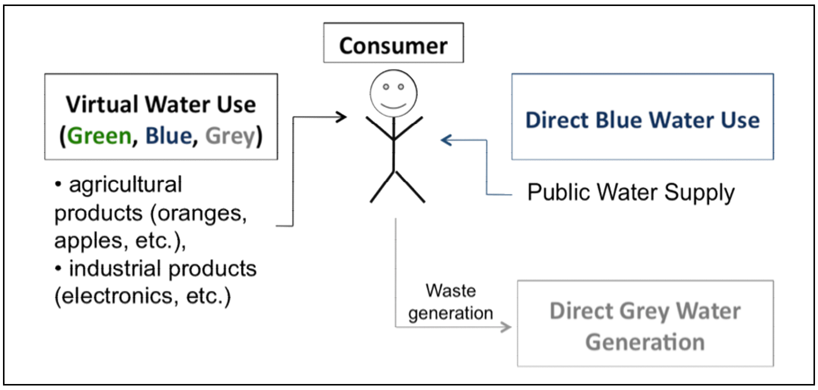

Figure 2.5: A sketch of the relation between direct water use and virtual water use.

The direct water use is important when applying the water footprint methodology to a delimited area in order to investigate the pressure on local resources, whereas one must use the virtual water approach whenever a broader perspective is needed. The consumption approach should be looked upon as an extension of the direct approach rather than a substitute. [Hoekstra, et al. 2011]

2.6 Water footprint in relation to trading

The notion of "consumption" is closely linked to the notion of "trade", since the goods for consumption has to be supplied from somewhere. Virtual water is thus being traded between people, companies and countries, thereby making is possible to establish trade balances. When considering an administrative area, such as a nation, one need to include "own production" into this balance. The overall principle is exhibited in figure 2.6. As illustrated, the consumption will be supplied from either internal supply or from external supply. The external supply can also be described as virtual water import. The remaining fraction will then, if not stored, supply the needs of the rest of the world, thus generating a virtual water export. It is by this approach possible to describe the water use of countries and other delimited areas. [Hoekstra, et al. 2011]

It is important to note that the natural water resource at the site of production is completely overlooked by this approach, as it only deals with the virtual water related to the trade of goods. The virtual water analysis can therefore not be directly used for assessing the environmental impacts of production, since it is unknown whether the water derives from regions with scarce or with abundant resources. However, one can argue that a certain consumer uses too much water, if the total water consumption, hereby also included the consumption of virtual water, surpasses the quantity of the local resource available.

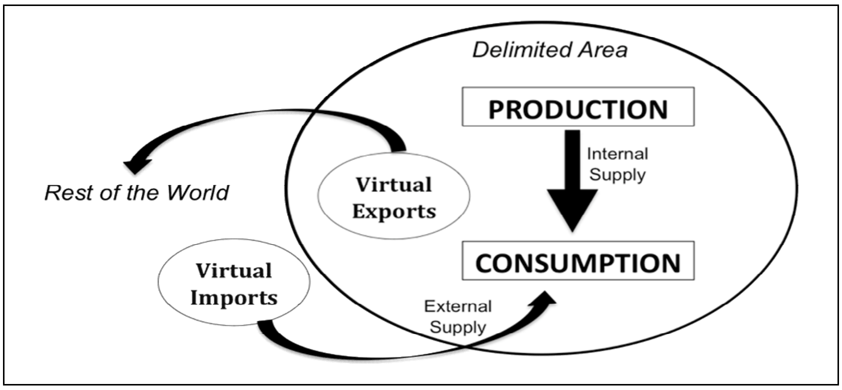

Figure 2.6: The virtual water balance of a delimited area. [Hoekstra, et al. 2011 - modified]

2.7 Water footprint in relation to other tools

The water footprint is a relatively new concept; however, it still leads to associations with other tools for evaluating environmental impacts due to the expression "footprint". This term relates to a similar outcome of a process, namely an impact that is created from extraction, production, transportation, use of a product, etc. The methodology can, as described in regards to the water footprint, be applied on products, activities or a consumptive unit. The common factor is that smaller impacts are summarised in order to achieve the overall footprint of the functional unit chosen.

The carbon footprint and the ecological footprint are such tools, and they also aim at assisting decision makers in evaluating policies, projects or technological options, according to their impacts. They seek at mitigating on the global problem of over-exploitation of natural resources; however, there exist several differences between the 3 management tools. Table 2.1 describes the main differences and similarities between the three footprints. All background information will be presented subsequently.

	Water Footprint	Carbon Footprint[1]	Ecological Footprint[2]
Aim	assessing freshwater withdrawal and pollution	assessing GHG emissions	assessing overexploitation of natural resources
Unit [b]	use of freshwater resources [m^3/yr] [b]	emissions of GHGs [CO_2 equivalents][b]	use of bio-productive land [ha] [b]
Footprint components [a]	Sub water footprints: green water blue water grey water	GHG emissions: CO_2 CH_4 N_2O,	6 land categories[a]: arable land pasture land forest and woodland built-up land productive sea area energy land
Local vs. Global	local perspective of a global problem	global	local perspective of a global problem
Weighting	water volumes are NOT weighted	GHGs are characterised as CO_2 equivalents, but they are NOT weighted	the land categories are NOT weighted

Table 2.1: Comparison between water footprint, carbon footprint and ecological Footprint
References: ***a =*** [Arjen Y. Hoekstra 2007]***, b =*** [Aldaya, Hoekstra 2010]

[1] The carbon footprint is an indicator that describes the outcome of human activities on climate change. Green house gases (GHG) (carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), etc.) are emissions that have a Global Warming Potential (GWP). The GWP shows the consequences of greenhouse gases on climate change. Each of the GHGs are converted and expressed in terms of CO2 eq., which makes the comparison between the effects they cause more simple, [CCC 2009]. Carbon footprint, and respectively CO2 eq., can be assigned to an activity, a process or to the life-cycle of goods and services, [EPLCA 2007].

[2] The idea of an ecological footprint assessment is to convert all the Earth impacts of individuals, processes, activities, or regions, into biologically productive areas. The method accounts for the flows of energy and matter to and from an economic activity. When estimated, these flows are then converted into six land-area categories required to sustain the activity. The ecological footprint is considered a useful tool when estimating the human exploitation of recourses, since it reduces complex processes to a single-dimension indicator. It has on the contrary been strongly criticized since it does not represent concrete land use and oversimplifies the ecological impact of human activities. Those issues will be briefly described in sub-section 2.7.7. [van den Bergh and Verbruggen 1999]

2.7.1 The aim of the tools

The most obvious difference between the 3 tools is the fact that they aim at assessing the impacts on 3 different problems, respectively fresh water scarcity, global warming and over-exploitation of natural resources. One can argue that fresh water scarcity and global warming are environmental and social impacts caused by over exploitation of resources; thus emphasising that the ecological footprint is tool that integrates many aspects of management into one indicator.

Consequently, the difference in the aim of the tools is projected onto the very nature of each of them. The water footprint only assesses freshwater withdrawal and pollution, while the carbon footprint will only includes greenhouse gases that contribute to global warming. The ecological footprint includes all impacts.

2.7.2 Global vs. local

All the 3 management tools are assigned to global problems in relation to specific activities; however, the nature of these problems creates an inconsistency. Global warming is an increasing problem by which all nations will be affected due to rising sea levels, changed precipitation patterns, ocean acidification, more extreme weather, etc, [GlobalWarming.com 2012]. This stands as a clear contrast to the problems assessed by the ecological footprint or the water footprint, since they mainly cause local problems. Land use change and water shortage will, for instance, always be a more severe problem in local regions where deforestation is causing sustainability problems or where water resources are scarce already, respectively.

Nevertheless, the vast amounts of trade occurring nowadays between nations with abundance or lack of recourses, as well as the demand for diverse products, leads to an increasing production of goods and causes overexploitation of land and water in areas with a shortage. This is the link that makes freshwater shortage and exploitation of other natural resources a global problem. The virtual water trade is thus serving the purpose of establishing scarcity of local water resources as a global concern, [Hoekstra, et al. 2011].

The water footprint differs from the carbon footprint by focussing on a global problem that mainly relates to local problems, and this local perspective shapes the very way that the problem can be solved. A carbon emission can in theory be compensated by planting more trees or by erecting wind turbines, since such initiatives will lower the overall concentration of greenhouse gases in the atmosphere – a so called "off-setting" activity. However, off-setting is not an option in regards to mitigation of the water footprint, since i.e. desalination facilities in Africa will not help communities without water in India. [Hoekstra, et al. 2011]

2.7.3 The necessity of weighting

Weighting is an optional step in any Life Cycle Assessment (LCA) where the obtained results are multiplied with a numerical factor according to some prior value-choices. Such choices may not have a strong connection to science, but they will still have a great influence on the interpretation of the LCA, since they convert the prior results according to the defined values. [ISO 2006, (b)]

Neither of the three tools have weighting as a mandatory step; however, there is a clear difference in whether weighting ought to be conducted.

Weighting is not important in regards to the carbon footprint since a certain GWP will have the same consequences independently of whether it is generated in Spain or in Denmark; however, than is not the case with the 2 remaining more locally important footprints. One cubic meter of water consumed locally may have very different sustainability consequences, depending on it being consumed in a community with abundant water or in a community with scare water reserves. The same is the case in relation to the ecological footprint where it can be argued that i.e. deforestation in one region may lead to a greater impact on sustainability and biodiversity than in other regions.

The Water Footprint Assessment Manual briefly mentions the concept of virtual water weighing; however, it has not yet been adopted in the concept of water footprinting. [Hoekstra, et al. 2011]

2.7.4 The credibility of the footprints

The three tools all suggest that a certain activity will have a water body, carbon equivalent or land use assigned. In such cases, it is always a good scientific practise to look into the credibility of such results – "are they showing the true picture?".

Assumptions are always made in order to produce a holistic picture of the size of the footprint, and this can lead to credibility problems. One can never be sure about whether the energy needed for producing one subcomponent in China has been produced by coal, wind or hydro power, and in regards to the water footprint it is very hard to estimate the true percentage of agricultural leach from each field. This generates an overall incredibility of all three footprints.

Despite the assumptions, one can argue that the carbon footprint and the water footprint have a good credibility, since studies can be made in order to characterise the quantities of greenhouse gas emissions or the quantity of water use in during the life cycle of i.e. a product. However, one can argue that the water footprint can have incredibility in regards to the grey water footprint, since a discharge to a saltwater recipient will be diluted in saltwater and thus not have any influence on fresh water scarcity.

The ecological footprint has lower credibility since is it not necessarily describes a real land use change. Furthermore it does not distinguish at all between whether a land use is sustainable or unsustainable, [van den Bergh and Verbruggen 1999]. An official study about the tool describes the credibility and utility of the ecological Footprint (EF) as such:

"*… the EF is unsuitable as a tool for informing policy-making:*
it can support unsustainable, inefficient and even immoral policy options",

[van den Bergh and Verbruggen 1999]

2.7.5 The acceptance of the tools

The carbon footprint is a well established tool for measuring environmental impacts. There exist numerous articles and various studies conducted on that topic, and the concept is directly assigned to the principles of ISO 14040, [Kørnøv, et al. 2007]. The ecological footprint did not gain as much popularity as the carbon footprint as a sustainability indicator. The main reasons are that ecological footprint represents hypothetical rather than actual land use and that it fails to make a distinction between sustainable and unsustainable land use. [van den Bergh and Verbruggen 1999]

The water footprint is gaining popularity in environmental assessments. It is a fairly new tool; the first Water Footprint Guide was published in 2009, followed by an updated version in 2011, [WFN 2012]. An ISO standard on water footprinting is currently under development, [ISO 2011]; however, the concept is acknowledged and used by large international institutions such as the United Nations Environmental Programme, [UNEP 2011], and World Wildlife Fund, [WWF, et. al 2010].

2.7.6 Synergies between the tools

It is now evident that both similarities and differences exist among the three tools: water footprint, ecological footprint and carbon footprint. However, it is not always a matter of "either, or" when selecting a tool prior to a sustainability evaluation - several studies have been made on combining the tools.

One study combines the ecological footprint and the carbon footprint to evaluate the environmental sustainability of policy options in Northern Ireland. By this synergy, it is possible to generate a more comprehensive recommendation for policymakers; compared to if the more well-known carbon footprint was the only tool in use, [European Commission 2012].

A synergy between the water footprint and the ecological footprint is furthermore suggested by the Water Footprint Network. They argue that the 2 methodologies rather easily can be adopted in the same analysis, though it will require more data and thus be more time consuming. A synergy can however result in research of a higher quality, since for instance the process of transport will be almost insignificant in regards to the water footprint methodology, though it might still result in unwanted non-water related environmental impacts. [Arjen Y. Hoekstra 2007]

Carbon Footprint Assessments are following the methodology of Life Cycle Assessments (LCA), described in ISO 14040 and ISO 14044, [Kørnøv, et al. 2007]. As written, an ISO standard on water footprinting is currently in the making; however, studies have already been made on the possibility of implementing the water footprint in LCA software tools such as SimaPro or Gabi. Reference [Jefferies, et. al 2010] is one of such studies, and it argues that the blue water footprint methodology can be successfully included into an LCA tools and databases if the concept of “consumed water” rather than “abstracted water” is adopted. It argues that this would enable a more comprehensive calculation while it will save time, [Jefferies, et. al 2010]. However, it might be difficult to introduce the green water footprint methodology to an LCA database, since evapotranspiration remains complex due to the absolute dependency on local climatic condition and water balances. Nevertheless, reference [Wiedemann and McGahan 2010] argues that an implementing of the green water concept into LCA software is a necessity in order to truly evaluate the stress on freshwater resources; hence, further improvement of the LCA methodology is needed before the two concepts can be merged.

3. Water Management in Denmark

Chapter 3 aims at establishing a foundation for applying the water footprint methodology to a Danish context. The country as a whole and the imbedded economic activities will be described. Moreover, the chapter will include a presentation of the Danish water resource and the management hereof. Conclusively, the focus shifts towards how the current management diverges from the principles of the water footprint methodology.

3.1 A short description of Denmark

This section provides demographic information about Denmark as well as an overview of the country's economic activities, i.e. trade, main industries, production and consumption patterns, etc.

