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A pilot in corporate water footprint accounting and impact assessment:

The water footprint of a sugar-containing carbonated beverage

Value of Water

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A PILOT IN CORPORATE WATER FOOTPRINT ACCOUNTING AND IMPACT ASSESSMENT:

THE WATER FOOTPRINT OF A SUGAR-CONTAINING CARBONATED BEVERAGE

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Summary

All water use in the world is ultimately linked to final consumption by consumers. It is therefore interesting to know the specific water requirements of various consumer goods, particularly for goods that are water-intensive, like food products and beverages. This information is relevant not only for consumers, but also for food processors, retailers, traders and other businesses that play a central role in supplying those goods to the consumers.

The objective of this study is to carry out a pilot study on water footprint accounting and impact assessment for a hypothetical sugar-containing carbonated beverage in a 0.5 litre PET-bottle produced in a hypothetical factory that takes its sugar alternatively from sugar beet, sugar cane and HFMS (high fructose maize syrup) and from different countries. The composition of the beverage and the characteristics of the factory are hypothetical but realistic. The data assumed have been inspired by a real case. Apart from water, the 0.5 litre bottle contains 50 grams of sugar, 4 grams of CO_2 and very small amounts of some flavours (including caffeine, vanilla, lemon oil and orange oil). This is the first study that assesses the water footprint of a product with a very broad scope with respect to the inputs considered. The study does not only look at the water footprint of the ingredients of the beverage, but also at the water footprint of the bottle and other packaging materials and at the water footprint of the construction materials, paper and energy used in the factory and of the vehicles and fuel used for transport. The aim is primarily to learn from the practical use of existing water footprint accounting and impact assessment methods and to refine these methods and develop practical guidelines.

The water footprint of the factory that produces the beverage consists of two parts: the operational water footprint and the supply-chain water footprint. The first is the amount of freshwater used in the factory operations itself, i.e. the direct freshwater use. The supply-chain water footprint is the volume of freshwater used to produce all the goods and services that form the inputs of production, i.e. the indirect freshwater use. The present study is the first to also differentiate between the water footprint that can be immediately associated with a particular product and the ‘overhead water footprint’. The latter is defined as the water footprint pertaining to the general activities for running a business and to the general goods and services consumed by the business. The term ‘overhead water footprint’ is used to identify water consumption that is necessary for the continued functioning of the business but that does not directly relate to the production of one particular product.

The study consists of a few steps. First, the production system for the 0.5 litre PET-bottle sugar-containing carbonated beverage has been identified, to distinguish the relevant process steps from source to final product. Subsequently, the water footprint of the beverage has been calculated by quantifying the water footprint of each input separately and by accounting for process water use as well. Three different water footprint components are distinguished: the green, blue and grey components. Finally, a local impact assessment has been carried out, by looking at the occurrence of environmental problems in the regions where the water footprint of the product is located.

Although most companies focus on their own operational performance, this report shows that it is important to address complete supply chains for fresh water usage. The water footprint of the beverage studied in this report has a water footprint of 169 to 309 litres of water per 0.5 litre bottle, of which 99.7-99.8% refers to the supply chain. The study shows that ingredients that constitute only a small fraction of the final product can significantly affect the total water footprint of a product. In the case of our hypothetical beverage, this holds for the caffeine extract from coffee and the vanilla extract from vanilla beans. On the other hand, the study also shows that many components studied hardly contribute to the overall water footprint. The overhead water footprint constitutes a minor fraction of the supply-chain water footprint (0.2 -0.3 %).

1. Introduction

Freshwater in sufficient quantities and adequate quality is a prerequisite for human societies and natural ecosystems (Costanza and Daly, 2002). Today, about 70% of the total freshwater withdrawal by humans is for irrigated agricultural use (Gleick, 1993; Bruinsma, 2003; Shiklomanov and Rodda, 2003; UNESCO, 2006). Agricultural as a whole is responsible about 86% of the worldwide freshwater use (Hoekstra and Chapagain, 2007). Agriculture has to compete with other water users like municipalities and industries (Rosegrant and Ringler, 1998; UNESCO, 2006). Freshwater is a basic ingredient for many companies’ operations, and effluents may pollute the local hydrological ecosystems. Many companies have addressed these issues and formulated proactive management (Gerbens-Leenes *et al*., 2003). A company may face four serious risks related to failure to manage the freshwater issue: damage to the corporate image, the threat of increased regulatory control, financial risks caused by pollution, and insufficient freshwater availability for business operations (Rondinelli and Berry, 2000; WWF, 2007).

The water footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business (Hoekstra and Chapagain, 2008). Water use is measured in terms of water volumes consumed (evaporated or incorporated into the product) and polluted per unit of time. The water footprint is a geographically explicit indicator, not only showing volumes of water use and pollution, but also the locations. The water footprint of a business is defined as the total volume of freshwater that is used directly and indirectly to run and support a business. The water footprint of a business consists of two components: the direct water use by the producer (for producing/manufacturing or for supporting activities) and the indirect water use (the water use in the producer’s supply chain). The 'water footprint of a business' is the same as the total 'water footprint of the business output products'. Compared to other water accounting tools, the water footprint provides the most extended and complete water accounting method, since it includes both direct and indirect water use and considers both water consumption and pollution. It has already been applied for various purposes, such as the calculation of the water footprint of a large number of products from all over the world (Chapagain and Hoekstra, 2004), but so far there have been few applications for business accounting.

The objective of this study is to carry out a pilot study on water footprint accounting and impact assessment for a hypothetical sugar-containing carbonated beverage in a 0.5 litre PET-bottle produced in a hypothetical factory that takes its sugar alternatively from sugar beet, sugar cane and HFMS (high fructose maize syrup) and from different countries. The aim is primarily to learn from the practical use of existing water footprint accounting and impact assessment methods and to refine these methods and develop practical guidelines. The composition of the beverage and the characteristics of the factory are hypothetical but realistic. The whole assessment has been inspired by a real case. From a scientific point of view, this study aims to assess the necessary scope of analysis and, in particular, to explore the degree of details required in such a study. Finally, an impact assessment of the water footprints is carried out, identifying the hotspots or high-risk areas.

2. Method

The study estimates the water footprint of a hypothetical 0.5 litre PET-bottle sugar-containing carbonated beverage. It looks into more detail at the water footprint of the sugar input, by considering three different sources (sugar beet, sugar cane and HFMS) and various countries of origin. The water footprint of different ingredients and other inputs is calculated distinguishing the green, blue and grey water components. The green water footprint refers to the global green water resources (rainwater) consumed to produce the goods and services. The blue water footprint refers to the global blue water resources (surface water and ground water) consumed to produce the goods and services. 'Consumption' refers here to 'evaporation' or 'incorporation into the product'. It does not include water that is withdrawn but returns to the system from where it was withdrawn. The grey water footprint is the volume of polluted water that associates with the production of goods and services. The various water footprint concepts used are defined as in Hoekstra *et al.* (2009). See also the glossary in the back of this report. The calculation methods applied also follow Hoekstra *et al.* (2009).

The total water footprint of a business contains various components as shown in Figure 1. The 'business' considered in this study refers to the part of the factory that produces our 0.5 litre PET bottle sugar-containing carbonated beverage. The factory produces also other products, but this falls outside the scope of this study. The water footprint of our product includes both an operational water footprint and a supply-chain water footprint. The operational (or direct) water footprint is the volume of freshwater consumed or polluted in the operations of the business itself. The supply-chain (or indirect) water footprint is the volume of freshwater consumed or polluted to produce all the goods and services that form the input of production of the business. Both operational and supply-chain water footprint consist of two parts: the water footprint that can be directly related to inputs applied in or for the production of our product and an overhead water footprint. In all cases, we distinguish between a green, blue and grey water footprint.

Figure 2 shows the production system of our product. It shows the four main ingredients of the beverage (water, sugar, CO_2 and syrup for flavouring) and the main other inputs of production (bottle, cap, label and glue, packing materials).

The production system shown in Figure 2 does not show the overhead of production. The overhead of production refers to all inputs used that cannot be solely attributed to the production of the specific product considered. The overhead water footprint refers to freshwater use that in first instance cannot be fully associated with the production of the specific product considered, but refers to freshwater use that associates with supporting activities and materials used in the business, which produces not just this specific product but other products as well. The overhead water footprint of a business has to be distributed over the various business products, which is done based on the relative value per product. The overhead water footprint includes for example the freshwater use in the toilets and kitchen of a factory and the freshwater use behind the concrete and steel used in the factory and machineries.

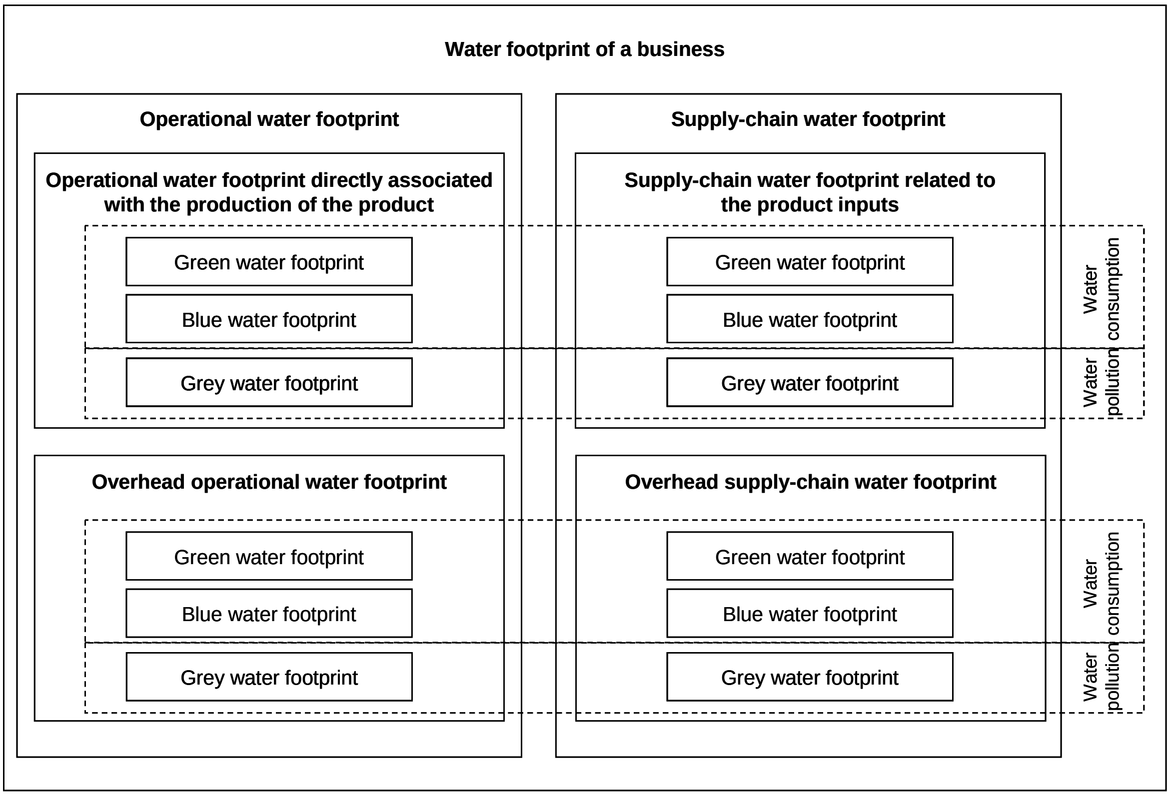

Figure 1. Composition of the water footprint of a business.

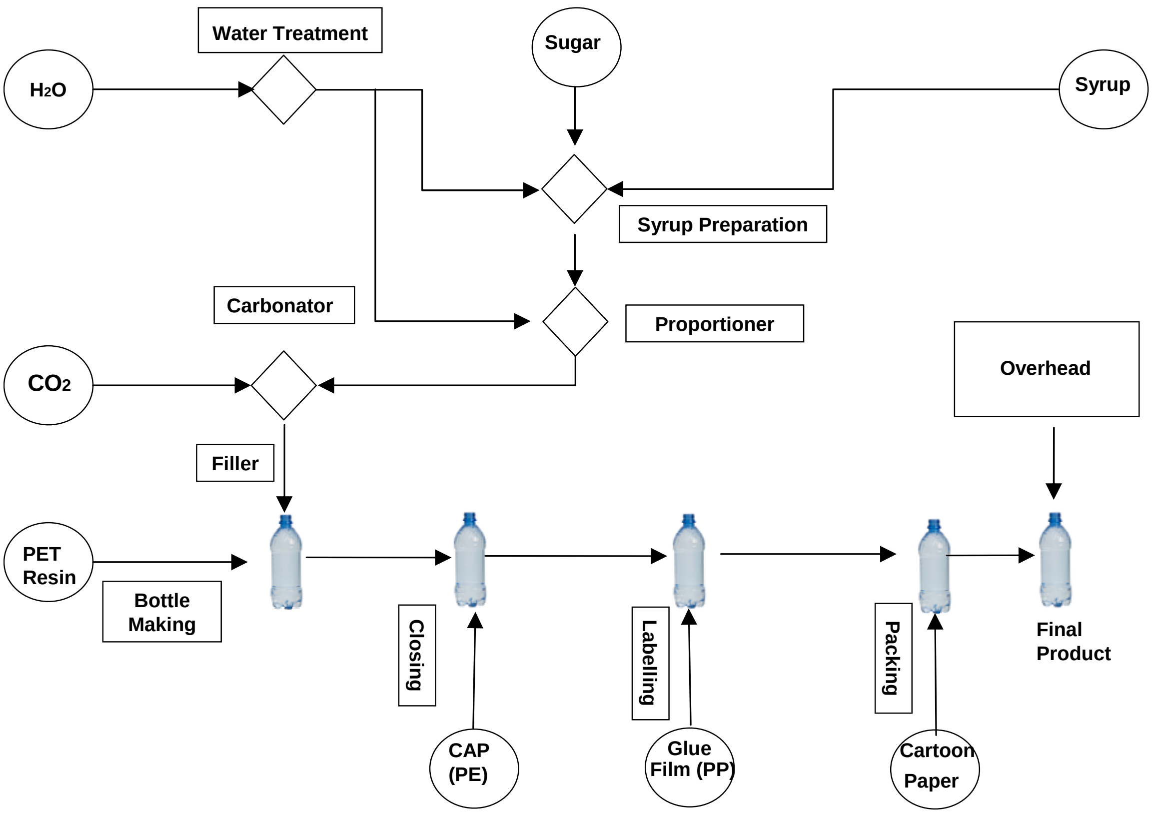

Figure 2. Production system of the 0.5 litre PET-bottle sugar-containing carbonated beverage.

