Environmental Engineering and Management Journal
August 2014, Vol.13, No. 8, 2087-2096
http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

WATER FOOTPRINT ASSESSMENT OF THE ETHYL ALCOHOL PRODUCTION

Simona-Andreea Ene Popa, Carmen Teodosiu*, George Barjoveanu

"Gheorghe Asachi" Technical University of Iasi, Faculty of Chemical Engineering and Environmental Protection, Department of Environmental Engineering and Management, 73 Prof. Dr.doc. D. Mangeron Street, 700050, Iasi, Romania

Abstract

Water is essential for development and its use for the industrial and agricultural sector has grown to exceed natural supplies in many parts of the world. Businesses have became more aware of the water-related risks of their products, facilities and/or supply chain and started to consider the water accounting tools useful for identifying the "hotspots" related to water use and its social and environmental impacts, improving operational efficiency and communication with stakeholders.

The main objective of this study is to consider the application of the water footprint instrument in industry. In order to achieve this objective, the description of the technological processes for the studied industry has been done; the water footprint for the alcohol production industry has been assessed by identifying the *blue*, *green* and *grey* water footprints for growing maize. The specifications of the water footprints related to both operational and supply chain within the business have been done and according to these results, recommendations for an efficient use of water resources in the alcohol industry context have been developed.

The water footprint assessment has identified where the water was used in the ethyl alcohol production and what type of water was used, being distributed as follows: 93% *green* water, 5.6% *grey* water and only 1.4% *blue* water. The results reveals that 98.6% of the total water footprint is linked to the indirect water use in the supply chain, and only 1.4% belongs to the direct water use in the company's operational stage.

Key words: water footprint, alcohol industry, sustainable production

Received: February, 2014; Revised final: August, 2014; Accepted: August, 2014

1. Introduction

Water is essential for human life, environment and the economy and although it is permanently renewed, it is affected by pollution, unequal consumption and cannot be made or replaced with other resources (EC, 2012). The world water problems are worsening each year due to the increasing world population, improved living standards and water demands, climate change, and the intensification of water pollution (Teodosiu et al., 2009). The European countries get through many severe water supply problems where agriculture will suffer the most. These issues are most visible in periods of extreme water-related phenomena like droughts and flooding which, unfortunately, have become more and more present in the late period, with major environmental, social and economical impacts in the last years in Romania (Teodosiu et al., 2012).

Businesses have became more aware of the water-related risks in their production, facilities and/or supply chain and have started to consider the water accounting tools useful for identifying the "*hotspots*", managing the social and environmental impacts, improving the operational efficiency and communicating the performances with stakeholders (Barjoveanu et al., 2010; Teodosiu et al., 2012).

The water footprint concept was first introduced in 2002 by Arjen Hoekstra at the

---

* Author to whom all correspondence should be addressed: e-mail: cteo@ch.tuiasi.ro

International Expert Meeting on Virtual Water Trade, held in Delft, the Netherlands, aiming to illustrate the hidden links between human consumption and water use, and between global trade and water resources management (Hoekstra and Hung, 2002). The WF concept has primarily been introduced in the water science community in order to demonstrate that both consumer and global dimensions should be added for "*good water governance*".

"The water footprint of a product is the volume of freshwater used to produce the product, measured over the full supply chain. It is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution; all components of a total water footprint are specified geographically and temporally. The *blue water footprint* refers to consumption of surface and groundwater resources (denoted as *blue water*) along the supply chain of a product. The *green water footprint* refers to consumption of rainwater (commonly denoted as *green water*) as long as it does not become run-off. The *grey water footprint* refers to the pollution potential and is defined as the volume of freshwater (*grey water*) that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards" (Hoekstra et al., 2011).

By measuring water consumption over the full supply chain, the water footprint offers a wider perspective than the classical measure of water withdrawal, on how a consumer or a producer relates to the freshwater system. It furthermore includes the *indirect* use of water (the water use in a producer's supply chain) as well as the *direct* water use.

The Water Footprint Network (WFN, 2008) has developed methods to calculate water footprints and it has started to formulate approaches for assessing their potential impacts and planning the response strategies (Hoekstra et al., 2009; 2011).

Water footprint assessment is an analytical tool, which aims to analyze the relation between human activities or specific products with water scarcity and pollution, and to see how those activities and products can become more sustainable from a water perspective (Ene and Teodosiu, 2009; Ene et al., 2013). The main objective of this study is to evaluate a water-intensive industry from a water footprint perspective. The case study approached in this paper is developed onto an alcohol-production facility for which all water footprint components have been calculated for both direct and indirect water uses. For this, after the description of the technological processes involved in the alcohol production the water footprint for the alcohol production industry has been calculated and assessed by identifying the *blue*, *green* and *grey* water components.

The specifications of the water footprints related to both operational and supply chain within the business have been performed and according to the results, recommendations for an efficient use of water resources in the alcohol industry have been developed.