3.1.1 Geographic and Demographic information of Denmark

Denmark is situated in North-western Europe, in the geographic region of Scandinavia. Its total area is 43,098 km^2, which is around 10 times smaller than the area of its neighbouring country to the East - Sweden and 8 times smaller than Germany – its border to the South. From the total landscape, 66% is agricultural land, urban development accounts for 10%, and nature accounts for 24%. [Statistics Denmark 2011, (a)]

The population of Denmark is around 5.6 million. The population density is 129.4 pr./km^2, [Statistics Denmark 2011, (b)], which is more than twice as much as the average density in Northern Europe, [United Nations 2011]. The population of Denmark, is not distributed evenly, since it is concentrated in cities. 21.6% of the population lives in the greater Copenhagen area, while only 13% lives in rural districts. [Statistics Denmark 2011, (b)]

3.1.2 Economic activities and indicators

Denmark is the 20th largest economy in the world with a Gross Domestic Product (GDP) of 310 billion dollars, which is close to for example the oil exporting nation Saudi Arabia, [40]. Being a small country, the GDP per capita (PPP) was $40,200 in 2011, and this places Denmark among the countries with the highest productivity and standard of living worldwide. [Central Inelegance Agency 2011]

Regarding trade, Denmark has experienced a positive trade balance during the past 20 years and the exports of goods and services are around 15% higher than the imports. Exports and imports account for 1/3 of the country's GDP. Denmark has been part of the European Union since 1973 and 68% of its trading activity is with EU member states. [Statistics Denmark 2011, (c)]

3.1.2.1 Exports

Denmark trades a large variety of goods, and on average for the years 2009 and 2010, the total export value is equivalent to about 520 00 mill. kr. Agriculture is a significant part the country's economy, since 14% of the total exports are products of agricultural origin, [Statistics Denmark 2011, (c)]. The number of farms in Denmark is in general decreasing, but their size and production capacity have increased to above the average for EU farms. Most of the cultivated land of Denmark is used for the production of cereals and crops for feeding cattle. In regards to meat production, a farm, on average, has 2,450 animals nowadays, compared to 150 animals in the 90's. Denmark is one of the largest exporter of pork meat in the world. Another big agricultural activity of Denmark is milk production. The milk produced each year is around 4.7 billion kg/year, of which 9% comes from organic diary farming. [Statistics Denmark 2011, (d)]

Manufactured goods is furthermore representing a big part of the economy, from which machinery and instruments account for 24% of the total exports and pharmaceutical products are equal to almost 10% of the exports. Since 1997, Denmark is also an oil exporter. About 8% of the total export is crude oil or different oil-based products. [Statistics Denmark 2011, (c)]

3.1.2.1 Imports

On average for the period 2009-2010, the Danish imports account for roughly 457 000 mill. kr.. The largest fraction of those is goods for household consumption, namely 32%, from which approximately 1/3 is food and beverages. The second largest group of imported goods is the intermediate goods used for other industries - paper, textile, plastic, metals, etc, which correspond to around 30% of the total imports. The imports of fuels, such as coal, petroleum, gas, etc. are not exceeding 7% of the imports. Around 2% of the total imports are fodder products, and this suggests that Denmark is dependent on imports of animal feed from other countries in order to sustain the current export of animal- and meat exports. [Statistics Denmark 2011, (c)]

3.2 The water resource of Denmark

Water is a vital resource for Denmark, as well as for all other countries. Denmark has a fairly wet climate with an average yearly precipitation of 703 mm/year - corresponding to around 30.29 km^3/year, [AQUASTAT 2010, (a)]. Situated in a coastal climate, Denmark has rather cold summers with average temperatures no higher than 20 ^oC [climatedata.eu], and this leaves good conditions for planting certain crops without using large amounts of irrigation due to low evapotranspiration. Population-wise, the total water withdrawal per capita is 154 m^3/year, [AQUASTAT 2012, (a)], [Statistics Denmark 2005]. This value is low, compared to Germany which abstracts more than 390 m^3/year per capita, [AQUASTAT 2010, (b)].

The total yearly renewable water resource is 6 km^3/year, and only 11% of this resource is abstracted for societal purposes, [AQUASTAT 2010, (a)]. This is quite remarkable since Denmark is a highly industrialised country with a dense population and a large agricultural industry, [AQUASTAT 2010, (a)]. Nevertheless, it is of central importance to adequately manage the water resource and comply with the restrictions on pollution loads and wastewater withdrawal.

3.3 Management of the Danish water resource

Water management became much more coordinated in the last end of the 19^{th} century with the establishment of nationwide sanitary systems and public waterworks; however, it was only minded towards solving practical problems of society back then. The law of watercourses from 1880 provided every farmer with a legal right to drain his land by the means of river maintenance and piping, while matters of water supply had the sole purpose of ensuring adequate amount of fresh water for industrial, agricultural and urban activities. Sanitary systems were constructed to divert wastewater away from the society in order to avoid epidemics, and there was thus no need for cleaning ones it reached the designated recipient. [Revsbech and Puggaard 2008], [Karlby and Sørensen 2002], [Winther, et.al 2006]

These improvements generated great societal benefits, but it turned out to be on the expense of the environment as both population and industrial activities grew. Problems started occurring after the middle of the 20^{th} century, and this forced policy makers to incorporate the environment when dealing with water related issues. The Environmental Protection Law was passed in 1974 and both the Water Courses Law and the Water Supply Law were later changed so that environmental matters are included, [Revsbech and Puggaard 2008].

Management of the Danish water resource is today conducted on all managerial levels in accordance with both national and international legislation. It is conducted according to the Danish planning system, and a summary of the overall system and the most important pieces of legislation are available for the reader as Appendix 1. 'Water related legislation'. Figure 3.1 is a sketch that illustrates the correlation between the institutional bodies and the most important water plans.

The Ministry of Food, Agriculture and Fishery is controlling agricultural nutrient leach, since they approve and manage the yearly manure accountancies of every single farmer in Denmark. They are furthermore in charge of producing national pesticide action plans in order to ensure that Denmark moves towards a sustainable use of pesticides, thus minimising the effects on the environment and human health. [The Danish ministry of Food, Agriculture and Fishery 2011], [The European Parliament 2009].

The Ministry of Environment is in charge of producing the national water plans, which describe the efforts needed in order to comply with the demands of the European Water Framework Directive. This Directive argues that all waters need to achieve good ecological status within 2015, and efforts are further specified in municipal plans, i.e. action plans, water supply plans, wastewater plans, etc. None of the plans produced on a municipal planning level are allowed to contradict the national water plans from the Ministry of Environment; hence, a power relation exists between the Ministry of Environment and the municipal administration. This power relation enables the Ministry of Environment to generate holistic plans that can ensure legal compliance with the Water Framework Directive. [The European Parliament 2000], [The Environmental Ministry of Denmark 2006], [The Environmental Ministry of Denmark 2009, (b)], [The Environmental Ministry of Denmark 2010, (c)], [The Environmental Ministry of Denmark 2010, (d)].

The legislation furthermore states that a municipal environmental impact assessments (EIA) must be prior to any decision on projects that might lead to unwanted environmental effects. [Revsbech and Puggaard 2008]

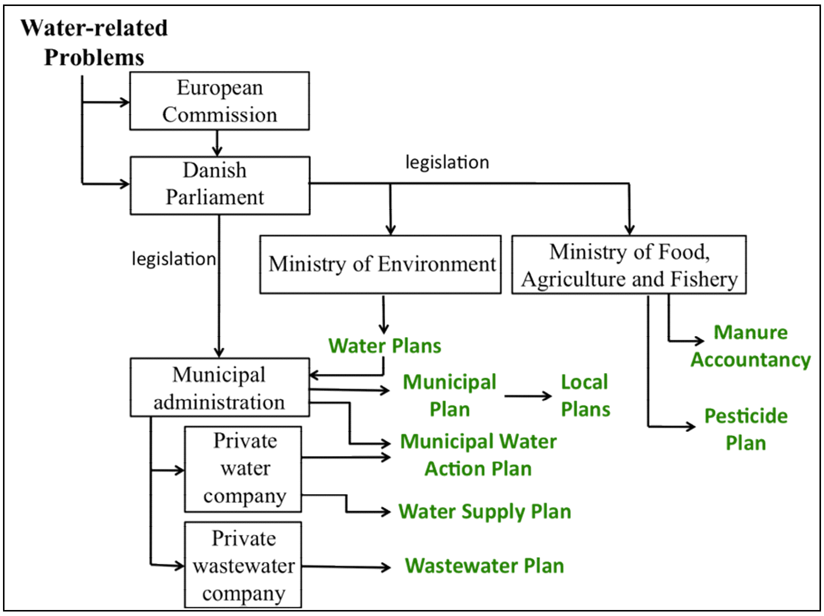

Figure 3.1: The institutional set-up and the plans related to water management in Denmark

The legislation and the plans cover all aspects of water management in Denmark in a traditional line of thought; however, it is a common denominator that only domestic direct freshwater consumption or pollution is included. After much searching, it has not been possible to find any legislation or official statement from governmental policymakers regarding virtual water or water footprint, and it can thus be concluded that the Danish footprint on the global freshwater resources is a topic that has been granted little political attention so far.

3.4 Water footprint in relation to the current water management

Obvious similarities exist between the water footprint methodology and the tools applied in the current Danish water management, since they deal with many of the same societal problems. Matters of appropriate allocation of water resources and reduction of polluting activities are central elements in both conceptual systems; however, clear methodological deviations also exist. The most dominant ones will be described subsequently, and they are all listed in table 3.1

	The current water management	**The water footprint methodology**
Aim	To solve water issues	To describe water issues
Water Supply	All abstracted water has an impact	Only consumed blue water has an impact
Pollution	Each substance is managed at source in order to secure good ecological status	Each pollution impact is described as the required dilution volume
Toxicity	Included i.e. by the use of DVFI	Excluded
Green Water	Excluded	Included
Virtual Water	Excluded	Included
Sustainability	Rather vaguely formulated	Dealt with in a mathematical way

Table 3.1: The differences between the current Danish water management and the principles from the water footprint methodology

The primary difference is that Danish water management aims at reducing unwanted impacts without compromising significantly on the societal activities, while the water footprint methodology merely aims at describing water related impacts [The Environmental Ministry of Denmark 2011, (c)], [Hoekstra, et al. 2011]. The water footprint should therefore in general be perceived as a tool to supplement rather than substitute areas in the current management.

The Danish water management is defined by a variety of different tools for different purposes in different institutions, and it would be bold to proclaim that the water footprint can substitute every single one of those tools. Matters of point source groundwater contamination will still be dependant on groundwater modelling tools, and eutrophication in fjords will still be dependent on models that can simulate the flow rate of seawater and therefore also the robustness of the recipient. One must also realise that compliance with the water framework directive cannot be documented by only the use of the water footprint methodology, since matters of physical habitat restoration cannot be describe by this tool, as it can only describe matters assigned to water usage and/or pollution.

Water abstraction is called blue water in the water footprint methodology, but there is in theory little practical difference between the abstracted water and the direct blue water footprint in a region. One exception is when water is released into a fascine, since it then will percolate back into the same groundwater reservoir and thus not be consumed according to the water footprint methodology, see chapter 2. This diverges from the current management where all abstracted water is perceived as missing from the natural run-off, [The Environmental Ministry of Denmark 2011, (b)], [Hoekstra, et al. 2011].

Pollution can impose either accumulative or acute toxic effects in recipients, and today's management strives at reducing the man-made contribution of such substances in order to secure good ecological status. This is done by establishing a correlation between how much the human influence need to be reduced in order to comply with some pre-defined quality standards. Acute toxicity is largely managed according to quality indices such as "Danish Watercourse fauna index" (DVFI), and the result is restrictions on land activities such as waste water discharges and agricultural fertiliser application. The water footprint differs significantly from this principle, since it merely uses the predefined quality standards for describing the magnitude of pollution. The aim of the footprint is to generate knowledge on pollution – not to reduce pollution. Consequently, it describes matters of pollution in a way that is much easier to communicate and understand for non-scientists, as all pollution loads are expressed as a water volume. The reader can derive the most severe accumulative problem by locating the pollution load that generates the highest water dilution volume; however, it will leave a blind spot in regards to acute toxicity, since critical peak loads will be hidden within the water footprint value. [The Environmental Ministry of Denmark 2011, (b)], [Hoekstra, et al. 2011]

The water footprint includes concepts that are new in the Danish water management. Green water use, or water taken up biologically from the soil matrix, is not defined in the current legislation as being a resource consumptive activity. One can argue that green water usage may be more relevant in countries with limited freshwater resources; however, it still provides a new edge and it supports a broader understanding of the resource. Virtual water is not described either, and this is critical since a rich country like Denmark with a high rate of trade and consumption ought to take such matters into consideration.

Matters of sustainability are managed in a rather vague manner in today's water management. The principles are mentioned as a vision on the webpage of the ministry, while the word "sustainable[3]" is not mentioned even once in the national water plans. The water footprint methodology supports a form of water management where sustainable allocation of freshwater resources can be communicated in a scientific and tangible way. Products or local activities can be compared by for instance [m^3/profit generated for the community] or [m^3/KJ food produced] and hold the possibility of providing decision-makers with knowledge of a higher quality when executing land use planning. [Hoekstra, et al. 2011], [The Environmental Ministry of Denmark 2011, (c)]

[3] In Danish: "bæredygtig"

4. Problem Formulation

This chapter serves the purpose of presenting the central research question of the study, as well as it will define the boundaries hereof. The relevance, structure, theory and epistemology of the study will also be described.

4.1 Presentation of the research question

Water as a resource is under threat. Danish legislation and Danish policy makers have since the mid-80's worked on sustaining the domestic resource by establishing a well-structured system of water plans on all managerial levels; however; matters of virtual water seem completely neglected in today's Danish water management.

The United Nation's World Water Assessment Programme (UN-WWAP) argues that fresh water resources will be even further under threat in the future due to an anticipated increase in both consumption and pollution as a result of development. Among the most important reasons, they argue that more wealth will increase the demands for luxurious water intensive products, and that this phenomenon is amplified by the increasing mobility of goods caused by globalisation. Such mobility may shift water intensive production to areas where it causes unnecessary problems, and UN-WWAP thus argues that water management ought to be assigned to the trading of goods. Consequently, water management should work more in the direction of Integrated Water Resource Management (IWRM); a concept that promotes holistic planning and cross-sectoral collaboration to establish sustainable use of water resources on all management levels. [UNEP 2009]

The argument of UN-WWAP is much in line with the principles of the water footprint, since one of the big cornerstones in the methodology is to reveal the true water use of a consumptive activity. It furthermore holds the possibility to provide policy makers with cross-sectoral data, as matters of water abstraction, water pollution, and land use, are included in one single indicator.