3. Data sources and assumptions

For the assessment, we have formulated a hypothetical sugar-containing carbonated beverage in a 0.5 litre PET-bottle and a hypothetical factory that takes its sugar alternatively from sugar beet, sugar cane and HFMS (high fructose maize syrup) and from different countries. The factory itself is assumed to be in the Netherlands, but many of the inputs come from other countries. The composition of the beverage and the characteristics of the factory are hypothetical but realistic. The set of data assumed has been inspired by a real case.

3.1 Operational water footprint

3.1.1 Operational water footprint directly associated with the production of the product

The following components are defined as operational water footprint:

- Water incorporated into the product as an ingredient.
- Water consumed (i.e. not returned to the water system from where it was withdrawn) during the production process (during bottling process, washing, cleaning, filling, labelling and packing).
- Water polluted as a result of the production process.

The first two components form the blue operational water footprint; the third component forms the operational grey water footprint. There is no use of green water (rainwater) in the operations, so there is no operational green water footprint.

The water used as ingredient is 0.5 litre per bottle. The production of the 0.5 litre PET-bottle sugar-containing carbonated beverage includes the following process steps: bottle making (from PET resins to PET-bottle forms), bottle cleaning (by air), syrup preparation, mixing, filling, labelling and packing. During all these processes, there is no water consumption.

All wastewater produced during the production steps of the beverage is treated at a municipal wastewater treatment plant. The concentrations of chemicals in the effluent of the wastewater treatment plant are equal and in some instances even lower than the natural concentrations in the receiving water body. With this assumption, the grey component of the operational water footprint is effectively zero.

3.1.2 Overhead operational water footprint

The overhead operational water footprint is the water consumed or polluted because of the following activities:

- Water consumption by employees (drinking water).
- Water consumption or pollution as a result of water use in toilets and kitchen.
- Water consumed or polluted because of washing working clothes of the employees.

- Water consumed or polluted because of cleaning activities in the factory.
- Water consumption in gardening.

The factory considered in this study produces a number of different beverage products; our 0.5 litre PET bottle sugar-containing carbonated beverage is just one of them. Therefore, only a fraction of the total overhead water footprint is attributed to our beverage product, based on the ratio of the annual value related to the production of this specific product to the annual value of all products produced in the factory. The annual production value of our beverage product is 10% of the total production value of all beverage products produced in the factory.

In this study we assume that drinking water is negligible and that there is no gardening. It is further assumed that all water used during the other activities specified above returns to the public sewerage system and is treated in a municipal wastewater treatment plant such that the effluent causes no grey water footprint. As a result, the overhead operational water footprint is estimated as zero.

3.2 Supply-chain water footprint

3.2.1 Supply-chain water footprint related to the product inputs

The supply-chain water footprint related to product inputs consists of the following components:

- Water footprint of product ingredients other than water (sugar, CO_2, phosphoric acid, caffeine from coffee beans, vanilla extract, lemon oil and orange oil).
- Water footprint of other inputs used in production (bottle, cap, labelling materials, packing materials).

Appendix I specifies, per ingredient, the precise amount contained in a 0.5 litre bottle. It also presents which raw material each ingredient underlies and what the country of origin of the raw material is. For sugar, the study considers three alternative sources: sugar beet, sugar cane and maize (which is used to make high fructose maize syrup). Appendix III specifies the amounts of the other inputs used, again per 0.5 litre bottle. The figures for the amounts used are based on realistic values, similar to the ones on the commercial market. During bottle production, 25% of the material consists of recycled material. This ratio is taken into account in the calculations by using a fraction of 0.75 to calculate the amount of new material used. A similar approach has been used for pallets, which have a lifespan of 10 years (fraction 0.1 applied to the total used).

For the beverage ingredients, data on the water footprints of the raw materials, process water requirements, and product and value fractions, are presented in Appendix II. The water footprints of the various forms of sugar from different countries have been taken mainly from Gerbens-Leenes and Hoekstra (2009). For four selected countries (France, Italy, Spain and the Netherlands), the water footprint of sugar beet is specifically calculated as part of the scope of this study. The detailed assessment of the water footprint of sugar beet from the selected countries is presented in Appendix VII. For the other inputs used in the production of a 0.5 litre bottle of our beverage, water footprints of raw materials and process water requirements are presented in Appendix IV.

3.2.2 Overhead supply-chain water footprint

The overhead supply-chain water footprint originates from all goods and services used in the factory that are not directly used in or for the production process of one particular product produced in the factory. The factory produces other products than our 0.5 litre PET bottle of sugar-containing carbonated beverage as well, so the overhead water footprint needs to be allocated only partly to our product.

Goods that can be considered for the calculation of the overhead supply-chain water footprint are for example: construction materials and machineries used in the factory, office equipments and materials, cleaning equipments and materials, kitchen equipments and materials, working clothes used by employees, transportation, and energy for heating and power. This list can be extended to a longer one. In the scope of this study, it was decided to include some selected materials for the calculation of overhead water footprint in order to understand the influence of such elements on the total water footprint of the final product. The materials selected for assessment are the following:

- Construction materials (concrete and steel)
- Paper
- Energy in the factory (natural gas and electricity)
- Transportation (vehicles and fuel)

The amounts of materials used in our factory are specified in Appendix V. For paper and energy use in the factory and transportation fuels, annual amounts are given. For construction materials and vehicles, total amounts are given with a specification of the lifespan of the totals. The lifespan can be used to calculate annual figures from the totals. Appendix VI gives the water footprints of the raw materials behind the overhead goods and the process water requirements.

The value of the 0.5 litre PET bottles of our beverage is 10% of the total value of products produced in the factory. Therefore, 10% of the total overhead water footprint of the factory will be allocated to our product. The annual production is 30 million bottles per year, so the overhead water footprint per bottle is found by dividing the overhead water footprint insofar allocated to our product by 30 million.

4. Results

4.1 Water footprint of a 0.5 litre PET-bottle sugar-containing carbonated beverage

The total water footprint of the 0.5 litre PET-bottle sugar-containing carbonated beverage as defined in the previous chapter amounts to 169 to 309 litres. (Table 1). In the calculation of the total water footprint of the product, the amounts of all ingredients and other inputs are kept constant; only the type and origin of the sugar is changed in order to understand the effect of sugar type and production location on the total water footprint of the beverage. The effect of the type and origin of sugar used is shown in Figure 3.

Table 1. The total water footprint of a 0.5 litre PET-bottle sugar-containing carbonated beverage.

	Water footprint (litres)			
Item	**Green**	**Blue**	**Grey**	**Total**
Operational water footprint	0	0.5	0	0.5
Supply-chain water footprint*	134.5-252.4	7.4-124	9.2-19.7	168-308.9
Total*	**134.5-252.4**	**7.9-124.5**	**9.2-19.7**	**168.5-309.4**

*The range reflects the fact that we have considered different types and origin of the sugar input.

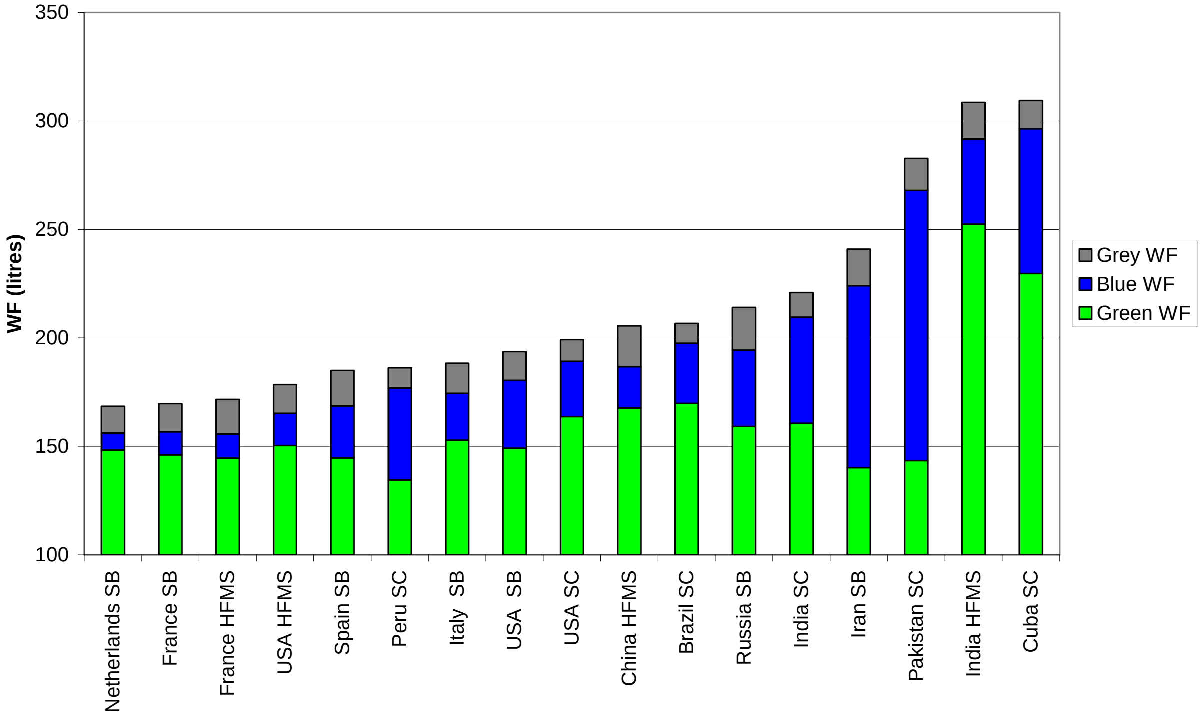

Figure 3. The total water footprint of 0.5 litre PET-bottle sugar-containing carbonated beverage according to the type and origin of the sugar (SB=Sugar Beet, SC=Sugar Cane, HFMS= High Fructose Maize Syrup)

The total water footprint of the beverage is the highest (309 litres) when the sugar originates from cane sugar from Cuba, and the lowest (169 litres) when the sugar comes from beet sugar from the Netherlands. If we compare the beet sugars, our product has the highest water footprint when beet sugar is from Iran (241 litres) followed by Russia (206 litres), USA (194 litres), Italy (189 litres), Spain (185 litres), France (170 litres) and the

Netherlands (169 litres). For sugar cane, our beverage has the highest water footprint when we take the cane from Cuba (309 litres), followed by Pakistan (283 litres), India (221 litres), Brazil (207 litres), USA (199 litres) and Peru (186 litres). When we use HFMS as a sweetener, the order is: India (309 litres), China (206 litres), USA (179 litres) and France (172 litres).

Almost the entire water footprint of the product is stemming from the supply-chain water footprint (99.7-99.8%). This shows the importance of a detailed supply chain assessment. Common practice in business water accounting, however, is to focus on operational water consumption. The results of this study imply that compared to the traditional water use indicator (water withdrawal for the own operations), the water footprint provides much more information. In this particular case, the operational water footprint cannot be lowered because it is precisely equal to the amount needed as an ingredient to the beverage. The traditional indicator of water withdrawal would show a larger number, because withdrawals include return flows, while the water footprint excludes those, because return flows can be reused, so they do not impact on the available water resources like consumptive water use does. In our case, there is no consumptive water use and wastewater is treated properly before returned to the system.

Figure 4 shows the colour composition of the total water footprint of the product for two different countries. The case for Pakistan is the one with the highest ratio for the blue water footprint. The case for the Netherlands is the case with the highest ratio for the green water footprint. Detailed estimates of the colours of the total water footprint for each sugar type and location are presented in Appendix II.

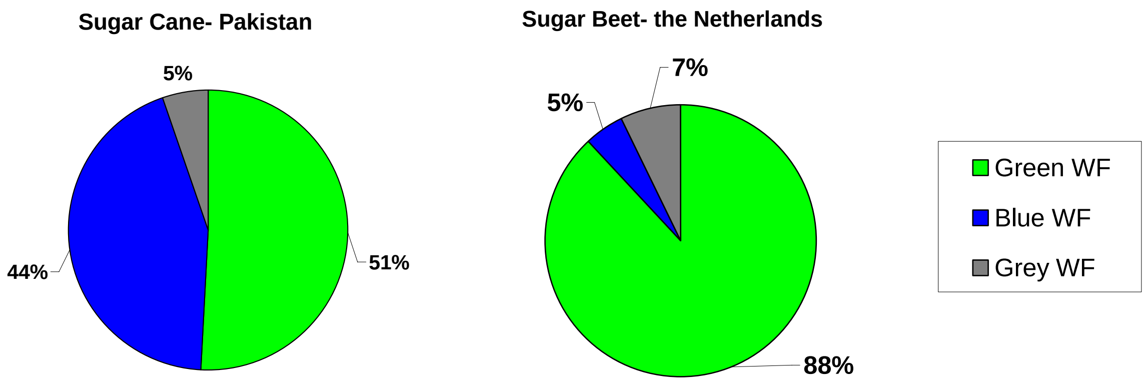

Figure 4. The water footprint colour composition of a 0.5 litre PET-bottle sugar-containing carbonated beverage for Pakistan (sugar cane) and the Netherlands (sugar beet).

4.1.1 Supply-chain water footprint

The supply-chain water footprint of a 0.5 litre PET-bottle sugar-containing carbonated beverage is calculated as a summation of the water footprints of all inputs (both ingredients and other inputs) and the water footprint of overhead activities. Table 2 presents the various components of the supply-chain water footprint of our beverage product.