The Water Footprint Network (WFN) argues that the water footprint is a management tool that "*offers a better and wider perspective on how a consumer or producer relates to the use of freshwater systems*". They do not claim that the methodology is the solution to all Danish water-related problems, but they argue that it is a tool that can "*feed the discussion about sustainable and equitable water use*" and that it "*supports a broader and better informed decision making*". [Hoekstra, et al. 2011]

The carbon footprint is winning ever more political importance and public acceptance as a tool to facilitate the reduction of global warming; could the water footprint serve the same purpose in relation to the Danish influence on freshwater resources nationally and internationally? The Water Footprint Network claims that the concept can be fully adopted in national water management, and that hypothesis is what we aim at investigating!

The research question of the study is defined as:

Can water footprint assessments provide new knowledge for Danish water management?

The research revolves around a comprehensive nation wide water footprint assessment of Denmark - see chapter 5 and 6. The assessment unveils the true water consumption assigned to the presence of the Danish population, and the results will be discussed and put into a holistic perspective in chapter 7, thus enabling us to answer the above stated research question in a qualified manner. The aim of the study is to challenge the current focus of water resource management in Denmark and in this way spark a debate about what water consumption really is.

Epistemologically speaking, our research is build upon the concept of logical positivism via the complete acceptance of the water footprint methodology. Little water is present in the products we purchase; however, the water footprint methodology argues that all water polluted or consumed by a product, can be described in a truthful way by summarising the individual water footprints generated trough out the product life cycle. These individual water footprints are generated on the basis of knowledge, science and empirical testing; hence, perfectly in line with the principles of logical positivism which states that the world can be truthfully described by the use of systematic empirical testing with roots in rational and logical scientific considerations, [Jacobsen, et. al 2003].

4.2 Delimitation of the research

The study is in its nature limited in regards to time, since only a four-month period has been granted by the study board. This restriction makes project delimitation an absolute necessity and it is therefore important to evaluate which compromises that will have least influence on the overall quality of the study.

The scope of the research will remain on a national management level, since this level enables us to retrieve data of a high quality regarding trading of goods and the water bodies assigned. This will generate an error since local managerial water problems can be overseen when only national data is applied to the study; however, it would be very hard to gain trustworthy data on how much water that is used in every region of the world, as well as data regarding what every region produce and how much of these goods that are exported to Denmark.

The grey water footprint methodology will not be applied when assessing the virtual water trade of Denmark, and this is a great loss since it could be very interesting to study how much water pollution Denmark is imposing or off-setting by international trade. The reason why it must be excluded is once more that it is very hard to retrieve trustworthy data, since the grey water footprint depends on very detailed data regarding pollution load and quality standards in every corner of the world. Moreover, the grey water footprint remains a politically determined water volume, as it is strongly dependant on the politically decided water quality standards. A pollution load released in a country with little environmental legislation would for instance result in a much lower grey water footprint than if that very same pollution load was released in European waters.

The calculations in the water footprint assessment are dependant on large quantities of data, and we as researchers are therefore strongly dependant on external data. We conduct all calculations single handed, see chapter 5, but this is only made possible by the use of a large data set of product-related water footprint values from the Water Footprint Network (WFN). The underlying calculations of these values are described in WFN report 47, [Hoekstra and Mekonnen 2010, (a)], and WFN report 48, [Hoekstra and Mekonnen 2010, (b)], and we perceive them as being of a sufficient quality. Data about trade, production and water consumption is also needed, and such is in general retrieved from large reliable organisation such as the United Nations. However, Danish databases are used whenever domestic data is needed since we perceive them as being even more accurate.

In the end, the aim of the research is to describe a topic that has been given little attention on a political level until now. Following this line of thought, a holistic approach is more appropriate than a narrow but more specific scope; hence, several more assumptions have been made. They are primary related to the allocation of the correct water footprint to each product and a description of every assumption can be found as comments in the related "Microsoft Excel" files. All these assumptions generate a mathematical error that makes the exact national water footprint values questionable; however, we are confident that the study succeeds in showing a truthful tendency.

4.3 Theory in use

As touched upon in chapter 3, the water footprint methodology holds characteristics that differ significantly from the focus of the current water management in Denmark, and this section will therefore present the *rational choice theory* as a follow up. The theory is important for the research because it verifies the significance of presenting new tools to policy-makers. Secondly, it concludes that an institutional change, which will incorporate new ideas for better management, is indeed feasible. The *rational choice theory* is thus legitimising that it is of true importance to investigate the water footprint methodology in a Danish managerial context.

The book *'Institutional Theory in Political Science' by* B. Guy Peters describes institutionalism as an approach that focuses on political behaviour, the interaction between institutions and society, and the effects caused by this interaction. B. Guy Peters argues that an institution, formal or informal, should involve groups of individuals with common values, should be stable over time, and most importantly – must influence individual behaviour. Institutionalism includes diverse approaches towards the role of an organization in policy-making. One variety of institutional theory is *rational choice theory*. It is selected as the main theory, since it best shows the possibility of changes in the current institutional system. *Rational choice theory* argues that institutions "*do emerge to meet social and economic necessities*", and that it is very important to make sure that an institutional system, such as the Danish, is capable of implementing a new management tool in case it is demanded by the public and/or policy-makers. [Peters B.G. 2005]

There are two main assumptions behind the *rational choice theory*. Firstly, individuals take personal "*utility-maximizing decisions*", which means that their actions are guided by their "*egoistic behaviour*", [Peters B.G. 2005]. They are considered acting only by taking into account their personal gains/losses of a certain activity and this fact contradicts with the notion of sustainable resource use, where i.e. overexploitation for personal gain is not tolerable. Secondly, as institutions gain power, they can more easily influence individual behaviour. This leads to the notion that if an institutional change has been decided politically, it will be easier to convince the civil society of the importance of a decision, if the institution is powerful enough. In the case of Denmark, we consider the institutional power as being dominant enough to have an effect on its society; hence, institutional modifications can be accepted on all hierarchal levels of decision-making. [Peters B.G. 2005]

It is important to mention that the philosophy of rational choice follows the assumption that no matter how institutions are formed and what routines they perform, new values can be easily adopted and individual behaviour can be shaped rather simple. Compared to other institutional theories, where status quo is kept, an institutional change occurs deliberately and without much effort in the *rational choice theory*, since rules have *"no claim of precedence over any other, so that change is actually quite natural"*, [Peters B.G. 2005]. This once more proves that an institutional change is possible if the water footprint is evaluated by policy-makers as a useful tool in the Danish water management.

A last idea that the rational choice theory considers important is 'When is an institution good?'. An institution is assumed successful if it manages to generate collectively desirable outcomes by coping with the drawbacks of the political or economic system. Efficiency is the institutions' capacity to evaluate the public preferences and transform then into socially acceptable policies, without violating the rules of democracy. [Peters B.G. 2005] Basically, this means that a good institution should carefully evaluate the possibility of implementing new tools into the policies.

Defining and discussing the *rational choice theory* is a key step in proposing an institutional change, as done in our research. It can be perceived as the argument that legitimises further water footprint research, since the theory ascertains that the water footprint can be included in the Danish water management if policy-makers decide it as socially, economically and environmentally desirable. Nevertheless, it should be noted that the theory may show insufficient when dealing with **HOW** the water footprint can be implemented, since institutions and the surrounding society may not always act completely as rational as stated in the *rational choice theory*. However, that is beside the scope of our research.

4.4 Related prior research

The Water Footprint Network (WFN) conducts research on sustainability in relation to both direct- and virtual water use. The team is a pioneer in studying virtual water consumption, establishing methods for calculating water footprints on a large list of products. The WFN has also conducted research on the water footprint of nations. The databases created by the WFN are considered a good source of reference, since all subsequent organizations or research groups, known to us, are basing their analysis on the WFN data. [WFN 2012]

In 2010 the World Wildlife Fund (WWF) published the 'Living Planet Report 2010 Biodiversity, biocapacity and development' in collaboration with the WFN and the Institute of Zoology in London. The paper includes topics on biodiversity conservation, ecological and carbon footprints, but it also underlines the significance of freshwater conservation by introducing the water footprint concept as an indicator of water consumption quantities on national and international levels. [WWF, et. al 2010]

After the publication of the 'Water Footprint Manual' by the WFN in 2011, UNEP issued a report named 'Water Footprint and Corporate Water Accounting for Resource Efficiency', which thoroughly describes the methodology behind the calculation of the water footprint. It also presents studies based on the concept of the water footprint, which are primarily conducted by the WFN team. The report mentions cases focusing on virtual water flows on different geographical levels. On a national level they are related to Egypt, Lebanon, Jordan and Japan. In the report, UNEP emphasises the necessity of improving the WFN databases, the methods for calculating industrial goods, and they suggest a more detailed description of the current sustainability indicators proposed by the WFN. [UNEP 2011]

It can be concluded that the water footprint is a well-established and well-recognized tool for investigating water-related problems. Studies have been conducted on a national scale prior to our research, but never with a specific focus on Denmark and the Danish consumption of commodities.

5. Methodology

The following chapter presents the method of calculation of the Danish water footprint, thus establishing a foundation for the results in chapter 6 and the discussion in chapter 7. The chapter is divided into two sections that present respectively the methodology related to the direct water use and the virtual water use. The calculations assigned to the methodology are conducted in multiple Microsoft Excel files, and Appendix 2 describes this correlation.

Crop choices, trading patterns and climatic variations are a source of error when one is using average data for crop water footprints and domestic precipitation. In order to minimise such an error, all calculations are in general based on 10-year averages from 2000 to 2009; hence, all results are calculated as yearly values after which a 10 year average is produced. The years 2010 to 2012 are not included because so recent crop trading statistics have not been filed by the United Nations. All values assigned to economic trade are converted into the unit US dollars 2009, taking into account the inflation rate and the exchange rate for each year, [Statistics Denmark 2012, (b)], [Statistics Denmark 2012, (c)], [US Inflation Calculator 2008-2012].

As touched upon already, a water footprint may be present on several different units. In general, all crop water footprints are described as [m^3/ton], while the Danish Water footprints are described as [mill. m^3/year].

5.1 The direct water footprint of Denmark

The direct water use is divided into four groups: Household water, Institutional water, Agricultural water and Industrial water. This division is done in order to improve the accuracy of data, as well as it enables the possibility of comparing patterns of water use in later analysis. The division is furthermore much in line with the division conducted in the Water Footprint Network report – '*The National water footprint accounts: The green, blue and grey water footprint of production and consumption, Report Series No. 50*' [Hoekstra and Mekonnen 2011].

The direct green water footprint is only assigned to agricultural activity, and the calculations are conducted according to equation 5.1.

$$WF_{green} = \sum(P * WF_{green,\ product})$$

Eq. 5.1: calculation of the total direct Danish green water footprint, [Hoekstra, et al. 2011]

Equation 5.1 can be perceived as a summarization of all the crop specific national water footprints. **P** represents the yearly crop production quantity, and the data is retrieved from the FAOSTAT database, [FAOSTAT 2012, (a)], while $\mathbf{WF_{green,\ product}}$ is a crop-specific water footprint from the Water Footprint Network report – '*The green, blue and grey water footprint of crops and derived crop products, Report Series No. 47*', [Hoekstra and Mekonnen 2010, (a)].

The Danish direct blue water footprint is merely a summarisation of all the domestic abstraction quantities by either public or private supply; however, the data is based on knowledge from different sources due to the institutional changes imposed by the Danish municipal reform in 2005. Data prior 2005 is official values from either Danish Statistics or the National Geological Institute GEUS, whereas data post 2005 derives from either DANVA (an Danish NGO) or the AQUASTAT database. The exact origin of the data is described in appendix A2, and the references are respectively [Statistics Denmark 2005], [GEUS 1999], [DANVA 2011], and [AQUASTAT 2012, (a)].

The direct grey water footprint is calculated according to equation 5.2.

$$WF_{grey} = L / (c_{max} – c_{natural})$$

Eq. 5.2: Calculation the grey water footprint, [Hoekstra, et al. 2011]

The grey water footprint is assigned to the polluting substance that generates the highest grey water footprint according to equation 5.2. The pollution load, **L**, from agricultural leach and discharges of nutrients are found in the yearly '*Water Course 2010*' report from DMU, [NOVANA 2011], while data on sewer overflows and discharges from waste water treatment plants are calculated on the base of the '*Point Source Contamination 2010'* report from the Danish Ministry of Environment, [The Environmental Ministry of Denmark 2011, (d)].

The ambient water quality standards, $\mathbf{c}_{\mathbf{max}}$, are a result of what recipient the pollutants are released into, and it is chosen to assume this as a coastal ecosystem. By doing so, an error is generated in regards to the impacts on rivers and the groundwater. Pollution of Nitrate, NO_3, is determined on its effects on eutrophication, and the quality standard is determined in line with the official method of the Danish Ministry of Environment. Hence, the eelgrass tool[4] is applied, and we assume a pristine depth colonisation of 5 metres. This depth may differ among the different Danish coastal regions. All remaining coastal quality standards are retrieved from European legislation, [European Commission 1991], [European Commission 2008].

5.2 The virtual water footprint of Denmark

The virtual water footprint of Denmark focuses on the trading activities from the agricultural and industrial sectors. Industrial water trade includes only blue water, while agricultural water trade includes both green and blue water. Grey water is excluded from the analysis due to the lack of precise data regarding origin, pollution load and ambient water quality standard in the countries exporting to Denmark.

The virtual water footprint is calculated according to the principles of figure 2.6; hence, equation 5.3

$$WF_{virtual} = WF_{direct} - \text{Virtual Water Export} + \text{Virtual Water Import}$$

Eq. 5.3: Calculation of virtual water footprint, [Hoekstra, et al. 2011]

5.2.1. Virtual industrial water

The industrial virtual water footprint is calculated based on the top-down approach, in compliance with other calculations of the Water Footprint Network. Our study focuses exclusively on the industrial water imports to Denmark from 55 countries, instead of the 230 countries that the Water Footprint Network examines. Nevertheless, those 55 countries chosen correspond to 98.1% of the total imports to Denmark, which creates a strong reliability of the calculation. For the sake of comparison, our research can be perceived as an extrapolation of the method used by the Water Footprint Network in the report "*The National water footprint accounts: The green, blue and grey water footprint of production and consumption, Report Series No. 50",* [Hoekstra and Mekonnen 2011]. Equation 5.3 describes the main correlation:

$$WF_{imp.} = \sum (Imp * (W * C / V))$$

Eq. 5.4: Calculation of industrial virtual water import, [Hoekstra and Mekonnen 2011]

The equation summarises the virtual water imports from all 55 countries as the total Danish virtual water import. This is done by expressing the industrial water in monetary terms – water consumed by every dollar of value created by the industrial sector.