Table 2. The supply-chain water footprint of a 0.5 litre PET-bottle sugar-containing carbonated beverage.

No	Item	Supply-chain water footprint (litres) Green	Blue	Grey	Total
Ingredients of the product					
1	Sugar	see Table 3	see Table 3	see Table 3	see Table 3
2	CO_2	0	0.3	0	0.33
3	Phosphoric acid or citric acid (e338)	0	0	0	0
4	Caffeine	52.8	0	0	52.8
5	Vanilla extract	79.8	0	0	79.8
6	Lemon oil	0.01	0	0	0.01
7	Orange oil	0.9	0	0	0.9
	Sub -total	*133.4-251.3*	*7.2-123.8*	*2.4-12.9*	*159.8-300.8*
Other components related to the product					
1	Bottle – PET	0	0.2	4.4	4.5825
2	Closure – HDPE	0	0.03	0.68	0.7
3	Label – PP	0	0.003	0.068	0.07
4	Label glue (not included)	0	0	0	0
5	Packing material	0	0	0	0
5.1	Tray glue (not included)	0	0	0	0
5.2	Tray cartoon - paperboard	1	0	0.5	1.5
5.3	Tray shrink film - PE	0	0.02	0.36	0.38
5.4	Pallet stretch wrap - PE	0	0.003	0.054	0.057
5.5	Pallet label (2x) - coated paper	0.001	0	0.0004	0.0015
5.6	Pallet - painted wood	0.033	0	0.007	0.04
	Sub -total	*1.1*	*0.2*	*6.1*	*7.4*
Overhead					
1	Construction				
1.1	Concrete	0	0	0.005	0.005
1.2	Steel	0	0.004	0.05	0.054
2	Paper	0.0012	0	0.0004	0.0016
3	Energy	0	0	0	0
3.1	Natural Gas	0	0	0.024	0.024
3.2	Electricity	0	0	0.13	0.13
4	Transportation	0	0	0	0
4.1	Vehicles	0	0.001	0.009	0.01
4.2	Fuel	0	0	0.5	0.5
	Sub -total	*0.001*	*0.004*	*0.8*	*0.8*
Total supply-chain water footprint		**134.5-252.4**	**7.4-124**	**9.2-19.7**	**168-308.9**

As an illustration of how the results have been achieved, we give a full elaboration below for two cases: the water footprint of vanilla extract derived from vanilla grown in Madagascar and the water footprint of refined sugar derived from sugar beet grown in the Netherlands.

The amount of vanilla used in the product is 0.01 g. The water footprint of vanilla from Madagascar is 199 thousand litres/kg (Chapagain and Hoekstra, 2004). The product fraction is 0.025, which means that one kg of harvested vanilla gives 0.025 kg of vanilla extract as used in our product. The value fraction is 1, which means that when vanilla is processed into our vanilla extract there is no valuable by-product. The water footprint of vanilla is calculated as: (199,000 × 1 × 0.00001) / 0.025 = 80 litres.

The amount of sugar used in the product is 50 g. The green, blue and grey water footprints of sugar beet cultivated in Netherlands are 45, 23 and 18 m^3/ton respectively (Appendix II). About 16% of the weight of sugar beet becomes raw sugar and about 92% of the raw sugar weight becomes refined sugar. The production fraction for refined sugar from sugar beet is thus 0.16 × 0.92 = 0.147. In the process from sugar beet to raw sugar there are also by-products with some value. The value of the raw sugar is 89% of the aggregated value of all sugar beet products. Therefore, 89% of the water footprint of the sugar beet is attributed to raw sugar and finally to refined sugar. The water footprint of the refined sugar as used in the beverage product is calculated by multiplying the water footprint of sugar beet by the value fraction and amount used and dividing by the product fraction. The green water footprint of the refined sugar is thus: (45 × 0.89 × 0.05) / 0.147 = 13.6 litres. The blue water footprint: (23 × 0.89 × 0.05) / 0.147 = 7.0 litres. The grey water footprint: (18 × 0.89 × 0.05) / 0.147 = 5.4 litres.

Sugar is one of the main water consuming ingredients in a 0.5 litre PET-bottle sugar-containing carbonated beverage. One of the aims of this study is to understand the effect of sugar type and origin on the total water footprint of the beverage. For this purpose, three different commonly used sugar types are selected: sugar beet, sugar cane and HFMS. For each type, some production countries are selected for the calculation, which have high, low and average water footprints. Table 3 presents the water footprint of the sugar input in our beverage product as a function of sugar type and origin.

Table 3. The water footprint of the sugar input for a 0.5 litre PET-bottle sugar-containing carbonated beverage.

No	**Item**	**Water footprint (litres)**				**Remarks**
		Green	**Blue**	**Grey**	**Total**	
1.1	**Beet sugar**					
1.1.1	Iran[1]	5.7	82.8	10.0	98.5	Highest WF, highest blue WF
1.1.2	Russia[1]	24.6	34.1	4.5	63.3	High WF, big producer
1.1.3	USA[1]	14.7	30.1	6.4	51.2	Second biggest producer in the world
1.1.4	Italy[2]	18.6	20.8	7.1	46.5	Close to global average WF
1.1.5	Spain[2]	10.0	23.1	9.7	42.8	Close to global average WF
1.1.6	France[2]	11.7	9.5	6.2	27.4	Biggest producer in the world
1.1.7	Netherlands[2]	13.6	7.0	5.4	26.0	Very low WF
1.2	**Cane sugar[1]**					
1.2.1	Cuba	95.2	65.7	6.2	167.0	Highest WF
1.2.2	Pakistan	9.0	123.5	8.0	140.4	High WF, highest blue WF
1.2.3	Brazil	35.3	26.6	2.4	64.3	Biggest producer in the world
1.2.4	India	26.2	47.9	4.6	78.6	Second biggest producer in the world
1.2.5	Peru	0.0	41.3	2.6	43.9	Lowest WF
1.2.6	USA	29.3	24.4	3.2	56.8	Close to world average
1.3	**HFMS 55[1]**					
1.3.1	India	117.9	38.2	10.2	166.2	Highest WF
1.3.2	USA	15.9	13.8	6.5	36.1	Biggest producer in the world and highest rate of maize usage for sugar input
1.3.3	France	10.1	10.0	9.2	29.3	Low WF
1.3.4	China	33.3	17.9	12.0	63.2	Close to global average WF

[1] *Gerbens-Leenes and Hoekstra (2009).*

[2] *Own calculations.*

When we choose to use sugar beet as sugar source of our hypothetical beverage, the water footprint of the sugar input can vary from 26 litres per 0.5 litre bottle (when the sugar beets are grown in the Netherlands) to 98.5 litres (Iran). If our source is sugar cane, the water footprint of the sugar input can vary from 43.9 litres per bottle (Peru) to 167 litres (Cuba). If we would use HFMS as a sweetener, not so usual in the world but common in the US, the water footprint of the sugar input will range from 29.3 litres per bottle (when the maize comes from France) to 166 litres (India). It is important to identify and analyse the colours of the water footprint of the product in order to assess the impacts of the water footprints. The highest *blue* water footprint related to the sugar input alone is 124 litres with sugar cane from Pakistan and the lowest is 7 litres with sugar beet from the Netherlands. The *grey* water footprint of the sugar input is the lowest when the sugar intake is cane sugar from Brazil (2.4 litres), and highest with HFMS from China (12 litres). This analysis shows that sugar type and production location affect the total water footprint of the product and the ratios green/blue/grey significantly. It shows that including the spatial dimension in water footprint assessment is important.

In our hypothetical beverage, the amounts of vanilla extract (0.01 g) and caffeine from coffee beans (0.05 g) inputs are very small in the total amount of the beverage. Although their physical content in the beverage is small (0.09% for caffeine and 0.02% for vanilla), their contribution to the total water footprint of the product is very high (maximum 33% for caffeine and 50% for vanilla). The study reveals that, without prior knowledge about the relevance of different inputs, a detailed and comprehensive supply-chain analysis is essential for the calculation of the water footprint of a product. Even small ingredients can significantly affect the total water footprint of a product.

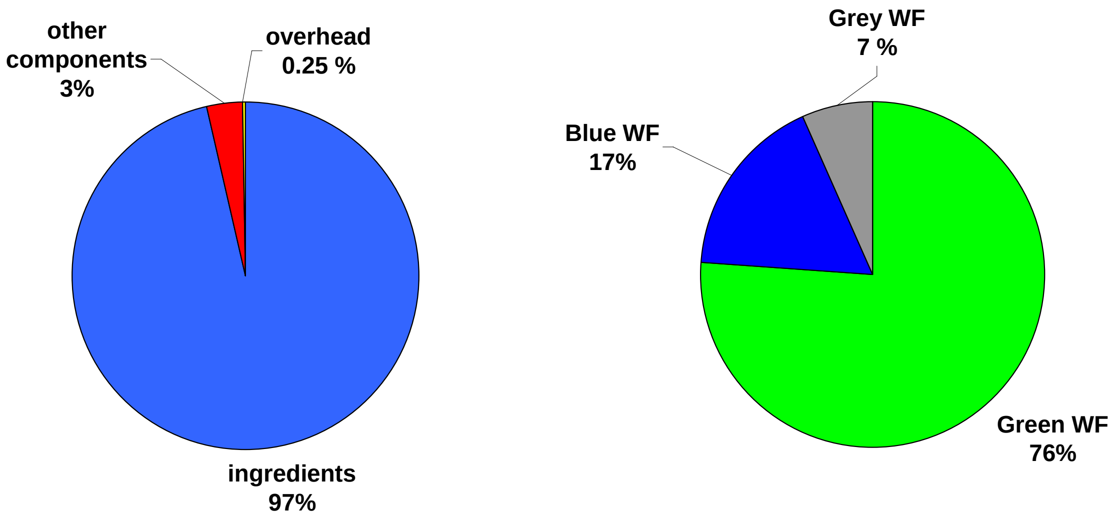

Figure 5. Composition of the supply-chain water footprint of a 0.5 litre PET-bottle sugar-based carbonated beverage (average values).

4.1.2 Operational water footprint

The operational water footprint of a 0.5 litre PET-bottle sugar-containing carbonated beverage has a number of components as shown in Table 4. Both green and grey water footprint are zero. The blue water footprint is 0.5 litre of water for one bottle. The total operational water footprint is thus no more than the water used as ingredient of the beverage. The 'water footprint' of the operations is lower than the 'water withdrawal' of the factory, because all water withdrawn by our hypothetical factory is returned (except for the water used as ingredient for the beverage) and purified before disposal.

Table 4. The operational water footprint of a 0.5 litre PET-bottle sugar-containing carbonated beverage.

No	Item	Operational water footprint (litres)			
		Green	**Blue**	**Grey**	**Total**
Inputs					
1	Direct water used for a 0.5 litre PET (as ingredient)	0	0.5	0	0.5
2	Net water used in production steps	0	0	0	0
2.1	Bottle making	0	0	0	0
2.2	Bottle cleaning (by air)	0	0	0	0
2.3	Ingredients mixing	0	0	0	0
2.4	Packing	0	0	0	0
	Sub -total	0	0.5	0	0.5
Overhead					
1	Domestic Water Consumption	0	0	0	0
	Sub -total	0	0	0	0
Total operational water footprint		**0**	**0.5**	**0**	**0.5**

4.2 Impact assessment of a 0.5 litre PET-bottle sugar-containing carbonated beverage

Stemming from its definition, the water footprint concept is a geographically explicit indicator, not only showing volumes of water use and pollution, but also showing the various locations where the water is used (Hoekstra and Chapagain, 2008). This means, water footprint analysis of a business/product shows impact of business activities to nature and society by answering two fundamental questions: where (location) and when (time). It is also useful to show the blue, green and grey components of the water footprint of a business/product, because the impact of the water footprint will depend on whether it concerns evaporation of abstracted ground or surface water, evaporation of rainwater used for production or pollution of freshwater.

Assessment of the impacts of a water footprint starts with quantifying, localising and describing the colour of the water footprint. Next step is identifying the vulnerability of the local water systems where the footprint is located, the actual competition over the water in these local systems and the negative externalities associated with the use of the water. This kind of an assessment may lead to a corporate water strategy to reduce and offsett the impacts of the water footprint (Hoekstra, 2008). Goals of a business with respect to reducing and offsetting the impacts of its water footprint can be prompted by the goal to reduce the business risks related to its freshwater appropriation. Alternatively, they can result from governmental regulations with respect to water use and pollution.

One of the main ingredients of our hypothetical beverage is sugar. It is important to understand and evaluate the environmental impacts of all crops if we are to achieve sustainable production systems. Understanding the impact of sugar beet, sugar cane and HFMS are particularly important as there are different countries where they can be grown, and also because there is a growing interest in their potential as a source for biofuel (Gerbens-Leenes and Hoekstra, 2009).

For the impact assessment of sugar usage, we compare the water footprint of sugar beet, cane and HFMS as quantified in the previous section with the water scarcity in the different regions where the water footprint is located following the method developed by Van Oel *et al*. (2008). For this purpose, a water scarcity indicator by Smakhtin *et al*. (2004a; 2004b) was used. This indicator deals with the withdrawal-to availability ratio per river basin taking into account the environmental water requirements, which are subtracted from runoff (Figure 6).