[4] The depth colonisation of eelgrass is an indicator for the ecological status in the coastal waters since it serves as both shelter and spawning ground for local species in most Danish coastal ecosystems, while it also stabilises the seabed. Like any other macrophyte, eelgrass can only grow if it has sufficient sunlight for photosynthesis and decreased turbidity, due to eutrophication, will thus have a direct influence on its depth colonization. The ambient quality standard for a 5-meter depth colonisation is calculated by the use of the Laurentius correlation. [The Environmental Ministry of Denmark 2011, (d)]

Imp represents the yearly industrial import from a country, and this data is retrieved from Denmark Statistic Database, [Statistics Denmark 2011, (e)]. **W** is the industrial water withdrawal of a country, and this data is retrieved from the AQUASTAT database for the period 1998-2007, instead of 2000-2009, due to lack of more precise data, [AQUASTAT 2012, (b)]. **V** is the value of the total industrial sector in each of the 55 countries, and such data is obtained from the United Nations Accounts Main Aggregates Database, [United Nations Accounts Main Aggregates Database 2011].

C represents the nationwide percentage of industrial water consumption according to the consumption definition from chapter 2. We assume that all imports deriving from coastal regions will be 100% consumed, since the waste water will be released into a salt water recipient - thereafter it ceases to be fresh water. It is consequently assumed that all water imports deriving from inland regions will be 0% consumed, since it will return to the same catchment and therefore be available for further downstream purposes. We further assume 0% evaporation loss in the industrial activities, and this will logically generate a minor error. The borderline between coastal and inland regions is in our study defined as 100km from the coast. All industrial activities are considered proportional to the population distribution, and data on the coastal population in each country is taken from a UNEP database, [UNEP 2006].

The exports of industrial blue water is calculated by the same principles as the calculation of the industrial blue water imports. The correlation is presented as equation 5.5.

$$WF_{exp.} = Exp * (W * C / V)$$

Eq. 5.5: Calculation of industrial virtual water export, [Hoekstra and Mekonnen 2011]

The average water withdrawal by the Danish industrial sector, **W**, is taken directly from the analysis of the direct Danish water footprint, whereas the consumption of Danish industrial water, **C**, is assumed 100% due to the coastal location of Denmark. The value added by the industrial sector is also here retrieved from the United Nations Accounts Main Aggregates Database, [United Nations Accounts Main Aggregates Database 2011].

The industrial exports, **Exp**, are determined as the difference between the total export and the value of the agricultural export. This data is respectively found from the Danish Statistics, [Statistics Denmark 2011, (e)], and the FAOSTAT database, [FAOSTAT 2012, (b)].

5.2.2 Virtual agricultural water

The agricultural virtual water footprint takes crops, live animals and animal products into account and the calculation hereof is, unlike the industrial virtual water trading, based on the bottom-up approach. This approach is chosen because the agricultural trade by far represents the largest fraction of the Danish water footprint, and it is made possible by the presence of very detailed agricultural trading data from the FAOSTAT database, [FAOSTAT 2012, (b)]. Both the imports and exports are estimated by the same method, and it is presented as equation 5.6.

$$WF = \sum (Trade * WF)$$

Eq. 5.6.: Calculation of agricultural water trading, [Hoekstra, et al. 2011]

Data on the **traded** mass of 418 agricultural products is obtained from the FAOSTAT Database, [FAOSTAT 2012, (b)], and these products are, for the purpose of later analysis, divided in eight different categories; namely "vegetables", "fruits", "nuts and seeds", "cereals[5]", "fodder", "live animals", "animal products", and "other (unspecified)". From these 418 products, a specific water footprint value, **WF**, is assigned to 282 items, while assumptions are made for 95 products in order to obtain a truthful water footprint value. 41 products have no water footprint assigned due to lack of data by the Water Footprint Network.

[5] A certain fraction of the traded cereal is for fodder purposes. This is a small error for the division of products in categories, but no error in regards to the final result.

The water footprint values very dependant on the origin of the products, and the products are therefore further divided, depending on the amounts export or import:

If: Exports > Imports → National origin
If: Exports < Imports → International origin

The blue and green water footprint of each product is attained from the Water Footprint Network reports from 2010 - *The green, blue and grey water footprint of crops and derived crop products, Report Series No. 47* and *The green, blue and grey water footprint of farm animals and animal products, Report Series No. 48* [Hoekstra and Mekonnen 2010, (a)], [Hoekstra and Mekonnen 2010, (b)]. Depending on the origin of the product, either a Danish water footprint or a world average value is taken. The origin of the 78 imports products that exceeds 1‰ (1 per mill) of the total imports of Denmark is further specified by origin in order to increase the validity and reliability for the research. Each of those 78 commodities are given a more accurate water footprint that matches their import origin; such data is also retrieved from the FAOSTAT database, [FAOSTAT 2012, (b)].

6. Results

This chapter serves the purpose of presenting the results of the research. The first two sections of the chapter will include results on the Danish direct and virtual water footprint, after which section three will describe how the water footprint has developed during the past 20 years. A national virtual water footprint is a complex parameter that can be challenging to fully understand, and the last section of the chapter will therefore describe how the results of this report is a consequence of product specific choices.

The results derive from a variety of sources; however, the structure of references is as follows: References are written in the text or figure caption whenever a value is taken directly from a reference. On the contrary, a reference is not written in the main text, whenever this reference has been greatly modified by our calculation. In such situations, the reference is stated in the assigned Excel file and in the methodology description.

6.1 The direct water footprint of Denmark

The Danish direct water footprints are listed in table 6.1 and they will be described subsequently.

	Blue	Green	Grey
[mill. m^3]	597	9343	641,263
[%]	0.1	1.5	98.5

Table 6.1: The Direct water footprint of Denmark

The result of the Danish direct blue water footprint adds up to 597 million m^3, which corresponds to roughly 10% of the yearly run-off in Denmark, [AQUASTAT 2010, (a)]. The water plans state that the environment will not suffer significantly when the abstraction is lower than 35% of the yearly run-off, and it can thus be concluded that Denmark as a whole receives sufficient amounts of rain water to sustain its activities, [The Environmental Ministry of Denmark 2011, (b)].

It can furthermore be concluded that the rainwater used by crops exceeds all abstracted water, respectively listed as the national green and blue water footprints in table 6.1. This is interesting since blue water currently remains the only focus within the Danish legislation. In total, 15.6 litres of water are used on the Danish fields every time one litre of water runs out of a Danish tap – the actual water quantity needed to sustain society. Figure 6.1 illustrates the effect of the conceptual change from only focussing on blue water, to also accounting for green water as a resource that should be managed. The agricultural sector accounts for a much larger part of the water footprint, and it should be noted that 84% of the total blue and green water footprint is assigned to domestic livestock production. This is especially due to the large pig production; see chapter 3.

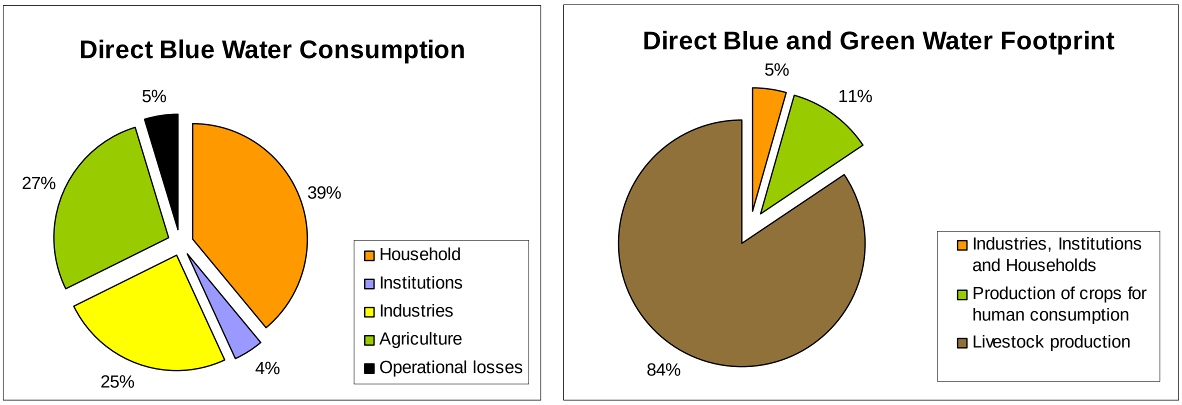

Figure 6.1: The distribution of the Danish direct water consumption

The grey water footprint accounts for 98.5% of the total water footprint. Nitrate is the critical substance, and the yearly discharge load generates a grey water footprint that is more than 70 times higher than the second most critical substance (mercury containing discharges). 98% of the grey water footprint is caused by agricultural leaching. Figure 6.2 presents the resulting domestic water balance. It can here be seen that the grey water footprint exceeds the yearly run-off volume available for dilution more than 100 times. This shows that the direct water use of Denmark is unsustainable since domestic activities lead to a continuous deterioration of the coastal water quality. The agricultural sector is largely to blame.

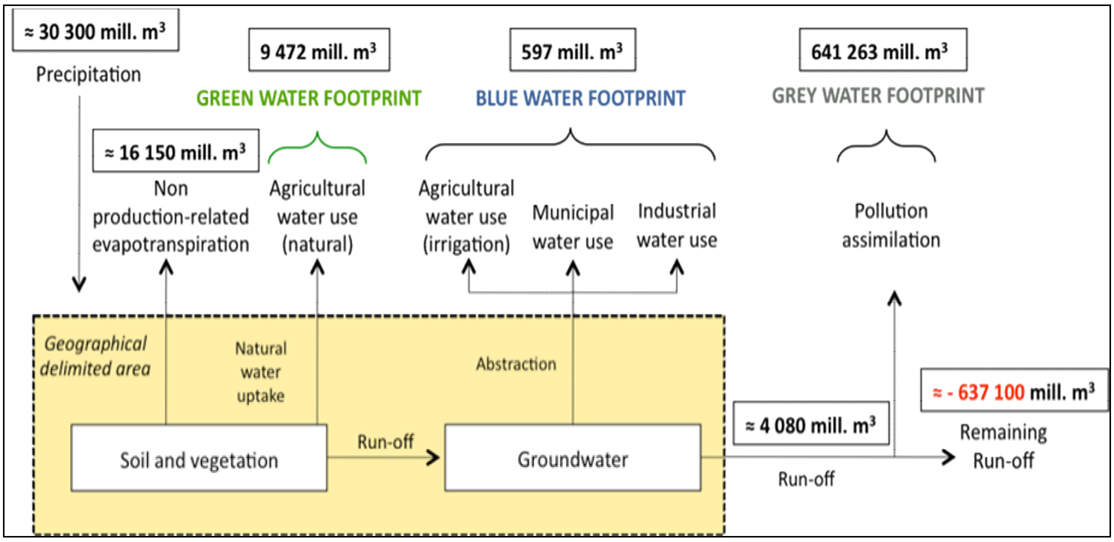

Figure 6.2: The water balance of Denmark [Hoekstra, et al. 2011] - ***modified]***

6.2 The virtual water footprint of Denmark

The virtual water footprint provides new information on how Danes use global virtual water through everyday consumer goods.

6.2.1 The water footprint of a Dane

Figure 6.3 illustrates how the conceptual shift from direct to virtual water use increases the blue water footprint of a Dane from 123 l/day to 480 l/day – thus revealing the true effect on global water supply. Consequently, the green and blue water footprint adds up to 4327 l/day. This result is 35% higher than the world average even though Denmark is a country with low crop water footprints due to low evapotranspiration.

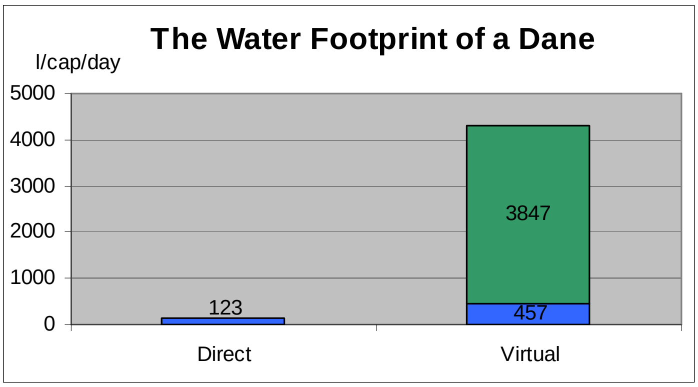

Figure 6.3: The green and blue water footprint of a Dane

The conceptual shift also means that the water use of a Dane can be assigned to the consumption of specific goods; figure 6.4 illustrates the resulting correlation. The consumption of animal products such as meat, milk, cheese, etc. adds up an astonishing 40% of the total water footprint, and this value is even an underestimate, since large quantities of the imported cereals serve as animal fodder; hence, it turns into animal products.

Direct blue water use is the only concern of today's water management, and it is thus surprising to witness how that only accounts for 3% of the total water footprint of a Dane. Nuts and seeds include products such as coffee, cocoa, palm oil and rapeseed, and these products add up to 31%. The industrial water footprint only adds up to 8% of the total water footprint of a Dane, and the study therefore shows that agricultural products hold a much larger footprint due to the green water definition.

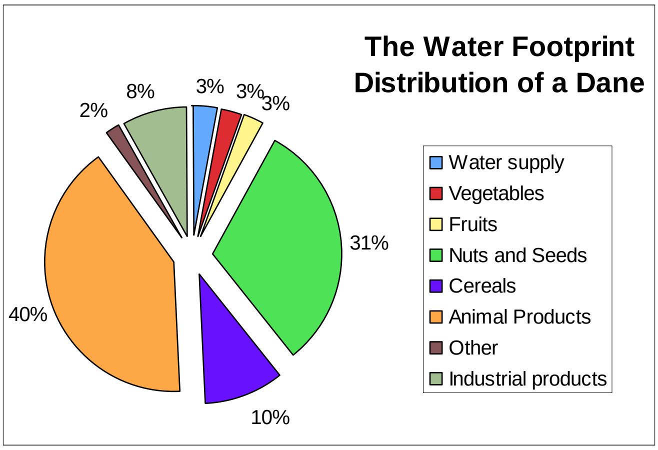

Figure 6.4: The Constituents of the virtual water footprint of a Dane (2005-2009)

6.2.2 The water footprint of Denmark

The picture also changes from a perspective of national water management – see figure 6.5. The virtual water footprint of Denmark actually proves to be 14% lower than the direct water footprint, and this is quite surprising since Denmark is a rich industrial country with a high rate of consumption – see chapter 3. Consequently, this means that Denmark as a whole has a positive virtual water trade balance.

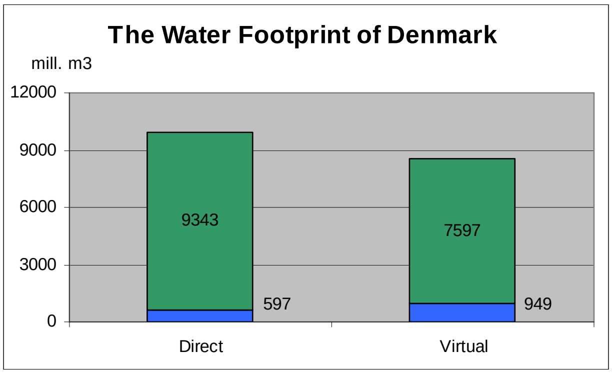

Figure 6.5: The green and blue water footprint of Denmark

The agricultural products remain the biggest part of the water footprint, and the trading regarding this fraction is illustrated in figure 6.6. The indisputable biggest virtual water export of Denmark is live animals and animal products – of which 84% are directly assigned to the Danish pig production. The total export of pig products adds up to a water volume equivalent to 2/3 of the total direct Danish water footprint, and it is supported by a substantial virtual water import in the form of fodder products.

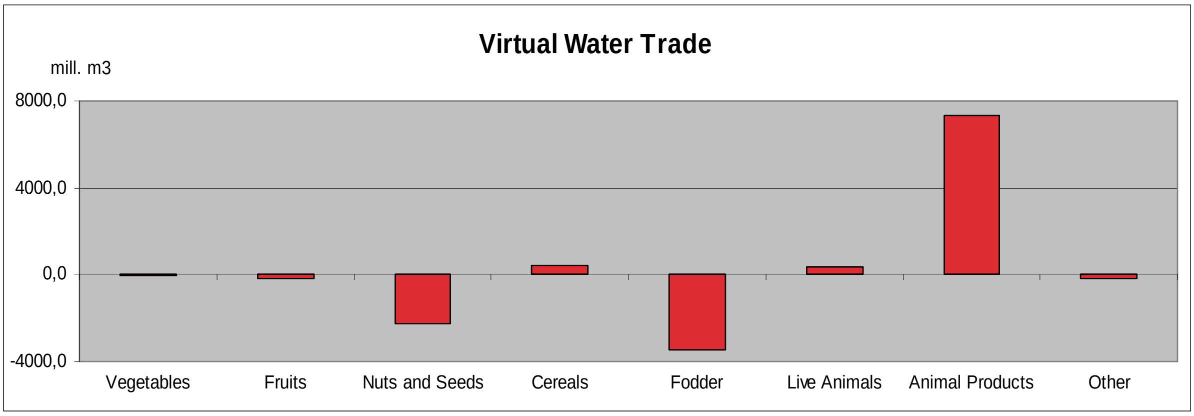

Figure 6.6: The agricultural virtual water trade

Denmark also exports virtual water in the form of cereal, but it is on the other hand importing a lot of virtual water in the form of vegetables, fruits, nuts and seeds. Much of this import is bound to luxury products such as coffee, chocolate, and palm oil products. The study further shows that Denmark imports almost 12 times more virtual industrial blue water than it exports, and this is quite remarkable since the value of all exports has remained around 15% higher than the imports for the past 20 years - see chapter 3. This suggests that the value creation in the Danish industries is less water intensive than that of the imported ones, and it underlines the dependency on external water intensive goods. The virtual blue water footprint is 59% larger than the direct water footprint.

6.3 The development of the water footprint

Lowering of the direct water consumption has been on the public agenda in many years now, and it is possible to buy a great variety of every day commodities with water saving features. The effect of this tendency is verified by figure 6.7, which illustrates how all water use related to households, institutions, industries and operational losses has decreased between 40% and 60% since 1990.

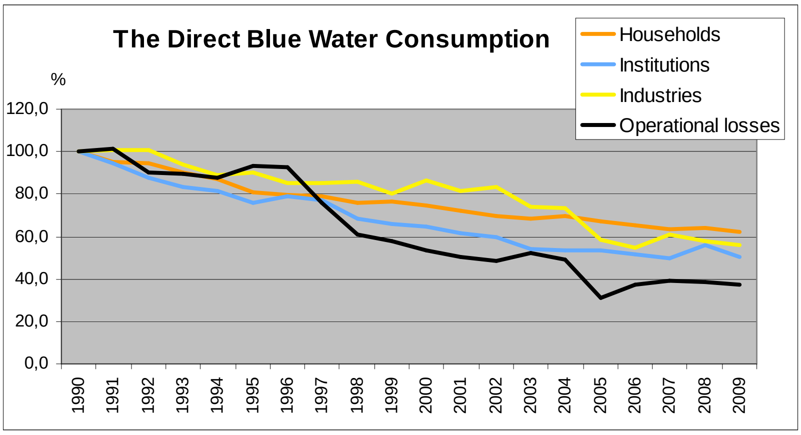

Figure 6.7: The direct water use of Denmark between 1990 and 2009,
[DANVA 2011], [AQUASTAT 2012, (a)], [Statistics Denmark 2005], [GEUS 1999]

However, the picture changes drastically when studying how the water footprint has developed in the very same period – see figure 6.8. Though the direct water use has lowered significantly since 1990, the water footprint has remained rather constant with little deviation. Figure 6.8 in relation to figure 6.7 is therefore a rather good picture of the current political focus.

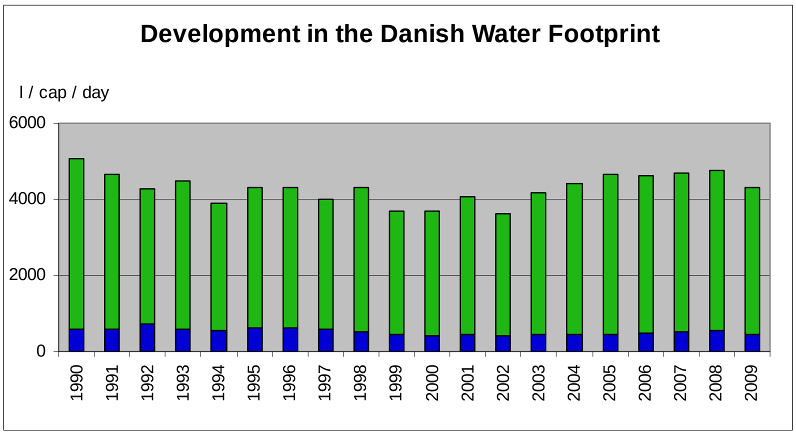

Figure 6.8: The green and blue water footprint of Denmark between 1990 and 2009

Figure 6.9 below shows that both the import and export of virtual water have been increasing constantly until 2007; however, the imports have increased more than the exports. The last 2-3 years of the period have been unstable due to the global economic recession and should therefore not be interpreted as representative for the overall tendency. Our research therefore indicates that the virtual water footprint of Denmark might increase if appropriate measures are not taken.

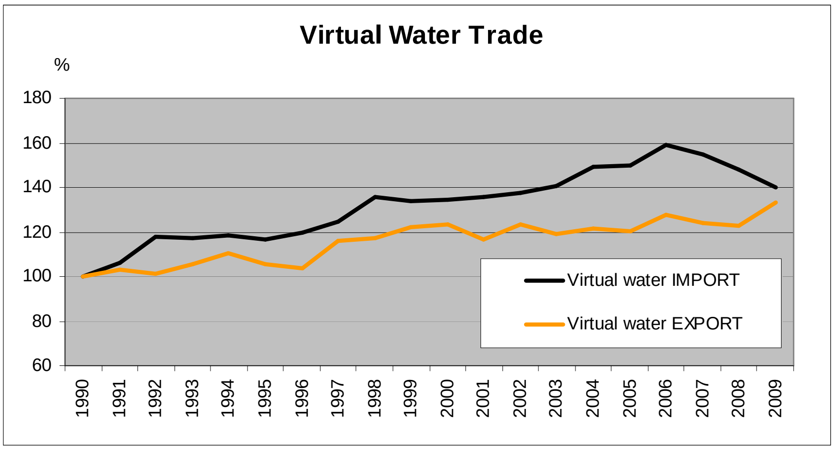

Figure 6.9: The virtual water trade of Denmark between 1990 and 2009

6.4 A product-specific perspective on the Danish virtual water use

In order to fully understand the tendencies of the Danish water footprint, it is vital to realise that the share size of the water footprint depends solely on the consumer choice of every single Dane.

6.4.1 Luxury products

People in the western world consume a variety of products that are not an absolute necessity in order to sustain a decent existence. Such products may not serve any vital role in the diet; however, a demand exists because of consumer preferences. The water footprint assessment contains only 377 agricultural products, and it was therefore not possible to assess the impacts on high-life products such as caviar or foie gras; however, even every day, easily accessible luxury products such a chocolate and coffee proved to have a great impact on the water footprint.

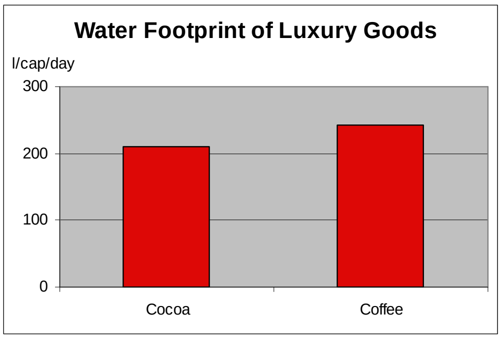

Figure 6.10: The virtual water trade of Cocoa products and coffee

Figure 6.10 illustrates how the Danish consumption of cocoa products adds up to 211 l/day/pers, while the Danish consumption of coffee adds up to 242 l/day/pers. Hence, the water assigned to coffee consumption is almost twice as big as the water used for bathing, cooking, drinking, cleaning, etc. Most cocoa beans and coffee beans are imported from the tropical regions of respectively Côte d'Ivoire and Brazil. [Hoekstra and Mekonnen 2010, (a)]

The United Nations expect that the global water resources of the planet will be even more threatened in the future due to global warming, increased population and increased wealth; hence, it could be discussed weather it is sustainable that Danes use 453 litres/day on products that have little or no dietary purpose.

6.4.2 Product choices

Every morning, a Dane makes a choice regarding what drink to supplement the breakfast, usually without taking into account the water assigned to each of his/her possible choices. Figure 6.11 shows that apart from water, tea appears to have the lowest water footprint value in the morning beverages group.

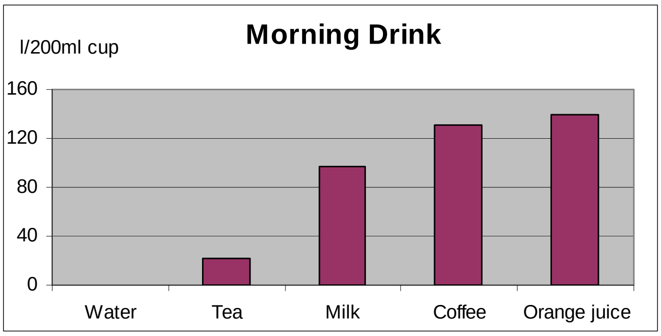

Figure 6.11: The water footprint of a morning drink

Coffee, though, contains around 130 litres of virtual water – about 6 times more than tea and 1.3 times more than milk. Orange juice has the highest water footprint value from all the 5 products, about 700 times more than water. [Hoekstra and Mekonnen 2010, (a)]

In the afternoon, when Danes decide between different fruits for a between-meals-snack, they consume between 30 to 100 litres of virtual water, shown in figure 6.12. Choosing a pear or an apple as a healthy snack instead of an orange, strawberries or papaya saves around 60 litres of water. [Hoekstra and Mekonnen 2010, (a)]

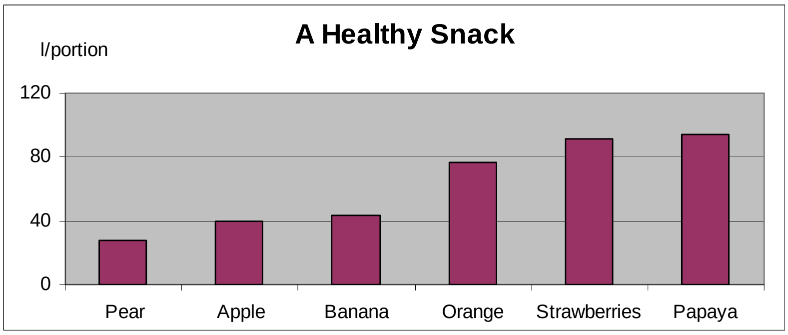

Figure 6.12: The water footprint of a healthy snack

In regards to cooking oil, figure 6.13 illustrates the radical difference of virtual water assigned. Rapeseed oil has the lowest water footprint - about 400 litres lower than sunflower oil. Olive oil, on the other hand, has 3 to 4 times higher water footprint. This is equivalent to around 7000 litres more water per litre of olive oil compared to a litre of sunflower- or rapeseed oil. [Hoekstra and Mekonnen 2010, (a)]

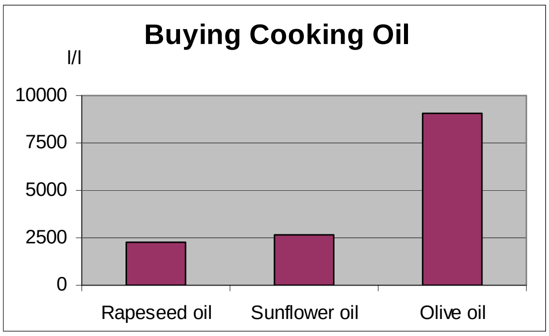

Figure 6.13: The water footprint of 1 litre cooking oil

Regardless of being a vegetarian or a meat consumer, each person needs a definite amount of proteins in his/her diet, and figure 6.14 illustrates that the different sources of proteins have diverse water impacts. Domestically produced chicken meat seems to be the least water consuming with a water footprint of around 260 litres, while pig and beef meat are about 3 times more water consuming – respectively 735 and 751 litres. From the vegetarian choices, beans have the lowest water footprint value, which is only 75 litres. Chick peas, on the other hand, are 9 times more water consuming than beans and about 2.5 times more than the least polluting meat product - chicken meat. [Hoekstra and Mekonnen 2010, (a)], [Hoekstra and Mekonnen 2010, (b)]