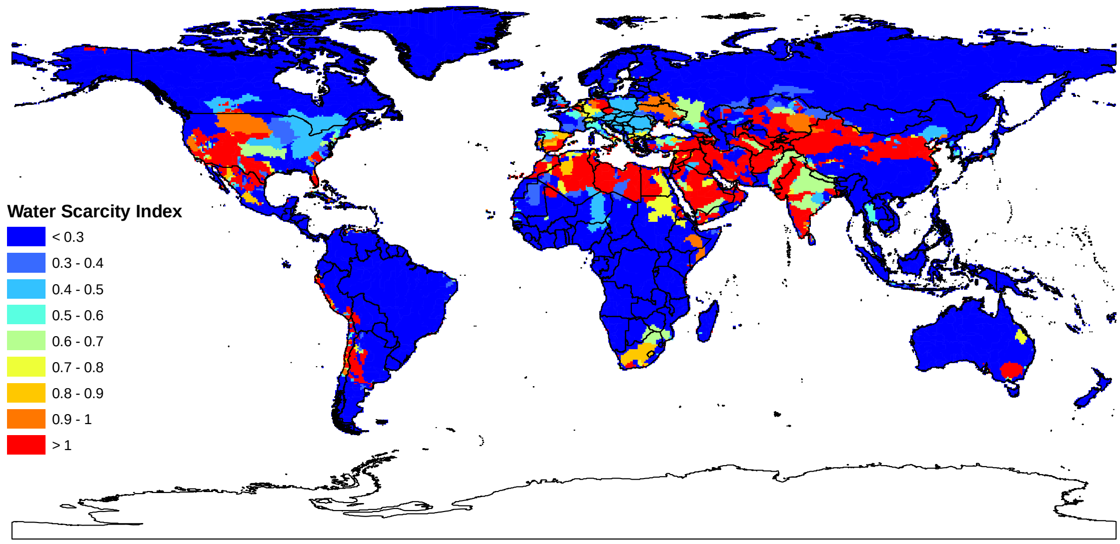

Figure 6. Water scarcity level by basin taking into account environmental water requirements. Source: Smakhtin et al. (2004a,b).

Hotspots are regions where the impact of the water footprint of sugar cane, sugar beet and HFMS is relatively large. The impact is obviously larger when the footprint is relatively large in a region where water stress is relatively large as well. Hotspots have been identified overlaying the map showing the geographical spreading of the water footprint of sugar production and the global water scarcity map.

Sugar beet

Our hypothetical drink has several impacts on water systems and environment when the sugar intake is beet. It is important to understand the impacts our hypothetical beverage on water scarce regions.

With a population of more than 65 million people, Iran is actually one of the most water-scarce countries of the world. It is estimated that the average annual supply of renewable freshwater per person will fall from 1,750 (2005) to 1,300 m^3 (2020). According to the ‘Falkenmark thresholds’, a country will experience periodic water stress when freshwater availability is below 1,700 m^3 per person per year (Falkenmark and Rockström, 2004). More than 94 percent of the total annual water consumption in Iran is used for agriculture, so agriculture plays a significant role in water stress in the country. In addition, the productivity of water (yield per unit of water) is very low (Water Conservation, Reuse, and Recycling, 2005). The water footprint of Iranian sugar beet is one of the highest in the world (Gerbens-Leenes and Hoekstra, 2009). The Iranian sugar beet usage in our product leads to 99 litres of water consumption per bottle, 84% of which are from blue water sources. Among all countries, sugar beet cultivation in Iran requires the most irrigation (highest blue water footprint). This leads to serious water problems in sugar beet cultivation regions, especially where the production rate is high. One-third of the country's sugar factories are in the three provinces of Razavi Khorasan, Northern Khorasan and Southern Khorasan (Iran Daily, 2004). Iran, with mostly arid climatic conditions, is currently experiencing extreme water shortages. Especially in these specific parts of the country, due to recent droughts, this problem has become more visible (Larijani, 2005).

Another country with a high water footprint of sugar intake is Russia with a sugar-related water footprint of 63 litres per bottle. Similar to Iran, the blue water footprint of sugar beet in Russia is high, 53% of the total water footprint. The most important problem due to sugar beet cultivation in Russia is in the area north of the Black Sea. Pollution in the rivers Dnieper and Don, which are flowing to the Black Sea, is causing serious environmental damage to the Black Sea ecosystem. Russian Federation’s Committee on Fishing reported several cases in 1992 that water bodies were completely contaminated by agricultural runoff. Besides pollution by excessive use of fertilizers, irrigation has resulted in water scarcity in some areas as well (Gerbens-Leenes and Hoekstra, 2009).

France is the biggest sugar beet producer in the world. Thus, impacts of sugar beet cultivation in France to water resources are important. In France, irrigation covers 11 to 12% of the total beet area (IIRB, 2004). The French sugar beet growing regions where irrigation is used are mostly located south of the river Seine (ibid.). A few beet fields may be irrigated in the North where farms are equipped for irrigating other crops (potatoes and vegetables), so this irrigation is opportunistic, depending on needs and the accessibility of equipment. Even if the water demand in the North of France is relatively high in relation to the water availability, sugar beet irrigation does not seem to represent a problem in quantitative terms. According to the Seine-Normandy Water Agency (2003), in the Seine-Normandy basin, irrigation has little quantitative impact on the resource, except for occasional cases of over-pumping that have been resolved by regulating demand.

The situation in Southern European countries, however, is completely different. In these countries, irrigation is essential for agricultural production. In Spain, 80% of the sugar beet, growing area is irrigated (IIRB, 2004). In this country, the `National Irrigation Plan´ has improved the efficiency of water management, resulting in reduced water consumption for the same agricultural output. Irrigation equipment and methods applied to beet growing and the timing of applications have been optimised. For instance, autumn sowing of sugar beet represents a strategy for using the available water for plant growth more efficiently in months with lower temperatures, and partially avoids summer drought. As seen in the Appendix VII, this is the case of the Autonomous Communities in the South of Spain (Andalucía and Extremadura) (Spanish Ministry of Agriculture, Fisheries and Food, 2001). Andalucía, however, is a clear hotspot since it is a water scarce region with a high water footprint in relation to sugar beet production. Sugar beet irrigation in this region has contributed to lower water levels in the Guadalquivir River, limiting the water reaching important wetlands during summer (WWF, 2004). These wetlands include Doñana, where many bird species rely on a healthy habitat (griffon vulture, booted eagle, red and black kites, short-toed eagle, Baillon's crake, purple gallinule, great spotted cuckoo, scops owl, red necked nightjar, bee eater, hoopoe, calandra, short-toed and thekla larks, golden oriole, azure winged magpie, Cetti's and Savi's warblers, tawny pipit, great grey shrike, woodchat shrike and serin) (ibid.). Concerning Italy, the sugar beet production mainly occurs in the northern part of the country where there is no water scarcity.

The water quality issue is a major concern since the overuse of fertilisers on beet crops is typical of farming in general (WWF, 2004). Environmental impacts generally arise because the nutrients in the fertilisers are not entirely taken up by the crop but move into the environment. The runoff of nitrate and phosphate into lakes and streams can contribute to accelerated eutrophication and the proliferation of toxic microalgae.

In the EU27, the average fertilizer N-supply for sugar beet is 122 kg/ha but there is scope to reduce this by using fertiliser placement techniques, which may allow for reductions of 10-20% (IIRB, 2004). Among the studied countries, Spain and France exceed the average European level. In the Seine-Normandy basin, irrigation has little quantitative impact on the resource, but does, however, have an indirect impact on quality because it favours intensive farming techniques and spring crops, which leave the soil bare for long periods of the year and increase the chemical load in the rivers by leaching and draining (The Seine-Normandy Water Agency, 2003). This has a harmful effect on both the environment and other water uses. Improving water quality is still the major concern of the basin, where non-point source pollution from farming and urban areas is still a major problem as nitrate, pesticide and heavy metal concentrations continue to increase (ibid.).

The water quantity consumed in relation to the sugar beet production in the Netherlands does not seem to be a problem. The low evapotranspiration rate of Dutch sugar beet only requires a small quantity of external water supply. According to the International Institute for Sugar Beet Research (IIRB, 2004), in this country, the average irrigated surface varies from 1 to 19%. Furthermore, in years with a shortage of rainfall, other crops like potatoes and vegetables will be irrigated first and sugar beet will not have a high priority (ibid.).

Application of fertilizers, organic manure or slurry for the sugar beet production could be regarded as a contamination problem if the applied rates of nutrients are higher than the need and uptake of the crop. The Dutch average fertilizer application rate is one of the lowest among the European sugar beet producing countries, with about 108 kg/ha (FAO, 2008b) (Appendix VII). Concerning the grey water footprint, it is one of the lowest among the studied European countries, with about 18 m^3/ton. According to the IIRB (2004), the Netherlands benefits from special legislation with regard to soil protection that governs fertilizer application, which is based on the principle of negligible risk for the ecosystem. This system reduces the risk of excessive application (ibid.). Nevertheless, even if the average fertilizer application rate and grey water footprint related to Dutch sugar beet production are one of the lowest among the European sugar beet producing countries, the quantity applied could contribute and perhaps aggravate the already existing nitrogen problem. According to the Netherlands Environmental Assessment Agency (2008), eutrophication is a major cause of the decline of nature in the Netherlands. Eutrophication concerns the enrichment of ecosystems with nitrogen and phosphorus, primarily from the application of manure and fertiliser on land. Nitrate leaching from farmland can not only lead to eutrophication of surface water, resulting in some cases in fish kills and degradation of the water quality of recreational surface waters such as swimming areas, but also to contamination of drinking water supplies in ground water.

Sugar cane

Sugarcane is the most important plant on Cuba and it was the most important foreign exchange earner on the tropical island for decades. The water footprint of sugar intake for our hypothetical product is the highest when sugar is sugar cane from Cuba, with 167 litres per bottle. Sugar cane production in Cuba has also the highest water footprint in the world compared to all sugar types and production locations. Related to sugar cane production, Cuba has been facing several environmental problems for the last decades. Cuba has high-quality resources of karst water, but the quality of this water is highly susceptible to pollution. Pollution resulting from sugar cane factories is one of the main reasons that the quality of karst aquifers has deteriorated (León and Parise, 2008). In addition, the untreated wastewater discharge from sugar factories in Cuba has led to oxygen deficiency in rivers and the dominance of aquatic macrophytes, which results in thick mats of weeds. This situation partially blocks the water delivery capacity of canals, which has negative effects on fishing and tourism (WWF, 2004). Due to sugar cane cultivation, deforestation in Cuba has become a major environmental problem (Monzote, 2008). Cuba’s forest area has also been drastically decreased as a result of demand for lumber; the sugar cane industry alone annually consumes 1 million cubic meters of firewood (Cepero, 2000).

Another country with a high water footprint for sugar cane is Pakistan. If we choose Pakistani sugar cane for our hypothetical product, the water footprint of sugar intake will be 140 litres per bottle. The sugar cane in Pakistan heavily depends on irrigation; the blue water footprint constitutes 88% of the total water footprint. Water abstractions for irrigation cause water shortage in the production regions and serious environmental problems. The Indus River is the major water resource of Pakistan. The freshwater reaching to the Indus Delta has significantly decreased (90%) as a result of over-usage of water sources in the Indus basin. Sugar cane is one of the main water consuming agricultural products in the basin. The decrease in freshwater flow to the Indus Delta has negative impacts on the biodiversity of the Delta (decrease of mangrove forestlands, and danger of extinction of the blind river dolphin). Additionally, excessive water use in sugar cane cultivation areas also leads to salinity problems in Pakistan (WWF, 2004). Moreover, untreated wastewater discharge from sugar mills causes depletion of available oxygen in water sources which results in endangering fish and other aquatic life (Akbar and Khwaja, 2006).

Being the largest sugar cane producer in the world, Brazil has faced several negative impacts of sugar cane production. However, most of the sugar cane produced is used as raw material for ethanol production. Extensive sugar cane production and demand in Brazil has led to deforestation of rain forests. Moreover, sugarcane fields in the state of San Paulo have reported to cause air pollution due to pre-harvest burning (WWF, 2004). Water pollution due to sugar cane industry and sugar cane agricultural practice (fertilizers and pesticides) is another major environmental problem in Brazil (Gunkel *et al*., 2006).

Like other countries, India is also facing environmental problems due to sugar cane cultivation. In the Indian state of Maharashtra, sugar cane irrigation contributes 60% of the total irrigation supply, which causes substantial groundwater withdrawals (WWF, 2004). India's largest river, the Ganges, experiences severe water stress. Sugar cane is one of the major crops cultivated in the area and increases water scarcity (Gerbens-Leenes and Hoekstra, 2009). Another problem resulted from sugar cane cultivation and sugar processing activity in India is pollution of surface and groundwater resources (Solomon, 2005).

Other ingredients and inputs

The results presented earlier in this chapter show that vanilla, which is part of the natural flavour of our beverage, has a large contribution to the overall water footprint (from 27% to 50%). The source of the vanilla is Madagascar, which is the main vanilla producing country in the world. Cultivation of vanilla is one of the most labour-intensive agricultural crops and it takes up to three years before the crop can be harvested. Harvested flowers need a process called curing in order to take its aroma. This process needs heating of the vanilla beans in hot water (65 degrees Celsius) for three minutes, which causes most environmental problems in the production countries. Thermal pollution occurs as a result of hot water discharged into freshwater systems, causing sudden increases in the temperature of the ambient water systems above ecologically acceptable limits. In addition to water contamination by means of temperature changes, the necessity of obtaining wood, the main energy source of heating, causes deforestation of rainforests (TED, 2003).

Another small ingredient of our hypothetical beverage is caffeine. Although the amount of caffeine used in the product is small, the water footprint is very high (53 litres per bottle). The caffeine is taken from coffee beans produced in Colombia, which is one of the biggest coffee producers in the world. Two major problems are seen in Colombia due to coffee cultivation: loss of bird species and soil erosion. Additionally, pollution of surface and ground water resources resulting from usage of fertilizers is a major environmental problem due to coffee cultivation (TED, 2001).

The oil based materials used for the bottle of our beverage (PET-bottle, cap, stretch films and labels) have particularly a grey water footprint. In PE production, large amounts of water are used for cooling. Cooling water is considered as grey water as it increases the temperature of the receiving freshwater bodies more than what is acceptable from an ecological point of view. Water quality criteria for aquatic ecosystems indicate that water temperature may not increase by more than a few degrees Celsius compared to natural conditions (CEC, 1988). Additional freshwater sources are required to dilute hot water stemming from cooling water (to decrease the temperature of discharged cooling water in order to meet standards with respect to maximum increase of water temperature).

5. Conclusion

The total water footprint of our hypothetical 0.5 litre PET-bottle sugar-containing carbonated beverage is calculated as minimally 169 litres (with sugar beet from the Netherlands) and maximally 309 litres (with sugar cane form Cuba). The operational water footprint of the product is 0.5 litres, which forms 0.2-0.3% of the total water footprint. The supply-chain water footprint constitutes 99.7-99.8% of the total water footprint of the product.

The operational water footprint of the 0.5 litre PET-bottle sugar-containing carbonated beverage consists of two components: the operational water footprint of the factory insofar it can immediately related to the production of the product and the 'overhead water footprint'. The first is equal to the water incorporated into the product, which is 0.5 litre. There is no other operational water footprint than this, because there is no other water consumption or pollution in the factory related to the production of the product. Cleaning of the bottles before filling is done with air, not with water as in the case of glass bottles. There is water use in the factory for general purposes such as flushing toilets, cleaning working clothes, and washing and cooking in the kitchen, but all water used is collected and treated in a public wastewater treatment plant before it is returned into the environment. Thus, the net abstraction from the local water system for those activities is zero.

The supply-chain water footprint of the product also consists of two components: related to product inputs (ingredients and other inputs) and overhead. Most of the supply-chain water footprint of the product is coming from its ingredients (95-97%). A smaller fraction of the supply-chain water footprint comes from the other inputs (2-4%), mainly from the PET-bottle. The overhead water footprint constitutes a minor fraction of the supply-chain water footprint (0.2-0.3%).

The main impacts of the hypothetical product are stemming from the grey and blue water footprints of the product. Ingredients like sugar, vanilla, caffeine (coffee) cause contamination of natural freshwater sources (grey water footprint) because of the use of fertilizers and pesticides. The biggest impact of the water footprint of the beverage is related to the sugar ingredient. Many sugar producing countries are water-rich countries where the water footprint does not relate to water stress. There are, though, several localised hotspots, such as the sugar beet production in the Andalucia region in the South of Spain, sugar cane production in Pakistan (Indus River) and India (Ganges River), and sugar beet from Iran. With regard to water quality, pollution by nitrates is an issue in several regions, such as the case of Northern France, Russia (Black Sea), India, Pakistan, Cuba, Brazil, Iran and China. A rational N fertilization is important to reduce the environmental impact of fertilization and to increase profitability in crop production. Better management practices to reduce the environmental impacts in the sugar industry do not necessarily imply reduced productivity and profits; indeed, measures to address environmental impacts can provide economic benefits for farmers or mills through cost savings from more efficient resource use. In addition, mostly sugar cane production relates to deforestation like in Cuba and Brazil. Other negative effects of sugar production are impacts on biodiversity (decrease of mangrove forestlands, and danger of extinction of the blind river dolphin in the Indus Delta).

The results of this study show the importance of a detailed supply-chain assessment in water footprint accounting. Common practice in business water accounting is mostly restricted to the analysis of operational water use. This study shows that compared to the supply-chain water footprint, the operational side is almost negligible. The results of this study imply that compared to other water accounting tools, the concept of the water footprint provides a more comprehensive tool for water accounting.

The study shows that the water footprint of a beverage product is very sensitive to the production locations of the agricultural inputs. Even though the amount of sugar is kept constant, the water footprint of our product significantly changes according to the type of sugar input and production location of the sugar. Additionally, the type of water footprint (green, blue and grey) shows completely different values from location to location. These results reveal the importance of the spatial dimension of water footprint accounting.

The results of the study show that even small ingredients can significantly affect the total water footprint of a product. On the other hand, the study also shows that many components studied hardly contribute to the overall water footprint. If the findings from this study are supported by a few more pilot studies, it will be possible to develop guidelines that specify which components can be excluded from this sort of studies.

The general findings of this study with respect to the ratio of operational to supply-chain water footprint and the relative importance of ingredients, other inputs and overhead can be extended to other beverages similar to our hypothetical beverage. The major part of the water footprint of most beverages will be stemming from the supply chain.

This is the first study quantifying the overhead water footprint of a product. Strictly spoken, this component is part of the overall water footprint of a product, but it was unclear how relevant it was. This study reveals that the overhead component is not important for this kind of studies and is negligible in practice.

By definition, the water footprint is a geographically explicit indicator, not only showing volumes of water use and pollution, but also showing the various locations where the water is used and the periods of the year in which the water is used (Hoekstra and Chapagain, 2008). The question in practical applications is, however, whether it is feasible to trace the precise locations and timing of water use in the supply chain of a product. In the current water footprint study for a 0.5 litre PET-bottle sugar-containing carbonated beverage we show that it is feasible to trace water use in the supply-chain relatively well, based on a desk study only. Even better and more precise results could be obtained in a more elaborate study including visits to the suppliers and finally to the farmers and mining industries producing the primary ingredients. Knowing the blue, green and grey components of the water footprint of a product and the precise locations and timing of water use is essential for water footprint impact assessment, which in turn is key for formulating mitigating policies. Accurate material flow accounting along the full supply-chain of a product would simplify water footprint accounting.

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Appendix I: Ingredients of the sugar-containing carbonated beverage (per 0.5 litre bottle)

No	Item	Amount[1] (grams)	Raw material	Origin of raw material
1	Sugar	50[2]	Sugar beet/-cane/HFMS	See the following table
2	CO_2	4	Ammonia by product	The Netherlands
3	Syrup	0.271	Several	Several locations all around the world
3.1	Caffeine	0.05	Coffee beans	Colombia
3.2	Phosphoric acid	0.2	Phosphate rock - by chemical process	USA
3.3	Vanilla extract	0.01	Vanilla beans	Madagascar
3.4	Lemon oil	0.007	Lemon	World market
3.5	Orange oil	0.004	Orange	World market

[1] Amounts are taken close to similar products on the commercial market.

[2] Breedveld *et al.* (1998).

No	Sugar type	Origin of raw material
1.1	**Sugar beet**	
1.1.1	Sugar beet	Iran
1.1.2	Sugar beet	Russia
1.1.3	Sugar beet	USA
1.1.4	Sugar beet	Italy
1.1.5	Sugar beet	Spain
1.1.6	Sugar beet	France
1.1.7	Sugar beet	The Netherlands
1.2	**Sugar cane**	
1.2.1	Sugar cane	Cuba
1.2.2	Sugar cane	Pakistan
1.2.3	Sugar cane	Brazil
1.2.4	Sugar cane	India
1.2.5	Sugar cane	Peru
1.2.6	Sugar cane	USA
1.3	**HFMS**	
1.3.1	HFMS	India
1.3.2	HFMS	USA
1.3.3	HFMS	France
1.3.4	HFMS	China

Appendix II: Water footprint of the ingredients of the sugar-containing carbonated beverage

No	Item	Raw material	Selected location for the calculation of the water footprint	Water footprint of raw material (m^3/ton)			Process water requirement (m^3/ton)			Fractions for products used	
				Green	Blue	Grey	Green	Blue	Grey	Product fraction	Value fraction
1.1.1	Sugar 1[1]	Sugar beet	Iran	21	298	36	0	0	0	0.16	0.89
1.1.2	Sugar 2[1]	Sugar beet	Russia	89	123	16	0	0	0	0.16	0.89
1.1.3	Sugar 3[1]	Sugar beet	USA	53	108	23	0	0	0	0.16	0.89
1.1.4	Sugar 4[2]	Sugar beet	Italy	50	56	19	0	0	0	0.12	0.89
1.1.5	Sugar 5[2]	Sugar beet	Spain	29	67	28	0	0	0	0.13	0.89
1.1.6	Sugar 6[2]	Sugar beet	France	36	29	19	0	0	0	0.14	0.90
1.1.7	Sugar 7[2]	Sugar beet	Netherlands	45	23	18	0	0	0	0.15	0.89
1.2.1	Sugar 8[1]	Sugar cane	Cuba	310	214	20	0	0	0	0.14	0.86
1.2.2	Sugar 9[1]	Sugar cane	Pakistan	29	402	26	0	0	0	0.14	0.86
1.2.3	Sugar 10[1]	Sugar cane	Brazil	115	87	8	0	0	0	0.14	0.86
1.2.4	Sugar 11[1]	Sugar cane	India	85	156	15	0	0	0	0.14	0.86
1.2.5	Sugar 12[1]	Sugar cane	Peru	0	134	8	0	0	0	0.14	0.86
1.2.6	Sugar 13[1]	Sugar cane	USA	95	79	10	0	0	0	0.14	0.86
1.3.1	Sugar 14[1]	HFMS	India	1163	376	100	0	0	0	0.36	0.73
1.3.2	Sugar 15[1]	HFMS	USA	156	136	64	0	0	0	0.36	0.73
1.3.3	Sugar 16[1]	HFMS	France	100	99	90	0	0	0	0.36	0.73
1.3.4	Sugar 17[1]	HFMS	China	328	177	118	0	0	0	0.36	0.73
2	CO_2	Ammonia by product	USA	0	0	0	0	83.5[3]	0	1[3]	1[3]
3	Phosphoric acid	Phosphate rock	USA	0	0	0	0	0	0	1	1
4	Caffeine	Coffee beans	Colombia	14470[4]	0	0	0	0	0	0.0137[5]	1
5	Vanilla extract	Vanilla	Madagascar	199383[4]	0	0	0	0	0	0.025[6]	1
6	Lemon oil	Lemon	World average	559[4]	0	0	0	0	0	0.4[7]	1
7	Orange oil	Orange	World average	457[4]	0	0	0	0	0	0.0021	1

[1] Gerbens-Leenes and Hoekstra (2009)

[2] Own calculations

[3] Van der Leeden *et al*. (1990).

[4] Chapagain and Hoekstra (2004).

[5] http://www.coffeedetective.com/caffeine-in-coffee.html

[6] Dignum *et al.* (2001)

[7] http://practicalaction.org/practicalanswers/product_info.php?products_id=106

Appendix III: List of other items used per 0.5 litre bottle of sugar-containing carbonated beverage

No	Item	Amount (grams)	Raw material	Origin of raw material
1	Bottle - PET	19.5[1]	oil	World market
2	Closure - HDPE	3	oil	World market
3	Label - PP	0.3	oil	World market
4	Label glue	0.18	Glue	World market
5	Packing material	4.7		
5.1	Tray glue	0.015	glue	World market
5.2	Tray cartoon - paperboard	2.8	wood	World market
5.3	Tray shrink film - PE	1.6	oil	World market
5.4	Pallet stretch wrap - PE	0.24	oil	World market
5.5	Pallet label (2x) - coated paper	0.003	wood	World market
5.6	Pallet - painted wood	0.09[2]	wood	World market

[1] It is considered that 25 % of the material used is recycled material.
[2] It is considered that pallets have 10 years of lifespan.

Appendix IV: Water footprint of raw materials and process water requirements for other inputs of a 0.5 litre bottle of sugar-containing carbonated beverage

No	Item	Raw material	Selected location for the calculation of the water footprint	Water footprint of raw material (m^3/ton)[1]			Process water requirement (m^3/ton)[1]		
				Green	Blue	Grey	Green	Blue	Grey
1	Bottle -PET	Oil	Sweden (raw) - Germany (process)	0	10	0	0	0	225
2	Closure - HDPE	Oil	Sweden (raw) - Germany (process)	0	10	0	0	0	225
3	Label - PP	Oil	Sweden (raw) - Germany (process)	0	10	0	0	0	225
4	Label glue	Glue	Germany	0	0	0	0	0	0
5	Packing material								
5.1	Tray glue	Glue	Netherlands	0	0	0	0	0	
5.2	Tray cartoon - paperboard	Wood	Belgium	369.4[2]	0	0	0	0	180
5.3	Tray shrink film - PE	Oil	Sweden (raw) - Germany (process)	0	10	0	0	0	225
5.4	Pallet stretch wrap – PE	Oil	Sweden (raw) - Germany (process)	0	10	0	0	0	225
5.5	Pallet label (2x) - coated paper	Wood	Finland (process)	369.4[2]		0	0	0	125
5.6	Pallet - painted wood	Wood	Sweden (process) - Russia	369.4[2]		0	0	0	75

[1] Van der Leeden *et al*. (1990).
[2] Gerbens-Leenes *et al*. (2009).

Appendix V: List of selected goods and services for assessing the overhead supply-chain water footprint

No	Item	Total amount used[1]	Unit	Raw material	Amount of raw material	Unit of raw material	Lifespan of material	Yearly amount
1	Construction							
1.1	Concrete	30000	ton	Cement	30000	ton	40	750
1.2	Steel	5000	ton	Steel	5000	ton	20	250
2	Paper	1	ton/year	Wood	1	ton/year	-	1
3	Energy	150000	GJ/year	Oil + gas	150000	GJ/year	-	150000
3.1	Natural gas	65000	GJ/year	Gas	65000	GJ/year		65000
3.2	Electricity	85000	GJ/year	Several	85000	GJ/year		85000
4	Transportation							
4.1	Vehicles	40	numbers	Steel	11.6[2]	tons/vehicle	10[3]	46.4
4.2	Fuel	150000	litres/year	Diesel	150000	litres/year	-	150000

[1] Ten percent of the total overhead will be attributed to the beverage product considered in this study, because the annual value of this beverage product contributes ten percent to the total annual value produced in the factory. Subsequently, this ten percent overhead is distributed over the annual number of bottles produced (30 million).

[2] http://kamaz.net/en/vehicle/serial/16

[3] it is assumed that average lifespan of a truck is 10 years. Usually it ranges from 7-13 years.