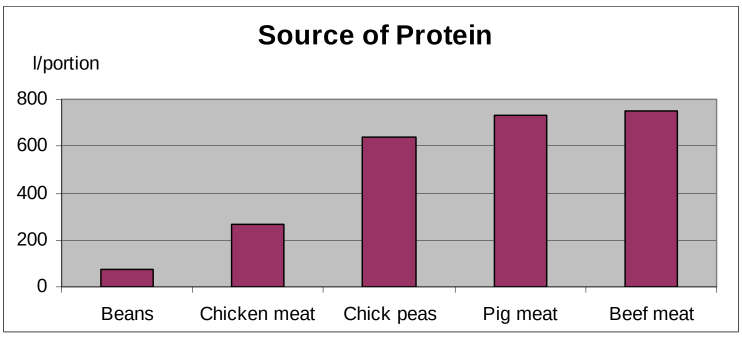

Figure 6.14: The water footprint of protein sources

Product related water footprints add up when preparing full dishes; hence, figure 6.15 represents the water footprint of four complete dinner meals for 4 Danes. The menus are:

Menus:

1. 'Spaghetti Carbonara
2. 'Frittata (omelette) with parmesan, basilicum, bread and green salad'[6]
3. 'Steak of minced meat with soft onion, gravy, potatoes and salad'[7]
4. 'Pork Roast with baked potatoes, gravy, cabbage and red wine'[8]

[Fogt, et. al 2006]

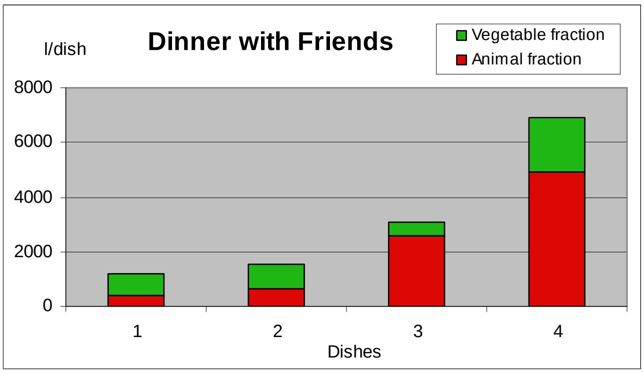

Figure 6.15: The water footprint of a 4-person dinner

The least water-consuming dish is 'Spaghetti Carbonara', with a water footprint of 1174 litres, while the vegetarian Frittata is the second least water consuming dish. Figure 6.15 shows that the 2 dishes with large meat content prove to have a much higher water footprint than the 2 without large quantities of meat. The meat alone in dish number 4 has a water footprint 4 times higher than the water footprint of 'Spaghetti Carbonara'. [Hoekstra and Mekonnen 2010, (a)], [Hoekstra and Mekonnen 2010, (b)]

6.4.3 Method of production

Animal products such as meat, eggs and milk account for the largest fraction of the Danish water footprint, and it is thus an ideal place to seek optimisation. The major fraction of an animal product water footprint is caused from growing the crops for feed; however, some feed is more water intensive than other. This is illustrated in figure 6.16.

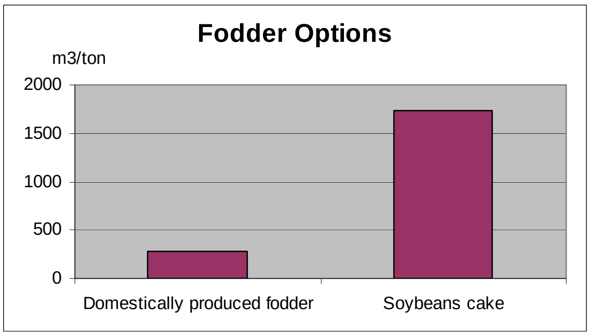

Figure 6.16: The water footprint of the most used fodder options

[6] In Danish: Omelet med parmesan, basilikum, brød og grøn salat
[7] In Danish: Hakkebøf med bløde løg, brun sovs, nye kartofler og Salat
[8] In Danish: Flæskesteg med hasselbackkartofler, brun sovs, rødkålssalat og rødvin

Statistics Denmark provides detailed information regarding the fodder supply of Denmark in the period 2005-2009. It is by the use of this data possible to identify cereals used for fodder, unlike in the rest of the research where an agricultural product cannot be both. In terms of mass, 12% of all fodder needed to support the Danish production of livestock is supplied by import. Among many, such fodder is wheat, barley, sugar beet residues and seed cakes. The biggest import of all is soybean cake that accounts for 39% of the total fodder import. [Statistics Denmark 2012, (a)]

Soybean cake holds a water footprint 6 times higher than domestically produced fodder, [FAOSTAT 2012, (b)]. The virtual water import assigned to soybean cake adds up to 28% of the total virtual water import of Denmark, and a change of fodder can thus greatly influence the water intensity of the Danish agriculture.

7. Discussion

This chapter will serve as a discussion on the results from chapter 6 and hereby establish a foundation for the conclusion of the research. The underlying assumptions and definitions embedded in the water footprint methodology will first be discussed, after which the focus will move towards the methodology specific to the research – see chapter 5. Conclusively, chapter 7 also includes proposals for further research.

7.1 The water footprint methodology

The methodology proposed by the Water Footprint Network is of great importance, since it establishes a standardised way of dealing with water management in regards to trade and communication. We acknowledge the work conducted by the Water Footprint Network prior to our research; however, it sparks a list of topics worth questioning.

7.1.1 The water footprint as a management tool

The aim of the study was to assess whether the water footprint methodology can provide new knowledge in the Danish water management. It must here be emphasised that little news value was produced in regards to the direct water consumption; as it is commonly known that Denmark has sufficient precipitation and that the agricultural leach of nutrients is the most severe source of pollution. Additionally, the methodology fails to fully describe the scale of domestic pollution, since it is built upon a dilution principal and thus excludes all acute toxic effects that may occur during certain discharges. The strengths of the water footprint is that it integrates matters of waste water treatment, water supply, land use and agricultural management into one indicator; however, our experience is that this simplification may lead to that local problems are overseen or dwarfed in comparison to other fractions of the water footprint. The direct water footprint is thus largely a simplified way of communicating already known knowledge! However, the direct water footprint assessment has a great utility, as it is the prior step of any virtual water footprint assessment – a method of analysis that in our research has resulted in much new knowledge. Furthermore, some new knowledge was generated via the conceptual shift from only focusing on blue water to also including green water.

The Water Footprint Network claims that the water footprint methodology is fully applicable on all managerial levels, [Hoekstra, et al. 2011]; however, we experienced great difficulties in applying it to any level lower than national, as this greatly limits the trading data available. Without detailed trading data, it is impossible to produce a reliable water footprint assessment. Furthermore, such a study may not serve any purpose since the main part of the water footprint will be assigned to agricultural consumer goods – a consumption category that municipal or local politicians have very little political power in regards to. We are therefore of the opinion that the methodology only serves a purpose when applied to a nation, a company or a product.

7.1.2 The green water definition

The green water use is a completely new concept in Danish water management, but some readers might oppose the importance of the indicator since green water basically is rain that will be utilised by nature or simply evaporate if not utilised by man. Moreover, one could question whether the indicator would not have a greater purpose in areas with water scarcity? The Water Footprint Network defends the green water definition by arguing that better green water understanding might lead to less blue water dependency, [Hoekstra, et al. 2011]. The green water footprint is a methodology that provides researchers and policy makers with a holistic overview on our resource utilisation, hereby enabling better management.

Moreover, the indicator remains closely related to matters of land use, as precipitation is distributed evenly in the respective climate regions. Bad green water management in Denmark may increase the demand for water intensive products, and this is likely to result in land use change.

When accepting that the water footprint is a tool for making better and more well-informed choices, one could argue that the green water footprint will favour countries with a colder climate, since they have lower evapotranspiration and thus lower water footprints on crops. The optimal location for any crop will therefore be in the coldest climate that allows the crop to grow with maximum yield, and this may lead to campaigns such as "*don't buy any products from southern Spain!*". Moreover, some crops grown in tropical climates near the Equator may use much water and still not cause environmental problems due to sufficient rainfall, and the indicator may therefore mislead the consumer in regards to certain products.

7.1.3 The grey water definition

The strength of the grey water indicator is that it merges complex and diverse matters of pollution into one unit, thereby making it easy to communicate which matters of pollution that are most pressing. However, it only deals with accumulative pollution and it is therefore not complete.

Moreover, the grey water footprint remains a politically decided dilution volume due to the direct dependency on the ambient water quality standard in use - it is not real water. Following the thought of methodology, a pollution load may result in a high water footprint in Europe, while that very same pollution load might generate a minimal water footprint in some third world countries with a low degree of environmental restrictions. The indicator must therefore be questioned in relation to trading, since the grey water footprint will be directly dependant on the legislation in the countries one decides to trade with.

7.1.4 Large amounts of data is required

A 100% reliable national water footprint assessment is very hard to produce since almost indefinite amounts of data is needed. No crop water footprint can truthfully be described without area specific climatic data, and data regarding both crop type and the assigned growth period. This data needs to be supplemented by exact data on the assigned pollution and the water quality standards in the region of production, after which an allocation must be made according to the product value fraction in the area of production. Such assessments must be conducted for every single imported product, and it is thus almost impossible to conduct a water footprint assessment without a long list of assumptions. We have in our research strived at minimising error regarding any product of significance.

7.2 The methodology in use

A lot of choices and assumptions are made in this study due to lack of time or lack of high quality data. In general, we aim at minimising sources of error; however, certain parts of the applied methodology can be discussed.

7.2.1 Data quality

The data used as a basis in our analysis is retrieved from diverse databases, i.e. United Nation's databases such as FAOSTAT provides information on crop production yields and livestock/crop trade value and quantities; AQUASTAT provides data on water withdrawal quantities; United Nation's Main Aggregate Database provides information on value added by each country's economic activity, etc. Those sources are considered trustworthy, since they are internationally acknowledged and provide a large array of data on all regions of the world.

Nevertheless, the use of secondary data from the Water Footprint Network database can be questioned. Data on all green and blue water footprints of all products is retrieved from the two Water Footprint Network reports 47 and 48, which deal with water footprints of respectively crop- and animal- products, [Hoekstra and Mekonnen 2010, (a)], [Hoekstra and Mekonnen 2010, (b)]. Yet, those reports show a low level of transparency when describing the method for obtaining the water footprints, since climatic factors, growth periods of crops, animal life span, animal consumption rates and product value ratios are not presented in the methodology. This is a problem, because those factors are essential for the level of accuracy when allocating the water footprint of products.

An example of such an issue is the choice of green and blue water footprint of ‘pig meat’. The Water Footprint Network does not provide a detailed description of the pig product allocation in their database; hence, both ‘swine meat’ and ‘pork ham and cuts’ could be considered pig meat products. It is an important choice, though, since ‘swine meat’ has a water footprint about five times lower than ‘pork ham and cuts’. In our calculation, we select the ‘pork and ham cuts’ value for computing the water footprint of ‘pig meat’, since we consider it the primary good of pork production.

7.2.2 Agricultural trade calculation

In this report, a simplification is made when allocating the origin of goods. As explained in subsection 5.2.2, the products with larger export than import quantities are considered with a national origin, while a world average value is used for most of the goods with higher import- than export- values. This fact creates an error in our calculation because factors such as climatic and soil conditions are simplified.

There also exists an issue with re-exported products, given that a large amount of the foreign goods imported to Denmark enter Europe through countries such as The Netherlands and Germany. Thus, the exact origin of some of the products is unknown. In order to lower the uncertainty, we track the most probable origin of imports to the Netherlands and Germany and assign the “correct“ water footprint value to them.

7.2.3 Industrial trade calculation

As proposed by the Water Footprint Network, the industrial trade is done by a top-down approach; however, this is a source of error. It is by this approach assumed that all industrial activities have an equal ration between value and water intensity, but this might not be the case. The rate of both pollution and water use differ tremendously among industries, and the imported industrial water footprint is thus highly dependent on the nature of the imported products. The only way to facilitate this problem is to apply a bottom-up approach similar to that of the agricultural water trade; however, such an approach requires much more data. It would be necessary to retrieve data on what specific products that are imported, as well as data on where and how they are produced.

Also, the value of the industrial import proved hard to determine, since the import values from each country are not specified according to agriculture and industry. We solve this problem by multiplying every import value with the national ration between industrial imports and total imports; nevertheless, this generated an error since some countries mainly export industrial products, while other mainly export agricultural products.

7.2.4 Product transformation

Some of the most interesting results regarding a national water footprint is to look into the products that the virtual water consumption and the virtual water trade is assigned to – see figure 6.4 and 6.6. However, such calculations are more complicated than they look due to product transformations.

A good example is that Danes do not consume fodder. Rather, they consume the meat deriving from the animals that consume fodder; hence, the fodder import turns into a domestic consumption of animal products. Additionally, some animals consume animal products, and loops therefore occur where fodder turns into animal product that then afterwards turns into another animal product; however, it still derives from the same amount of fodder. Hence, product transformations impose the risk of double counting, and we have tried to limit such as much as possible in the calculations.

Another example is that of palm oil. Denmark imports more than 600 mill. m^3 virtual water in the form of refined palm oil; however, such oil is not used directly for household purposes, and one can then wonder where all that oil goes? Among many purposes, palm oil is used for chocolate, processed food and soap, [UP 2012], and it is thus hard to see if some of these products are in fact exported as a secondary palm oil product and thus <u>not</u> consumed in Denmark. This imposes an error on figure 6.4, since 31% of the total virtual water footprint is not consumed as pure oil – it is consumed or exported as a secondary palm oil product.

Product transformation also falsifies the assumption of industrial products only having a blue water footprint, since agricultural products can be part of an industrial product or used when producing a industrial product.

Nevertheless, these transformations only impose a source of error when investigating the constituents of the Danish water footprint. It has no influence on the size of the overall water footprint.

7.2.5 Comparison with the prior research

Ideally, any assessment should be tested in order to validate the quality of the research; however, this is not possible with water footprint assessment since neither the green water footprint nor the grey water footprint can be measured on a large scale. Being so, we are forced to evaluate the quality of our research by comparison to prior studies. To our knowledge, there exists only one piece of comparable research prior to our and that is "*Research Report Series No 50 - National water footprint accounts: The green, blue and grey water footprint of production and consumption*", [Hoekstra and Mekonnen 2011].

Our research is conducted much in line with the methodology of this report, and the respective Danish virtual water footprints only deviate by 19%. Still, this deviation can be explained by small differences in the applied methodology.