Appendix VI: Supply-chain water footprint of the selected overhead goods and services

No	Item	Raw material	Selected location for the calculation of the water footprint	Water footprint of raw material (m^3/ton)			Process water requirement (m^3/ton)[1]		
				Green[2]	Blue[1]	Grey	Green	Blue	Grey
1	Construction	Several							
1.1	Concrete	Cement	Belgium (process)	0	0	0	0	0	1.9
1.2	Steel	Steel	Sweden (process) - USA (raw material)	0	4.2	0	0	0	61
2	Paper	Wood	Finland (process)	369.4	0	0	0	0	125
3	Energy (GJ)	Oil + gas							
3.1	Natural gas	Gas	World average	0	0	0	0	0	0.11
3.2	Electricity	Several	World average	0	0	0	0	0	0.47
4	Transportation								
4.1	Vehicles	Steel	Sweden (process) - USA (raw material)	0	4.2	0	0	0	61
4.2	Fuel	Diesel	World average	0	0	0	0	0	1.06

[1] Van der Leeden *et al.* (1990).
[2] Gerbens-Leenes *et a*l. (2009).

Appendix VII: Assessment of the water footprint of the sugar beet input for four selected countries in Europe

The water footprint of sugar beet (m^3/ton) related to evaporation has been calculated as the ratio of the volume of water used during the entire period of crop growth (crop water requirement, m^3/ha) to the corresponding crop yield (ton/ha) in the producing region. The total crop water requirement, together with the effective rainfall and irrigation requirements per country have been estimated using the CROPWAT model (Allen *et al*., 1998; FAO, 2003a). Climate data have been taken for the most appropriate climate stations located in the major crop producing regions, from the Royal Netherlands Meteorological Institute (KNMI, 2008) in the case of the Netherlands and from the CLIMWAT database (FAO, 2003b) for the rest of the countries (Table VII-1). For regions with more than one climate station, the data for the relevant stations have been equally weighed, assuming that the stations represent equally sized crop producing areas. The actual irrigation water use is taken equal to the irrigation requirements as estimated with the CROPWAT model for every region. Second, since data on irrigated and rain-fed production per crop were not available and just rough data on irrigated and rain-fed area for some of the countries were accessible (IIRB, 2004), crop water requirements are assumed to be always fully satisfied. Crop coefficients and crop periods for different crops are taken from FAO (Allen *et al*., 1998; FAO, 2003a) and from the work of Chapagain and Hoekstra (2004).

The green water footprint has been estimated as the ratio of the green water use to the crop yield, where green water use is equal to the minimum of effective rainfall and crop water requirement. The blue water footprint has been taken equal to the ratio of the volume of irrigation water used to the crop yield. Both green and blue water footprints have been estimated separately by region (Table VII-2). Then, national average green and blue water footprints have been calculated on the basis of the respective share of each region to the national production. Data on average crop yield and production by region are taken from the Institute of sugar beet research in the Netherlands (IRS, 2008) from the Ministère de l'Agriculture et de la Pêche (2008) for France, from the Italian National Institute of Statistics (ISTAT, 2008) for Italy and from the Spanish Ministry of Environment and Rural and Marine Affairs (2008) for Spain.

The grey component in the water footprint of a primary crop (m^3/ton) is calculated as the load of pollutants that enters the water system (kg/year) divided by the maximum acceptable concentration for the pollutant considered (kg/m^3) and the crop production (ton/year) (Hoekstra and Chapagain, 2008). The quantity of nitrogen that reaches free flowing water bodies has been assumed to be 10 percent of the applied fertilization rate (in kg/ha/yr) (Hoekstra and Chapagain, 2008). The effect of the use of other nutrients, pesticides and herbicides to the environment has not been analyzed. The total volume of water required per ton N is calculated considering the volume of nitrogen leached (ton/ton) and the maximum allowable concentration in the free flowing surface water bodies. The standard recommended by the EU Nitrates, Groundwater and Drinking Water Directives for nitrate in water is 50 milligrams per litre (measured as NO_3^-). This limit was used to calculate the necessary water volume for assimilation. This is a conservative approach, since natural background concentration of N in the water used for assimilation has been assumed negligible. Data on the application of fertilizers have been obtained from the FERTISTAT database of FAO (FAO, 2008b). The grey water footprint in relation to the use of nitrogen fertilisers has been estimated at a country level. The results are shown in Table VII-3. The grey water footprint is highest in Spain, where the fertiliser application rate is highest.

When a primary crop is processed into a crop product (like sugar beet processed into raw sugar and then into refined sugar), there is often a loss of weight, because only part of the primary product is used. The water footprint of crop products is calculated by dividing the water footprint of the root (input) product by the product fraction (Hoekstra and Chapagain, 2008). The product fraction is defined as the quantity of the processed product obtained per quantity of root product. The product fractions for various crop products are derived from different commodity trees as defined in FAO (2003c) and Chapagain and Hoekstra (2004). If the root product is processed into two or more different products, one needs to distribute the water footprint of the root product across its separate products. This is done proportionally to the value of the root products. The value fraction for a processed product is defined as the ratio of the market value of the product to the aggregated market value of all the products obtained from the root product. If during processing there is some water use involved, the process water use is added to the water footprint value of the root product before the total is distributed over the various processed products. Sugar beet is processed by grinding, pressing out the sap and crystallising to produce molasses (unrefined sugar syrup), brown sugar and finally white sugar (by repeated crystallisation) (Van Wyk, 2005). The sugar industry by-products are shown in the production diagrams in Figure VII-1. The diagrams show the relevant product fractions. The value fraction for raw sugar is 89%; the remaining 11% of the value is in the by-products. Based on the water footprint of the sugar beet and the product and value fractions, we have calculated the water footprint of refined sugar. The results are shown in Table VII-4.

Table VII-1: The green and blue water footprint of sugar beet for the four selected countries over the period 1997-2007, planting period, harvesting period and climate stations.

Country	Water footprint (m^3/ton)		Planting period*	Harvest period*	Climate stations**
	Green	Blue			
France	36	29	April	September	Alencon, Auxerre, Bale-Mulhouse, Boulogne, Bourges, Caen, Chateau-Chinon, Chateauroux, Cherbourg-Maupertus, Clermont-Ferrand, Dijon, Le-Puy-City, Lille, Macon, Mont St Vincent, Nevers, Orleáns, Paris-Le-Bourget, Paris-Parc-St-Maur, Reims, Romilly-sur-Seine, Rouen, Strasbourg, Tours, Vichy
Italy	50	56	March-April	September	Ancona, Bologna, Cagliari elmas, Calopezzati, Caraffa di catanzar, Crotone, Ferrara, Foggia, Govone, Padova, Parma, Peruggia, Pescara, Piacenza, Rimini, Roma, Roma Ciampino, Siena, Termoli, Udine, Venezia, Verona
Spain	29	67	March-April (rest of Spain), October-November (Andalucía and Extremadura)	September (rest of Spain), May (Andalucía and Extremadura)	Algeciras, Ávila, Badajoz, Burgos, Cádiz, Ciudad Real, Córdoba aeropuerto, Jaén, Jerez de la Frontera, León Virgen del Camino, Logroño, Palencia, Salamanca, San Fernando, Segovia, Sevilla, Soria, Valladolid, Zamora
Netherlands	45	23	10 April	September	De Bilt, De Kooy, Eelde, Gilze-Rijen, Leeuwarden, Maastricht, Rotterdam, Schiphol, Twenthe, Vlissingen, Volkel

* Sources: Allen *et al*. (1998); Chapagain and Hoekstra (2004).

** Source: Royal Netherlands Meteorological Institute (KNMI, 2008) for the Netherlands, CLIMWAT database (FAO, 2003b) for the rest of the countries.

Table VII-2: Evapotranspiration (mm), crop water use (m3/ha), yield (ton/ha), production (%) and water footprint (m^3/ton) for different regions in the selected countries.

	ET_g mm	ET_b mm	ET mm	CWU_g m^3/ha	CWU_b m^3/ha	CWU m^3/ha	Y* ton/ha	Prod* %	WF_g m^3/ton	WF_b m^3/ton	WF m^3/ton
FRANCE									36	29	65
Picardie	285	221	506	2845	2211	5056	74	36	38	30	68
Champagne-Ardenne	268	243	511	2683	2432	5115	78	21	34	31	65
Nord - Pas-de-Calais	241	166	407	2407	1661	4069	75	15	32	22	54
Ile-de-France	270	288	557	2697	2875	5572	73	10	37	39	76
Centre	266	279	545	2657	2793	5450	80	6	33	35	68
Haute-Normandie	267	145	412	2668	1452	4120	76	6	35	19	54
Basse-Normandie	253	182	435	2528	1822	4350	75	2	34	24	58
Bourgogne	322	214	536	3223	2140	5363	67	2	48	32	80
Alsace	295	210	506	2953	2102	5056	76	1	39	27	66
Auvergne	314	207	521	3143	2069	5213	75	1	42	27	69
ITALY									50	56	106
Emilia Romagna	280	288	568	2800	2883	5683	56	34	50	51	101
Veneto	305	203	508	3047	2034	5081	65	20	47	31	78
Marche	280	286	566	2799	2861	5660	41	11	69	70	139
Lombardia	276	257	533	2759	2575	5334	62	10	44	41	86
Puglia	192	547	739	1921	5470	7391	42	6	46	130	176
Piemonte	211	293	504	2107	2932	5038	50	5	42	58	100
Friuli	446	68	514	4461	677	5138	65	3	69	10	79
Toscana	259	329	588	2592	3291	5884	41	2	63	80	142
Abruzzo	244	347	592	2444	3474	5918	46	2	53	76	129
Lazio	227	432	658	2265	4316	6581	47	2	48	92	140
Umbria	288	212	500	2883	2120	5003	46	2	62	46	108
Molise	159	400	558	1586	3997	5583	40	1	40	101	140
Sardegna	84	658	742	840	6583	7424	44	1	19	150	169
Calabria	123	565	688	1230	5649	6879	51	1	24	111	135
SPAIN									29	67	96
Valladolid	163	613	775	1626	6128	7754	80	17	20	77	97
Sevilla	227	318	545	2271	3183	5454	63	17	36	51	87
Cádiz	280	303	584	2802	3035	5837	43	12	65	70	135
León	206	479	685	2061	4793	6854	77	9	27	62	89
Palencia	127	583	711	1272	5834	7106	74	7	17	79	96
Salamanca	125	559	684	1246	5593	6839	73	5	17	76	93
Burgos	224	397	621	2237	3971	6208	71	5	31	56	87
Zamora	110	619	729	1104	6188	7292	76	5	15	81	96
Avila	169	520	689	1690	5201	6891	84	5	20	62	82
Segovia	183	520	703	1833	5195	7029	75	4	24	69	93
Albacete	124	621	744	1236	6207	7443	79	3	16	78	94
Alava	206	482	688	2057	4821	6878	76	3	27	64	91
Ciudad Real	124	621	744	1236	6207	7443	83	2	15	75	90
Córdoba	236	349	585	2364	3491	5855	55	2	43	64	107
La Rioja	206	482	688	2057	4821	6878	81	2	25	59	84
Soria	238	427	665	2381	4271	6652	69	1	35	62	96
Jaén	250	258	508	2499	2581	5080	60	1	42	43	85
Badajoz	223	418	642	2235	4181	6415	47	1	48	89	136

	ET_g	ET_b	ET	CWU_g	CWU_b	CWU	Y*	Prod*	WF_g	WF_b	WF
	mm	mm	mm	m^3/ha	m^3/ha	m^3/ha	ton/ha	%	m^3/ton	m^3/ton	m^3/ton
The Netherlands									45	23	68
Noord en Zuid-Holland	280	126	406	2795	1262	4058	65	14	43	20	63
Noordelijke klei	283	132	415	2826	1324	4150	63	11	45	21	66
Noordelijk dal/veen	286	134	420	2857	1342	4198	59	11	49	23	71
Limburg	277	140	417	2774	1397	4171	61	10	46	23	69
Oost en Zuid Flevoland	292	148	439	2916	1476	4391	74	9	40	20	60
Noordelijk zand	286	134	420	2857	1342	4198	57	9	50	24	74
Zeeuwse Eilanden	286	169	455	2859	1689	4548	64	8	44	26	71
Zeeuws-Vlaanderen	286	169	455	2859	1689	4548	65	7	44	26	71
West-Brabant	299	169	468	2990	1694	4684	63	6	48	27	75
Noordoostpolder	292	148	439	2916	1476	4391	71	6	41	21	62
Oost-Brabant	281	123	403	2805	1225	4030	58	6	48	21	69
Gelderland	281	131	412	2810	1310	4121	56	3	50	23	74

* Source: Institute of sugar beet research in the Netherlands (IRS, 2008) French Ministère de l'Agriculture et de la Pêche (2008), Italian National Institute of Statistics (ISTAT, 2008), Spanish Ministry of Environment and Rural and Marine Affairs (2008), FAOSTAT (FAO, 2008a) for the rest of the countries.

Table VII-3. The grey water footprint of sugar beet for the four selected countries.

	Average fertilizer application rate			Area*	Total fertilizer applied**			Nitrogen leached to the water bodies	Max. conc	Volume of assi-milation water required	Produc-tion*	Grey WF of sugar beet crop	Grey WF of refined sugar
	kg/ha			ha	ton/year			ton/year	mg/l	10^6 m^3/year	ton	m^3/ton	m^3/ton
	N	P	K		N	P	K		g/m^3				
France	145	38	35	415852	60299	15802	14555	6030	10	603	31216876	19	125
Italy	90	60	55	222982	20068	13379	12264	2007	10	201	10533330	19	140
Spain	178	100	108	113945	20282	11395	12306	2028	10	203	7322191	28	191
Netherlands	108	50	70	102823	11105	5141	7198	1110	10	111	6163436	18	109

* FAOSTAT for the year 1997-2007 (FAO, 2008a).

**FERTISTAT for the year 1999-2000 (FAO, 2008b).

Table VII-4: Green, blue and grey water footprint for sugar beet in the four selected European countries.

Country	Water footprint of sugar beet (m^3/ton)				Water footprint of refined beet sugar (m^3/ton)			
	WF_{green}	WF_{blue}	WF_{grey}	WF_{total}	WF_{green}	WF_{blue}	WF_{grey}	WF_{total}
France	36	29	19	84	232	190	125	548
Italy	50	56	19	125	367	411	140	918
Spain	29	67	28	124	203	459	191	852
Netherlands	45	23	18	86	275	137	109	521

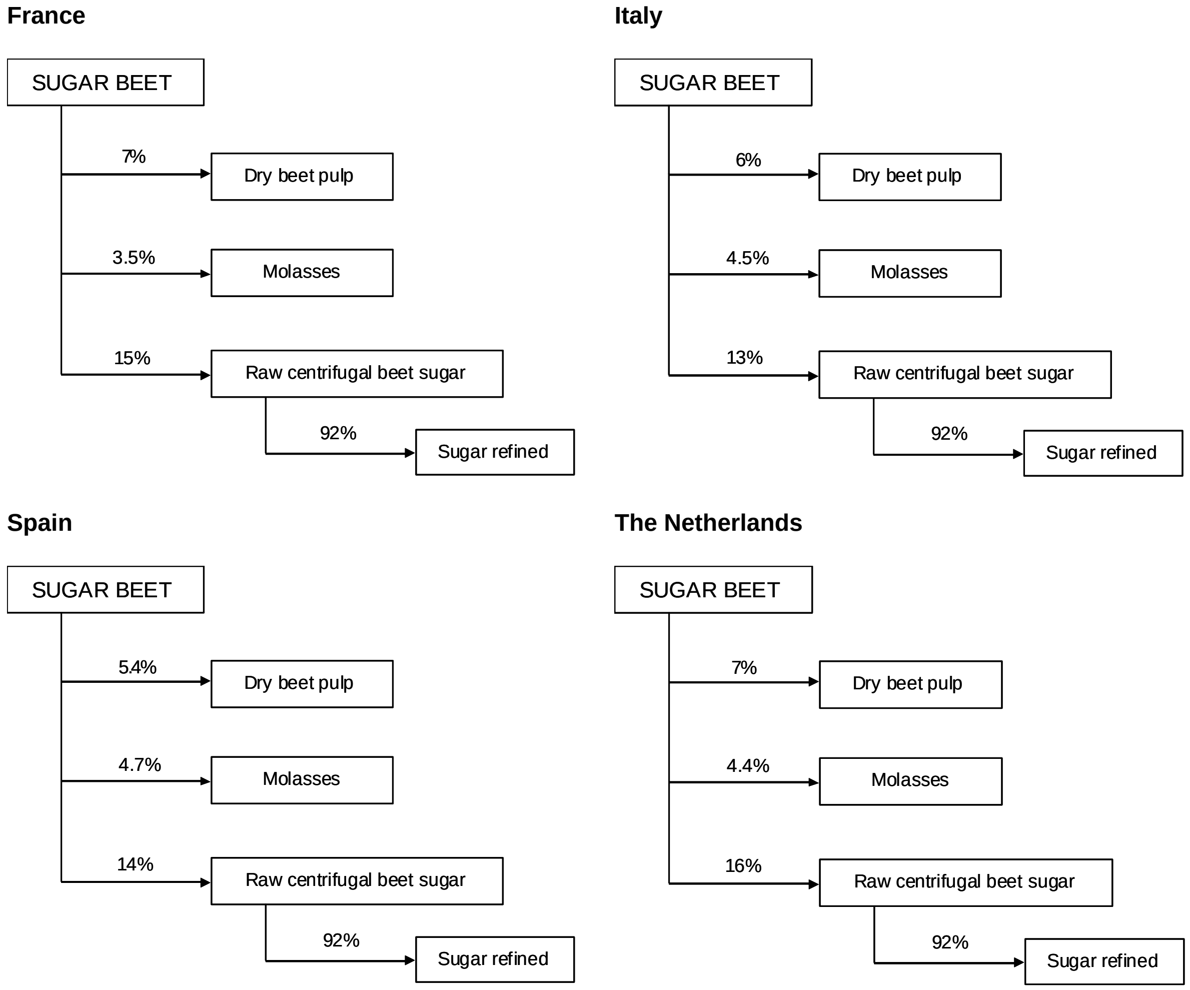

Figure VII-1: Production system of refined sugar for the four selected countries, showing product fractions. Source: Own elaboration based on FAO (2003c).

Within the European Union Member States the most important sugar beet producing regions are depicted in Figure VII-2.

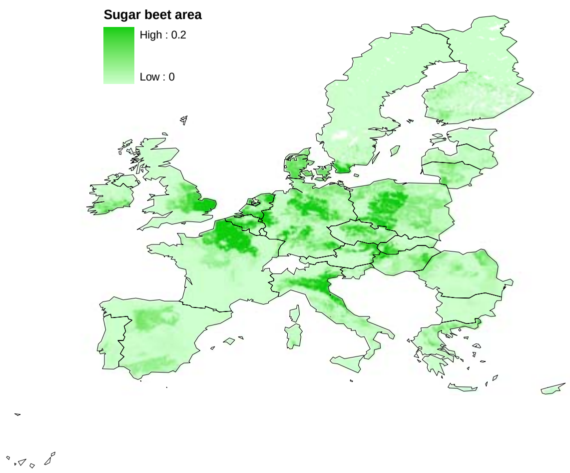

Figure VII-2. Sugar beet area in EU-27. Source: Monfreda et al. (2008)

French sugar beet production

As shown in Figure VII-3, within France, the sugar beet producing regions are located in the northern regions of the country, mainly in Picardie and Champagne-Ardenne regions. Concerning the water footprint related to the evapotranspirative demand, the main bulk of the total water used is mainly coming from green water resources (Figure VII-4).

Italian sugar beet production

Sugar beet production in Italy mainly takes places in the Northern regions of Emilia-Romagna and Veneto, where temperatures are lower and green water resources more abundant (Figures VII-5 and VII-6).

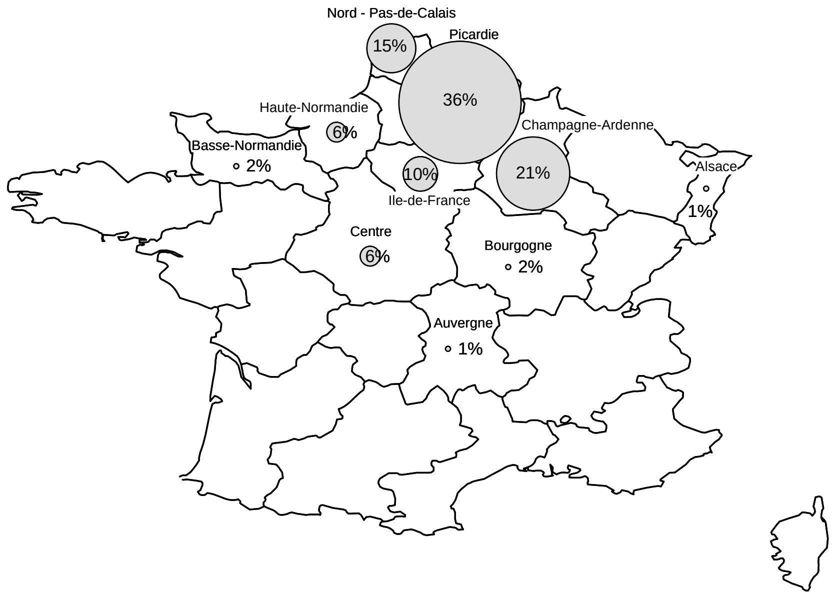

Figure VII-3. French sugar beet production by region (in percentage). The size of each pie reflects the regional contribution to the national production. Year 1997-2007. Source: Ministère de l'Agriculture et de la Pêche (2008)

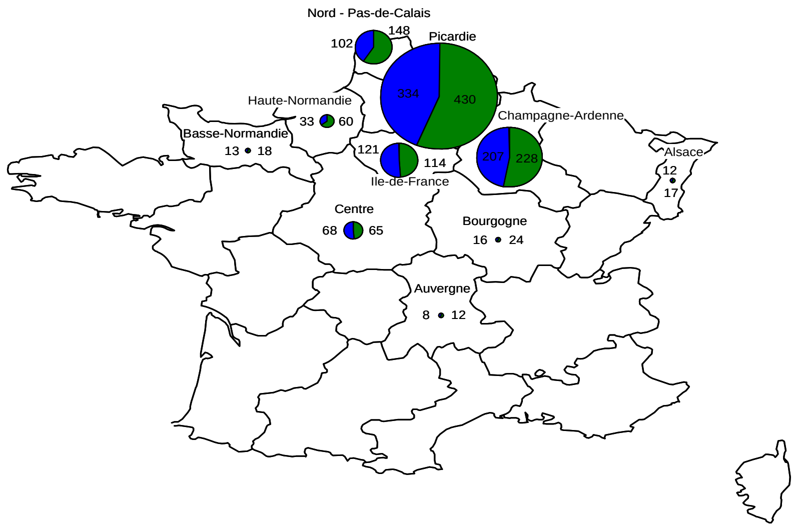

Figure VII-4. Green and blue water footprint (10^6 m^3/year) for the French sugar beet production by region. 1997-2007 year average. Source: Own elaboration based on Ministère de l'Agriculture et de la Pêche (2008) data.

Figure VII-5. Italian sugar beet production by region (in percentage). The size of each pie reflects the regional contribution to the national production. Year 1999-2007. Source: Italian National Institute of Statistics (ISTAT, 2008).

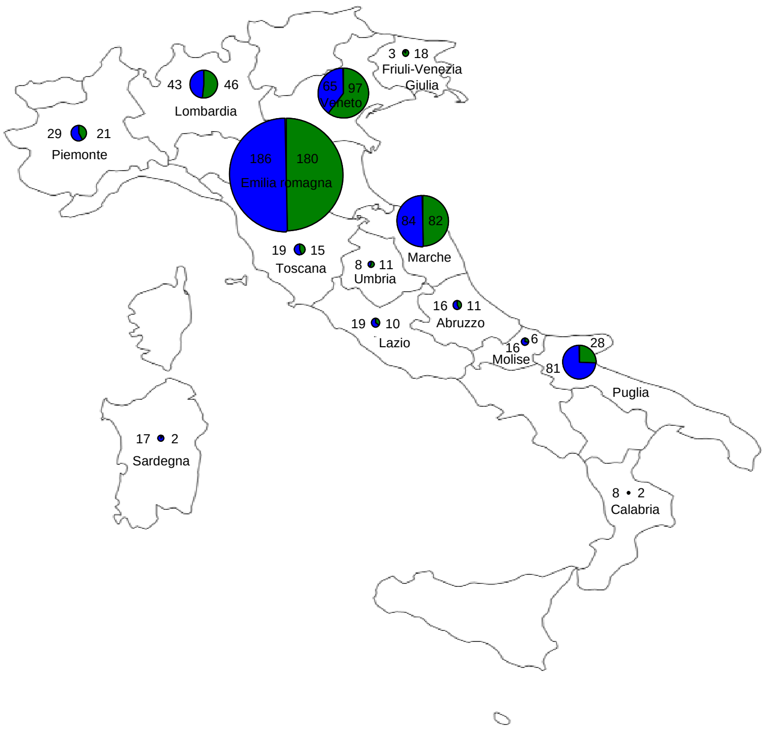

Figure VII-6. Green and blue water footprint (10^6 m^3/year) for the Italian sugar beet production by region.1999-2007 year average. Source: Own elaboration based on the Italian National Institute of Statistics (ISTAT, 2008) data.

Spanish sugar beet production

In the case of Spain, sugar beet is mainly produced in Castilla y León and Andalucía Autonomous Communities (Figure VII-7). In this country, 80% of the sugar beet growing area is irrigated (IIRB, 2004). However, autumn sowing of sugar beet represents a common strategy for using the available water for plant growth more efficiently in months with lower temperatures, and to avoid summer drought (ibid.). This is the case of the Andalucia and Extremadura Autonomous Communities in the south of Spain where sugar beet is planted in autumn taking advantage of the low winter evapotranspiration and available green water resources (Figure VII-8) (Spanish Ministry of Agriculture, Fisheries and Food, 2001).

Dutch sugar beet production

In the case of the production process in the Netherlands, there are two granulated sugar production plants, located in Dinteloord and in Groningen (Suiker Unie, 2008) (Figure VII-9). These production plants process approximately 33,000 tonnes of beet into some 5,500 tonnes of white sugar each day (Suiker Unie, 2008). The sugar beet is produced in different regions in the Netherlands (Figure VII-10).

Sugar beet is grown all over the Netherlands on about 95,000 ha, with a range of different soil types, from sand and reclaimed peat to heavy clay soils (IRS, 2008). The national average water footprint related to the sugar beet evapotranspiration is about 68 m^3/ton, using 45 m^3/ton of green water and 23 m^3/ton of blue water. This estimate is in line with the 65 m^3/ton calculated by Hoekstra and Chapagain (2008) for the water footprint of sugar beet from the Netherlands. Regional differences concerning the green and blue water proportions are very small (Figure VII-11).

The Dutch grey water footprint, measured as the volume of water required to assimilate the nitrate fertilizers used in the sugar beet cultivation in order to achieve the European standards, amounts to 18 m^3/ton.

The water used in the sugar beet processing is negligible since the water contained in the sugar beets is purified and reused (Suiker Unie, 2007). The water footprint related to the evapotranspirative demand of the refined sugar is about 412 m^3/ton, amounting to 275 m^3/ton the green water component and to 137 m^3/ton the blue water. The grey water footprint of the refined sugar is about 109 m^3/ton.