We calculate averages for the period 2000-2009, while the Water Footprint Network (WFN) applies the period 1996-2005; hence, our research is more up to date. Secondly, we use national sources for calculating the direct water footprint, while the WFN uses data from international organisations. Thirdly, the WFN assumes a constant industrial blue water consumption rate of 5%, thus assuming that the remaining 95% returns to the same water catchment area. We perceive this approach too imprecise, and we therefore produce specific blue water consumption percentages for every country of import according to the coastal population. [Hoekstra and Mekonnen 2011]

The WFN includes virtual grey water, and this is excluded in our research. They facilitate the problems of the grey water footprint by only taking nitrogen into account – of which they assume a global 10% leach. They furthermore apply European quality standards for the pollution loads of all trade partners. [Hoekstra and Mekonnen 2011]

We believe that the assumptions made by the WFN regarding virtual grey water are big enough to damage the validity of the study. All in all we therefore believe that our result is more precise.

7.3 Further research

To our knowledge, little research about water footprint in Denmark has been conducted prior to this study, and much work can therefore still be done in order to improve the liability and the quality of the results. It is a new and important field of study, as it is the link between Danish activities and global water shortage and pollution.

7.3.1 The water footprint of the Danish pig production

The Danish production of livestock, more specifically the pig production, is the absolute most important domestic activity in terms of virtual water, since vast quantities of water is bound to fodder production and foreign fodder import, as well as to animal products export and consumption. More research should therefore be conducted on this industry, thus ensuring an adequate and precise value allocation on Danish animal products. More research is also needed in regards to the green, blue and grey water footprints of fodder. Such research would improve the quality and transparency of the total Danish water footprint, but it would also be in the interest of Danish farmers in case water labels become a tool of the future. Danish grown fodder seems little water consuming due to our cold climate, while the Danish pig production is already specialised and optimised; hence, Danish pig meat may end up being some of the least water intensive in the world.

7.3.2 Improvement of the product specific water footprints

A national water footprint assessment is basically a summarisation of many traded and produced product specific water footprints; hence, any improvement in this regards would increase the quality of the study. Such improvements could be made by extrapolating on the list of products with an assigned water footprint, but also by improving the water footprints per se.

The calculation of the industrial water footprint has been rather simplified in this study due to limitations on both time and available data. In future studies, researchers must try to divide industrial trade into products with specific water footprints.

The green water footprint remains much larger than the blue water footprint, but our research proved that the grey water footprint may end up being the most significant of all three. The quality of the world's water could be improved, if all products were listed with an indicator of the aquatic pollution they cause – such as the grey water footprint. Further grey water research would make it possible to locate trade of water pollution – hence for instance show if rich countries are buying pollution from third world countries. The possibilities are many, but the indicator is restricted by its own definition. Before any trade statistics can be made, world communities must agree on one appropriate water quality standard for each substance – otherwise water pollution matters may be overseen in third world production countries with poor environmental legislation. Moreover, further data is needed on the discharge loads assigned to the production of all goods.

7.3.3 The water footprint of a Dane

For the sake of future information campaigns and future policy making, more research needs to be conducted on the different constituents of the Danish water footprint. This is only possible by studying product transformations, since this would enable consumers to make more thought-through choices on how they can lower the water footprint assigned to their way of life. Much research has already been done on how the direct water use of a Dane is distributed, but it could be interesting to further study how this relates to green, blue and grey water – see figure 6.4.

One related research idea could be:

"*What part of a dishwashing holds the biggest water footprint? The water or the soap?*"

7.3.4 Water footprint in relation to Environmental Impact Assessment

Like both the carbon footprint and the ecological footprint, water footprint is an indicator that describes how a certain action or a certain product impacts the biosphere in relation to a problem. The water footprint is a bit more diverse than that, since a 100 m^3 of water consumption may impose much greater problems in dry regions than in regions with abundance of water. As already touched upon in section 2.7, this fact can end up hiding the "true" impact of products, and more research in therefore needed on investigating the link between water footprint in relation to environmental impact assessments. Would it for instance be possible to make a "un sustainable water use"-water footprint?

8. Conclusion

Clean fresh water is a valuable natural resource and a precondition for all life on Earth. It is furthermore a resource under threat due to an anticipated increase in both consumption and pollution, and competent management is thus required in order to secure a supply that matches the demand of the future. The aim of this study was to investigate whether the water footprint methodology can provide new knowledge for the Danish water management, thus throwing light on new and previously disregarded patterns of water consumption.

The investigation of the Danish direct water footprint mainly confirmed already known knowledge, since water management is a well-studied field of science in Denmark. It proved that the agricultural sector is the number one consumer and polluter of water in Denmark, and that 84% of all water is used for livestock production. It furthermore helped to gain a little perspective on water as a resource, since around 16 litres of water is used on the fields for every litre of water a Dane thinks that he consumes.

The virtual water footprint of Denmark took trade of foreign products into account, and this provides the reader with a more diverse and holistic perception of water consumption. The Danish water footprint proves to be 35% higher than the world average, and this is very high since Denmark is situated in a cold coastal climate in Northern Europe with assigned low crop evapotranspiration; hence, the green water footprint should in fact be lower than the world average. From the traditional 123 l/day assigned to a Dane, the daily blue water use increases to 480 l/day when including consumer goods. The agricultural products hold the highest fraction of the water footprint due to the definition of the green water footprint, and consumption of animal products corresponds to 40% of the water footprint of a Dane. Nuts and seeds add up to another 31%, while the traditional household water only adds up to only 3% of the virtual water footprint.

From a national perspective, Denmark imports 12 times more industrial blue water than it exports, and this suggests that the value creation in the Danish industries is less blue water intensive than that of the countries of import.

The virtual water footprint of Denmark proved to be lower than the direct water footprint, which is largely due to a massive export of water intensive animal products. The pig production remains the sole activity with most virtual water assigned. It can only be sustained through large imports of virtual water in the form of foreign fodder, and the water footprint of the total Danish pig export adds up to a virtual water volume equivalent to 2/3 of the total direct Danish water footprint. Further research should be made on this sector before it can be concluded whether the Danish pig production is causing unnecessary water related problems.

The research has been a pilot project in a Danish context, and much more research is needed before the results are reliable enough to spark any real change; however, we believe that we have created a starting point for further academic extrapolation. In the long run, we believe that the water footprint methodology can serve as a tool for making smarter choices. It will be possible to identify problems of improper water use, aquatic pollution assigned to trade, the water impacts assigned to consumption of foreign goods, and much more.

Next step could be water labelling or information campaigns similar to the ideas in section 6.4. We here proved that the personal water footprint of a Dane can be greatly lowered by making better product choices, and it is evident from those examples that the water footprint methodology is effective when expressing product consumption in relation to the assigned impacts on the global fresh water resources.

The water footprint methodology can provide new knowledge for the Danish water management.

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Title: No name
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Source: Microsoft Power Point; version 2008 for iMac

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Title: No name
Description: Pictures used for the figure
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Title: No name
Description: A picture of a potato plant
URL: http://www.littlepiggy.ca/wp-content/uploads/2010/07/potatoes-diagram.gif

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Year: 2005
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Author: Statistics Denmark
Title: FODER1: Foderforbruget efter fodermiddel, oprindelse og enhed
English Title: The fodder use according to type, origin and unit
Year: 2012
URL: http://iisboy4.dst.dk/statbank5a/SelectVarVal/Define.asp?MainTable=FODER1& PLanguage=0&PXSId=0

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Year: 2012
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URL: https://www.retsinformation.dk/forms/r0710.aspx?id=137028

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Year: 2006
URL: *https://www.retsinformation.dk/Forms/R0710.aspx?id=13071*

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Author: The Environmental Ministry of Denmark
Title: Bekendtgørelse af lov om naturbeskyttelse
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URL: *https://www.retsinformation.dk/forms/r0710.aspx?id=127104*

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English Title: Declaration of the law about planning
Year: 2009
URL: *https://www.retsinformation.dk/forms/r0710.aspx?id=127131*

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Author: The Environmental Ministry of Denmark
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English Title: Declaration about settlement of matters between municipalities and supply companies
Year: 2010
URL: *https://www.retsinformation.dk/Forms/R0710.aspx?id=130647*

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Author: The Environmental Ministry of Denmark
Title: Bekendtgørelse af lov om kommuners afståelse af vandforsyninger og spildevandsforsyninger
English Title: Declaration of the law about municipality cession of water supply and wastewater supply
Year: 2010
URL: *https://www.retsinformation.dk/forms/r0710.aspx?id=132106*

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Author: The Environmental Ministry of Denmark
Title: Bekendtgørelse af lov om miljøbeskyttelse
English Title: Declaration of the law about environmental protection
Year: 2010
URL: *https://www.retsinformation.dk/forms/r0710.aspx?id=132218*

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Author: The Environmental Ministry of Denmark
Title Bekendtgørelse af lov om vandforsyning
English Title: Declaration of the law about water supply
Year: 2010
URL: *https://www.retsinformation.dk/forms/r0710.aspx?id=132254*

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Author: The Environmental Ministry of Denmark
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English Title: Regarding the water plans
Year: 2011
URL: *http://www.naturstyrelsen.dk/Vandet/Vandplaner/Om_vandplanerne/*

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URL: *http://www.naturstyrelsen.dk/NR/rdonlyres/CA1493A0-608A-486E-9C4C4E44BF1EE2F/0/1_7_Aarhus_Bugt_19dec_2011.pdf*

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Title: Mission og Vision
English Title: Mission and Vision
Year: 2011
URL: *http://www.naturstyrelsen.dk/Om+os/Mission+og+vision/*

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Year: 2012
URL: *http://www.naturstyrelsen.dk/NR/rdonlyres/C88AD233-0775-45B5-8C500A93B11F133D/120342/Bilag5.pdf*

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Year: 2000

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Author: The European Parliament
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Year: 2009

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Author: The European Parliament
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Year: 2012
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Appendix 1.
Water-related legislation

This appendix serves as a short introduction to the relevant legislation in Danish water management. It provides the reader with a broader understanding on the institutional power as well as the resulting plans on water matters.

A1.1 The Danish planning system

All planning in Denmark regarding land use is conducted according to the regulations written in the Law of Planning[9]. This law defines a hierarchical system by which national and international regulations are transformed into local plans, thus ensuring local compliance based on local knowledge. The primary goal of the law is to ensure holistic and well-coordinated planning as a way to preserve the nature and environment of the country with a respect to urban development. The main principle is presented in figure A1.1. [The Environmental Ministry of Denmark 2009, (b)]

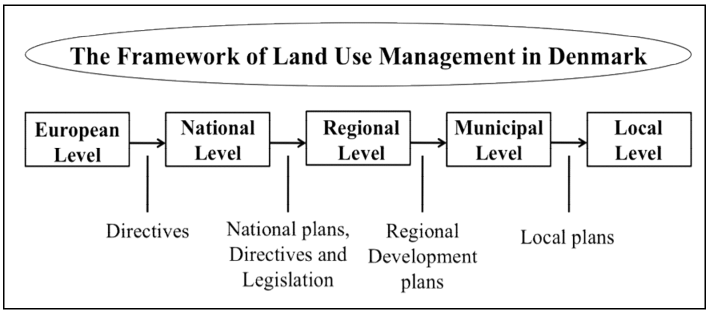

Figure A1.1: The framework of land use management in Denmark, [Revsbech and Puggaard 2008]**.**

Figure A.1.1 illustrates with arrows how the different institutional levels influence each other through laws, directives and plans. The direction of the arrow indicates the power relations that shape the entire framework of planning. Each level can act independently according to internal policies, but such actions must not conflict with the plans of higher institutional levels. Moreover, several national laws also apply to the municipal planning, though it might not be directly described in the intermediate regional planning. Hence, power relations apply to all the lower institutional levels. [The Environmental Ministry of Denmark 2009, (b)]

The power relation between the European level and the national level is most commonly, in regards to land use planning, expressed in the form of international directives that need to be integrated into the national legislation. The planning system was greatly altered in 2005 with the municipal reform, during which all responsibilities regarding rural planning were moved from the regional level and down to the municipal level. As a consequence, regional planning today aims at planning the overall goals for regional development, rather than it aims at being concrete. The regional development plan has almost no influence on the Danish water management. [Revsbech and Puggaard 2008]

The municipal level is where most policies and plans are transformed into direct action plans. Such plans describe the future changes resulting from both internal and external decisions, and they are defining the link between local development and the legislation imposed from both national and international legislative bodies [Revsbech and Puggaard 2008]. Planning on the municipal level was furthermore altered in 2010, when the former government privatized all water supply and waste water treatment services in Denmark, thus creating joint-stock companies, with the municipalities as main shareholders, to deal with such matters, [The Environmental Ministry of Denmark 2010, (a)], [The Environmental Ministry of Denmark 2010, (b)]. The municipal regulative body is therefore rather divided in regards to water management, since some certain matters are managed by the municipality itself while others have been outsourced.

[9] In Danish: Planloven

The local level is where all policies are made into specific projects. Local plans can be perceived as the individual pieces that realise the planning on a municipal level. In regards to water management, a local plan could include a plan about when to renovate the sewers in a neighbourhood, for in this way to comply with the total sewer system renovation presented in the municipal wastewater plan. [The Environmental Ministry of Denmark 2009, (b)]

A1.2 Water related legislation

This section serves as a short introduction to the relevant legislation in Danish water management. It provides the reader with a broader understanding on the institutional power as well as the resulting plans on water matters.

A1.2.1 The Nature Protection Law[10]

The Nature Protection Law has its roots in both nature preservation and access to nature, and it differs from other environmental legislation because it deals with entire nature types rather than it implies to specific projects or emissions. The most known part of the law is §3 which states that it is illegal to in any way to change the natural condition in lakes larger than $100m^2$ or in watercourses granted §3 protection. The paragraph also applies to all moors, marshes, swamps and meadows. [The Environmental Ministry of Denmark 2009, (a)]

This has a strong link to water management since both water abstraction, river maintenance or any sort of discharge is illegal in all water bodies covered by §3. Both the municipality and the environmental minister have the authority to exclude certain water bodies from §3 due to societal importance [The Environmental Ministry of Denmark 2009, (a)]. The law therefore centralises the power to the local authority regarding any violation on protected areas.