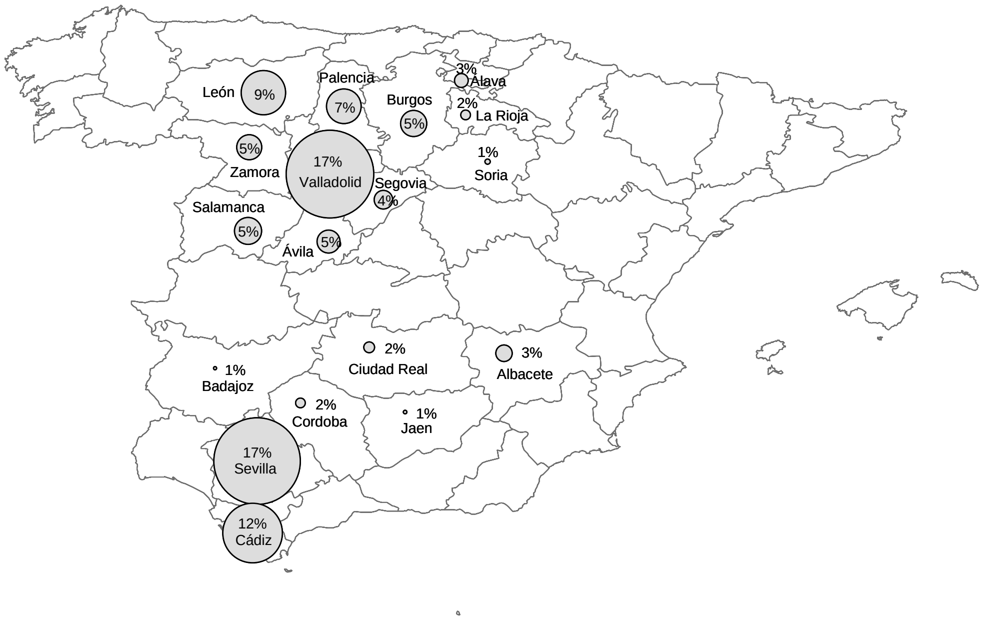

Figure VII-7. Spanish sugar beet production by province (in percentage). The size of each pie reflects the regional contribution to the national production. Period 2000-2006. Source: Spanish Ministry of the Environment and Rural and Marine Affairs (2008).

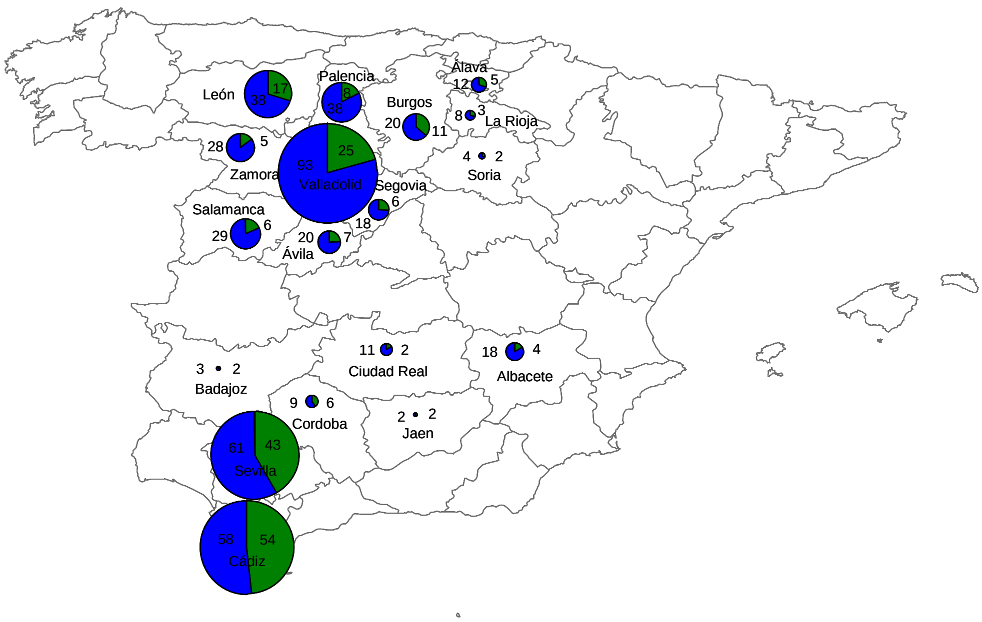

Figure VII-8. Green and blue water footprint (10^6 m^3/year) for the Spanish sugar beet production by region. Average for the period 2000-2006. Source: Own elaboration based on Spanish Ministry of the Environment and Rural and Marine Affairs (2008) data.

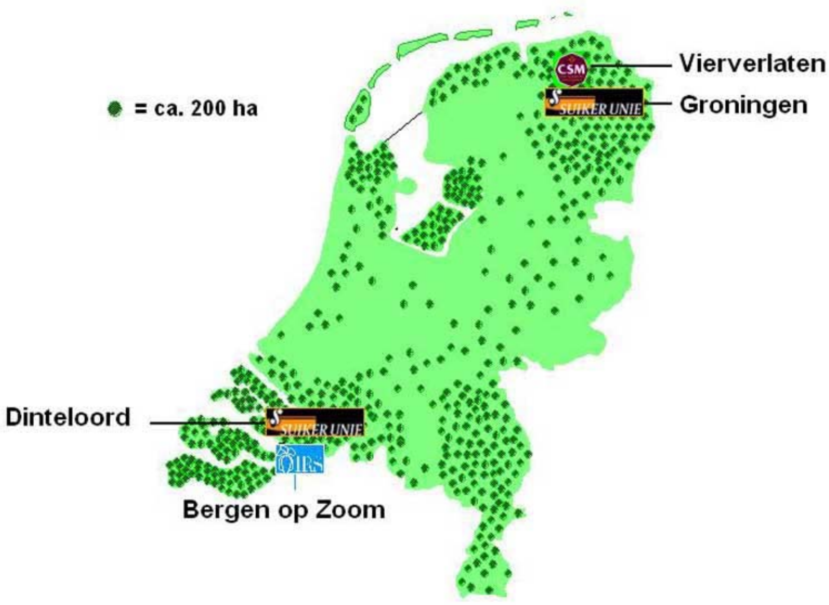

Figure VII-9. Sugar factories in the Netherlands: Dinteloord and Groningen.

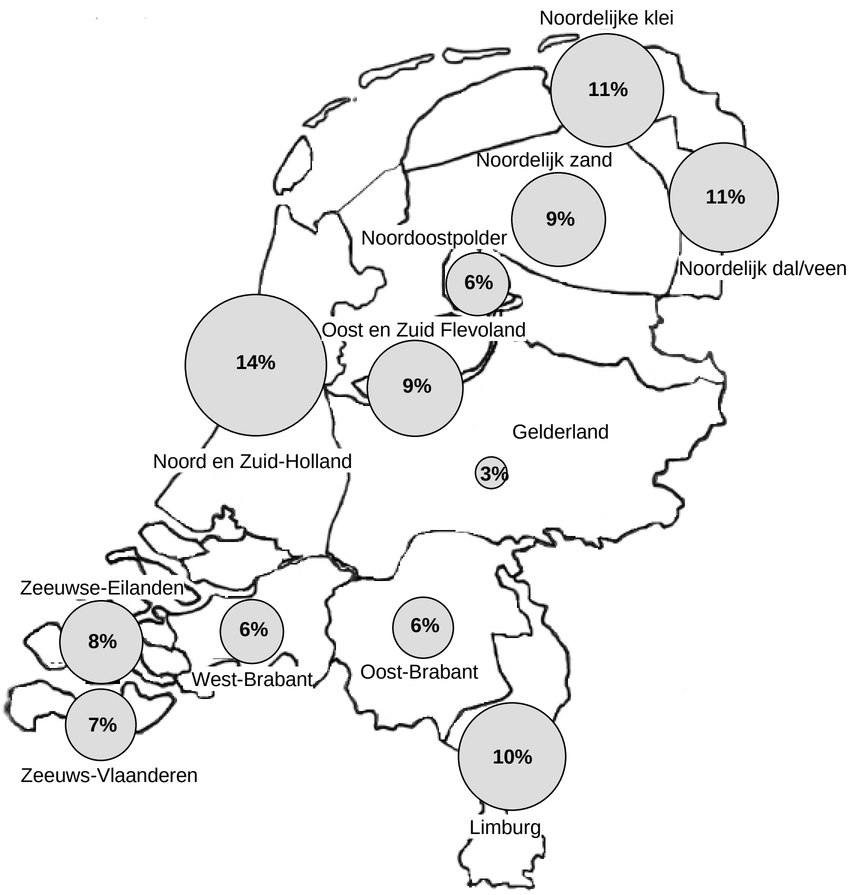

Figure VII-10. Dutch sugar beet producing regions (in percentage). Period: 1999-2006. Source: IRS (2008).

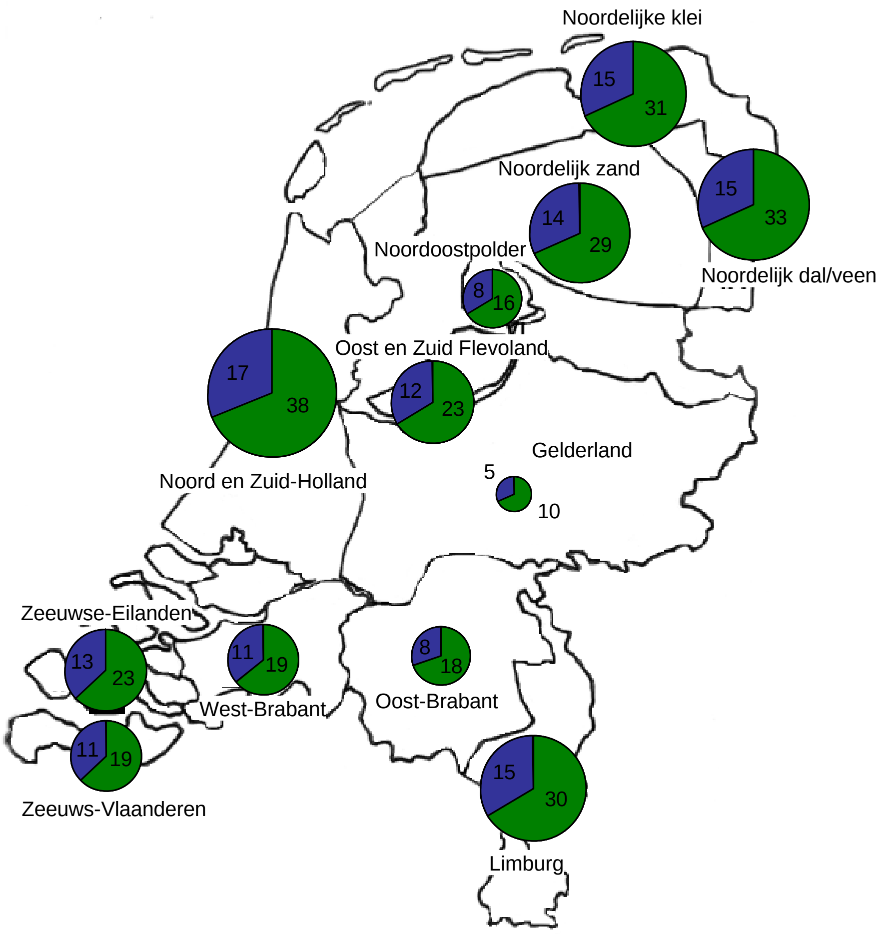

Figure VII-11. Green and blue water footprint (10^6 m^3/year) for the Dutch sugar beet production by region. Average for the period 1999-2006.

Glossary

Source: Hoekstra *et al*. (2009).

Blue water footprint – Volume of surface and groundwater consumed as a result of the production of a good or service. Consumption refers to the volume of freshwater used and then evaporated or incorporated into a product. It also includes water abstracted from surface or groundwater in a catchment and returned to another catchment or the sea. It is the amount of water abstracted from ground- or surface water that does not return to the catchment from which it was withdrawn.

Green water footprint – Volume of rainwater consumed during the production process. This is particularly relevant for agricultural and forestry products (products based on crops or wood), where it refers to the total rainwater evapotranspiration (from fields and plantations) plus the water incorporated into the harvested crop or wood.

Grey water footprint – The grey water footprint of a product is an indicator of freshwater pollution that can be associated with the production of a product over its full supply chain. It is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards. It is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards.

Operational water footprint – The operational (or direct) water footprint of a business is the volume of freshwater consumed or polluted due to its own operations.

Overhead water footprint – The water footprint of a product consists of two elements: the use of freshwater that can immediately be related to the product and the use of freshwater in overhead activities. The latter element is called the 'overhead water footprint'. The overhead water footprint refers to freshwater use that in first instance cannot be fully associated with the production of the specific product considered, but refers to freshwater use that associates with supporting activities and materials used in the business, which produces not just this specific product but other products as well. The overhead water footprint of a business has to be distributed over the various business products, which is done based on the relative value per product. The overhead water footprint includes for example the freshwater use in the toilets and kitchen of a factory and the freshwater use behind the concrete and steel used in the factory and machineries.

Supply-chain water footprint – The supply-chain (or indirect) water footprint of a business is the volume of freshwater consumed or polluted to produce all the goods and services that form the input of production of a business.

Water footprint – The water footprint is an indicator of freshwater use that looks at both direct and indirect water use of a consumer or producer. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business. Water use is measured in terms of water volumes consumed (evaporated or incorporated in the product) and/or polluted per unit of time. A water footprint can be calculated for a particular product, for any well-defined group of consumers (e.g. an individual, family, village, city, province, state or nation) or producers (e.g. a public organization, private enterprise or economic sector). The water footprint is a geographically explicit indicator, not only showing volumes of water use and pollution, but also the locations.

Water footprint of a business – The water footprint of a business – which can also be called alternatively corporate or organizational water footprint – is defined as the total volume of freshwater that is used directly and indirectly to run and support a business. The water footprint of a business consists of two components: the direct water use by the producer (for producing/manufacturing or for supporting activities) and the indirect water use (the water use in the producer’s supply chain). The 'water footprint of a business' is the same as the total 'water footprint of the business output products'.

Water footprint of a product – The water footprint of a product (a commodity, good or service) is the total volume of freshwater used to produce the product, summed over the various steps of the production chain. The water footprint of a product refers not only to the total volume of water used; it also refers to where and when the water is used.

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