A1.2.2 The Environmental Protection Law[11]

The goal of the Environmental Protection Law [The Environmental Ministry of Denmark 2010, (c)] is to protect the environment in relation to pollution and resource use, unlike the Nature Protection Law that concerns preservation of certain nature types. §27 states that any discharge of substances to watercourses, lakes or to the sea is prohibited, if this discharge can lead to pollution. §28 further states that the municipal board is the authority that can grant permission for such discharges, hence no waste water treatment installation can operate without a prior municipal permission. [The Environmental Ministry of Denmark 2010, (c)]

§32 obligates every municipality to produce official waste water plans that documents a structured and well planned strategy in compliance with plans produced higher in the hierarchy from figure A1.1, [The Environmental Ministry of Denmark 2010, (c)]. The waste water plan must include a description of all current areas connected to public wastewater system, as well as it has to include which areas will be connected in the future. The waste water cleaning methods must also be included. The general aim of the plan is to present both the current conditions of waste water treatment system, and a time line on when which improvement can be expected. [Revsbech and Puggaard 2008]

A1.2.3 The Water Supply Law[12]

The goal of the Water Supply Law is to make sure that utilisation and protection of drinking water resources is managed in a structured and coherent way. It aims at ensuring supply of a high quality while taking the needs of the public, the nature, and businesses into account. §18 states that no water can be abstracted without a prior permission, and §20 emphasises that such permits can only be granted by the municipality, [The Environmental Ministry of Denmark 2010, (d)].

[10] In Danish: Naturbeskyttelsesloven
[11] In Danish: Miljøbeskyttelsesloven
[12] In Danish: Vandforsyningsloven

Mapping of drinking water resources is conducted as part of the national water plans that are described in section A1.2.6; however, the Water Supply Law obligates the municipality to produce a water action plan for those chosen areas. §14 further states that every municipality must produce a water supply plan that describes how water in the municipality will be supplied to the public. The plan is the drinking water equivalent to the waste water plan, and it is thus a rather technical plan that ensures coherent resource management. [The Environmental Ministry of Denmark 2010, (d)]

A1.2.4 Legislation in regards to Environmental Impact Assessments (EIA)

Public or private projects may influence the environment in a variety of ways, and this also applies to matters of water management. Directive 2011/92/EU has been in use since 1985 and it applies to all projects likely to result in significant environmental effects. The directive obligates all European member states to ensure that an EIA is prior to any decision on projects that might lead to unwanted environmental effects. Both projects of groundwater abstraction and waste water discharges are mentioned in article 4 of the directive. The directive furthermore states that the public must be informed about those potential environmental impacts early in the phases of decision-making. [The European Parliament 2011]

It is decided in the National Law of Planning that all efforts assigned to Directive 2011/92/EU are implemented on a municipal planning level in Denmark. Consequently, the official municipal plans must include information about guidelines and decisions regarding the size and location of specific projects that may influence the environment in a significant way. An official EIA must be conducted prior to this, and it must be a part of the underlying municipal explanatory assessment[13]. [The Environmental Ministry of Denmark 2009, (b)]

The municipal information about conducted EIA's must include a description of the specific project, a description of the relevant alternatives, a description of how the surroundings can be effected, and a description of the short-term and long-term effects caused by the project. [Revsbech and Puggaard 2008]

However, a series of exceptions have been made in regards to the EIA procedure, in accordance with existing specific national laws on subjects that would need an environmental impact assessment according to Directive 2011/92/EU. Matters of water abstraction are managed by Water Supply Law §18, matters of waste water discharges are managed by the Environmental Protection Law §28, and matters of raw material extraction are managed by the Raw Materials Law[14] §7. However, none of such projects can be realised before they are accepted and included in the municipal plan. [Revsbech and Puggaard 2008]

A1.2.5 Legislation the Agricultural sector

The agricultural sector is one of the big polluters in Denmark, and there are thus a variety of laws, plans and regulations that aims at managing unwanted impacts. This subsection will include 2 regulations about leaching nutrients and pesticide application.

The Law about Agricultural Use of Fertiliser and about Plant Cover[15] aims at limiting the agricultural leaching of Nitrogen. It states that every agricultural business must be granted a maximum quota of nitrogen for field fertilisation, and this quota must be calculated according to the size of the fields, the type of soil and the kind of cultivated crops. This quota entitles the business to buy a certain quantity of fertiliser without taxation; however, the business will be fined if it uses more than the yearly quota given. All agricultural businesses are thus obligated to produce nitrogen accountancy each year in order to prove that they have complied with the given quota. The authority that gives out quotas and assesses all accountancies is the Danish Ministry of Food, Agriculture and Fishery. [The Danish ministry of Food, Agriculture and Fishery 2011]

Directive 2009/128/EC applies to all member states of the European Union, and it aims at achieving sustainable use of pesticide on a European level by "*reducing the risks and impacts of pesticide use on human health and the environment*". It obligates all member states to adopt national pesticide action plans in which objectives, target lines, measures and times tables are described. These plans need to be revised and assessed every fifth year and all three pillars of sustainability must be included. In the end, appropriate measures must be taken to protect aquatic ecosystems and drinking water resources from the use of pesticides. [The European Parliament 2009]

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[13] In Danish: Kommuneplanredegørelse
[14] In Danish: Råstofloven
[15] In Danish: Lov om jordbrugets anvendelse af gødning og om plantedække

A1.2.6 The water Framework Directive

Directive 2000/60/EC [The European Parliament 2000] is more commonly known as “The Water Framework Directive”. It was established in 2000 and it is a legislative framework that encompasses all the legislation described in the prior subsections. It obligates all European member states to ensure good ecological status in all domestic water bodies before 2015; and so it includes groundwater, surface water and coastal water. It is a comprehensive piece of legislation, since the goal of the directive is to protect and enhance aquatic ecosystems within a 15 year period. This implies restoration of aquatic habitats and a reduction in all man-made pollutants that enter the water bodies. It further implies that there must be an adequate balance between the recharge rate of groundwater aquifers and the quantities abstracted for societal needs. [The European Parliament 2000]

The member states are required to produce a basis analysis of the characteristics and condition of each river catchment, as well as they are obligated to analyse to what extent society influences the current condition. The member states must then subsequently decide the adequate tool needed to produce a cost-effective good ecological status in all water bodies. [The European Parliament 2000]

The Water Framework Directive is implemented to Danish legislation through the Law of Environmental Goals[16], and it states that all planning regarding the requirements of the Water Framework Directive is managed directly by the Danish Ministry of Environment. The basis analysis and the means for achieving good ecological status are presented in national water plan that span 6 years. The water plans will be subdivided into national water districts, i.e. water plan 1.7 only concerns Århus Bay. The plan will subsequently be realised through municipal action plans that are more specific about how the environmental goals will be achieved. [The Environmental Ministry of Denmark 2006]

A1.3 The institutional constellation

The end product of all the above-mentioned legislation is a series of plans that aim at managing different aspects of the overall Danish water management. The institutional set-up and the plans related to water management are illustrated in figure A1.2.

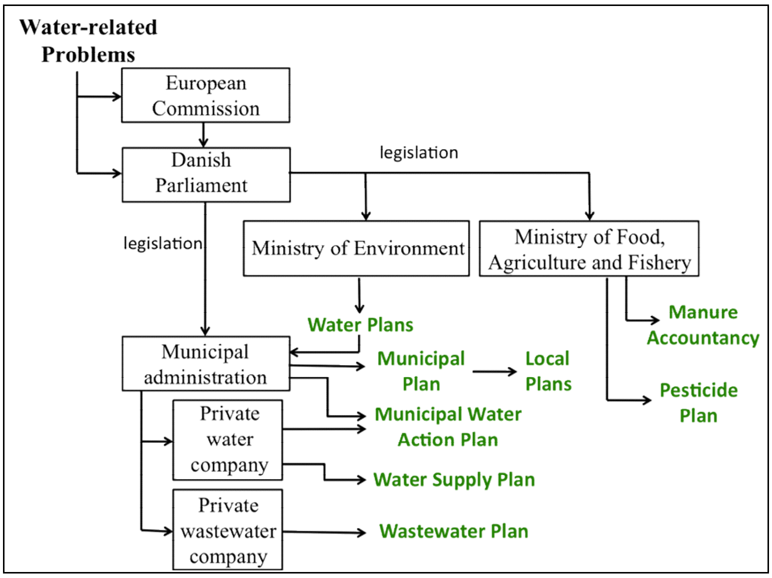

Figure A1.2: The institutional set-up and the plans related to water management in Denmark

As shown, all water management has its starting point in a water related problem or concern that then influences both national and international policy-makers. This is the catalycist for the environmental legislation that is implemented through official plans.

16 In Danish: Miljømålsloven

It is important to notice how almost all the plans that influence society are produced by the municipal administration. This constellation was finalised in 2005 with the munucipal reform, and all planning regarding aquatic discharges, water abstraction, and influences of any kind on protected areas can therefore not be conducted without municipal approval. The municipality is thus also the authority in charge of legisltive compliance in ragards to these matters. There is a clear power relation between the municipality administration and the society it governs; however, no plan can be finalised without public participation [Revsbech and Puggaard 2008].

None of the plans produced by the municipality are allowed to contradict the national water plans from the Ministry of Environment; hence, a power relation exists between the Ministry of Environment and the municipal administration. This power relation enables the Ministry of Environment to generate holistic plans that can ensure legal compliance with the Water Framework Directive.

Figure A1.2 reveals a potential institutional problem, since all management assigned to the agricultural sector is conducted by the ministry of Food, Agriculture and Fishery. There exist no power relations among the ministries, and the Danish state has thus assigned the obligation for compliance with the Water Framework Directive to an institution without the power to manage the pollution from the most water polluting industry in Denmark.

It is furthermore unthinkable that the directive could be implemented without consent from the Ministry of Economy, since the initial public investment of the first water plan is more than 500 million Euros [The Environmental Ministry of Denmark 2011, (a)]. The current water plans have thus been implemented on an inter-ministerial level - an example of this is the report "*Fagligt udredningsarbejde om virkemidler i forhold til implementering af vandrammedirektivet*", in which 5 ministries collaborates with research institutes such as the Danish Institute for Environmental Assessment[17] and Århus University in order to evaluate the cost-effectiveness of several means to comply with the Water Framework Directive. [The Finance Ministry of Denmark, et. al 2007]

[17] In Danish: Danmark Miljø Undersøgelser (DMU)

Appendix 2.
A guide for the Microsoft Excel files

All calculations assigned to the results of the report are conducted in eight "Microsoft Excel" files. The following appendix serves as a guide for these files; hereby enabling the reader to find the documentation that he or she might request while reading the report.

The files are structured accordingly: DATA files, RESULT files, ADDITONAL files.

A2.1 The DATA files

Little scientific research has been conducted on water footprint in Denmark prior to our research, and it has thus been necessary to retrieve data from a large array of sources. The report contains 83 different references and most of them are directly assigned to the calculations; however, the data needs to be modified before fitting the context of the water footprint assessment, and this is the purpose of the DATA files.

The files are by nature rather heavy to read due to the vast amount of data; however, they have been made as manageable as possible by:

- giving the sheets appropriate names,
- cutting away all excess data,
- the use of colour codes,
- adding frames around respective groups of calculations

Furthermore, references are present above every column in which are directly used. This improves the transparency of the calculations, and it enables the reader to check the values of the primary reference if he or she is in any doubt regarding the liability of the study.

All information in the files is specified for the entire period 1990 to 2009, and an average is calculated for the period 2000-2009. Being so, the DATA files are fully applicable when assessing both the average water footprint and the development of the water footprint. The results from the DATA files are emphasised with bold text, thereby making it clear which data that will be applied in the RESULT files.

The three DATA files are:

1. "DATA - Direct WF"
2. "DATA - Agricultural Trade"
3. "DATA - Industrial Trade"

File 1 includes all the data related to the direct water footprint of Denmark; hence, it contains data on water abstraction discharge load on pollutants, crop production and the assigned water footprint.

File 2 includes all the water assigned to trade of agricultural products; hence, it contains data on the traded quantities and the assigned water footprint values. These water footprint values are further specified according to origin by the use of file 7.

File 3 includes all the blue water assigned to trade of industrial products; hence, it contains origin-specific information of the import value and the assigned virtual water. It also includes similar data regarding the Danish export of industrial goods. All trade is calculated in 2009 currency in order to prohibit error due to inflation.

A2.2 The RESULT files

The purpose of the RESULT files is to process and graphically present the information from the DATA files. It is the graphs from these files that are directly used in the main report, and the files are in general conducted with minimal data in order to make them small, manageable and easy to understand for the reader. A table in a RESULT file may be a result of much reference modifications in a DATA file, and references are thus listed in the top of every sheet without a direct correlation to what value they directly refer to. The reader must therefore return to the underlying DATA file, if such documentation is requested.

Certain explanatory data will be included in the RESULT files, though it does not serve a direct purpose in the RESULT calculations. One example is the assigned water footprint values, since they help to illustrate why a trade water footprint is lower or higher than expected.

The three RESULT files are files are:

4. "RESULT - Direct WF"
5. "RESULT - Virtual WF"
6. "RESULT - Development in the WF"

File 4 includes the direct water footprint of Denmark as an average value for the period 2000-2009. It exclusively uses data from file 1, and the most important results are illustrated and presented in section 6.1

File 5 includes the virtual footprint of Denmark as an average value for the period 2000-2009; hence, it includes water supplied from both domestic and foreign activities. Conclusively, it uses data from all 3 data files, and the most important results are illustrated and presented in section 6.2

File 6 includes the development of the virtual water footprint between 1990 and 2009; hence, it also includes water supplied from both domestic and foreign activities. Conclusively, it uses data from all 3 data files, and the most important results are illustrated and presented in section 6.3.

A2.3 The ADDITIONAL files

Writing a master thesis is a turbulent process, and it is therefore not possible to foresee every result before initiating an assessment. Being so, certain results may end up catching particular interest, while others seem less important than anticipated. We chose to spend the last weeks of our study on improving the overall quality and liability of the research by a series of additional calculations and considerations - some of these fitted into the prior excel files while others seemed rather independent. Those calculations that seemed illogical to directly include in sheet 1-6 are presented as the ADDITIONAL files.

These additional files have a reference structure matching that of the DATA files, and the two ADDITIONAL files are:

7. "ADDITIONAL - WF values of imports larger than 0.1‰"
8. "ADDITIONAL - Calculations"

File 7 specifies and improves the water footprint value of all agricultural products that add up to more than 0.1‰ (per mill) of the total agricultural virtual water import. This is done by specifying the origin, thus enabling us to pick a more adequate water footprint value. The resulting values are directly inserted in DATA file 2 and marked with a colour code.

File 8 contains calculations that compliment the results of the water footprint assessment without being directly assigned. It includes the calculations of section 6.4 and a more specific assessment of the water footprint distribution of an average Dane, conducted for a 5-year period between 2005 and 2009 (presented as figure 6.4).