This study is the first assessment that considers the water footprint approach in a maize based ethyl alcohol production facility. Though, the weighted global average water footprint of maize has been assessed and ranges between 566 and 2537 m^3/t (Gerbens-Leenes and Hoekstra, 2012). However, in our case study, the inputs needed to calculate the water footprint for the maize production and for the production of ethyl alcohol from maize was performed based on real data obtained from the alcohol production facility, representing the reality of the production system.

2. Methodology and data acquisition

Data acquisition was based on the records of county administration organizations, from the alcohol production industry database as well as on the selected references specified in the text. Water footprint accounting was carried out based on the approach presented in the Water Footprint Manual (Hoekstra et al., 2009; 2011).

The water footprint of crops was calculated according to the methodology developed by Hoekstra and Chapagain (2008). The total crop water requirement, effective rainfall and irrigation requirements were estimated using the CROPWAT model (Allen et al., 1998; FAO, 2004). The evaluation of the *green*, *blue* and *grey* water footprints of growing a crop requires a substantial volume of data as presented in this study.

The **climatic parameters** have been obtained from the National Institute of Meteorology and Hydrology (NIMH, 2010), for the three closest and most representative meteorological stations for Botosani County, situated near the considered crop producing region, for the 2005-2008 period, a period containing years with different precipitation regimes.. The data have been used as input in the CROPWAT 8.0 model.

Data on **crop parameters** such as the duration of maize growing stages, sowing and harvesting periods and crop coefficients are sourced from Allen et al. (1998), Chapagain and Hoekstra (2004) and FAO (2004) as listed in Table 1.

The Romanian National Institute of Statistics (INS, 2010) has provided the **production quantity, yield and harvested area** for maize in Botosani County in the 2005-2008 period, as shown in the table bellow (Table 2).

In this study, nitrogen (N) fertilizer has been chosen as an indicator of the impact of its use in the production system. The total volume of **dilution water required** per ton of nitrogen has been calculated by considering the volume of N leached (t/t) and the maximum allowable concentration in the water bodies.

Table 1. Crop parameters and growing period

Crop	***Date***		***Length of development stages (Days)***					***Crop coefficient***		
Maize	*Planted*	*Harvested*	*Initial*	*Development*	*Mid-season*	*Late season*	*Total*	*Kc, ini*	*Kc, mid*	*Kc, end*
	15May	11 Oct	30	40	50	30	150	0.30	1.20	0.50

* *Initial development stage* runs from planting date to approximately 10% ground cover; *Crop development stage* runs from 10% ground cover to effective full cover; *Mid-season stage* runs from effective full cover to the start of maturity; *Late season stage* runs from the start of maturity to harvest or full senescence; *Kc, ini* - Crop coefficient during the initial stage; *Kc, mid* - Crop coefficient during the mid-season stage; *Kc, end* - Crop coefficient during the late season stage.

Table 2. Production quantities, yields and harvested area of maize for Botosani County (INS, 2010)

Year	***Area (ha)***	***Yield (t/ha)***	***Production (10^3 t/y)***
2005	127195	3.1	393.4
2006	97309	2.8	267.8
2007	101172	2.3	233.4
2008	95585	3.7	352.8

The quantity of nitrogen that reaches surface water bodies has been assumed to be 10% of the applied fertilization rate (in kg/ha/y) (following Ene and Teodosiu, 2011). The Nitrates Directive (91/676/EEC) and the Drinking Water Directive (98/83/EC) set a maximum allowable concentration for nitrate of 50 mg/Ll, measured as NO_3^- (EEA, 2003). Data on the application of nitrogen fertilizers in 2005-2008 period have been provided by INS (2010).

The total *water footprint of a business* (Gerbens-Leenes and Hoekstra, 2008) is equal to the sum of the supply-chain water footprint and the operational water footprint. The operational (*direct*) water footprint of a business is the volume of freshwater consumed or polluted due to its own operations while the supply chain (*indirect*) water footprint is the volume of freshwater consumed or polluted to produce all the goods and services that constitute the inputs of production of the business (Hoekstra et al., 2009). The water footprint assessment for the ethyl alcohol production industry has been done following Gerbens-Leenes and Hoekstra (2008) methodology.

3. General description of the ethyl alcohol production facility

For this study a large-size company from Botosani County which produces ethyl alcohol from maize was selected. The company produces ten months a year, 24/24 hr, 7/7 days in continuous flow. The production capacity of the company reaches 145.000 L ethyl alcohol /month
(14,500 hL/y).

The key process stages for ethyl alcohol production are (as presented in Fig. 1):

● Storage and Milling

The raw material used is grains, specifically maize. There is a landing platform and three storage tanks. The landing platform and the maize deposit are equipped with an elevator and two screw conveyors for transporting the maize. Yearly, 4800 tons of maize are stored and processed. The grains are milled with a hammer mill with a milling capacity of 5 t/h.

● Moulding and Saccharification

In this phase, the flour from mill, carried by a screw is mixed with water in ratio of 1:3, in a saccharification container, with a 20 m^3 capacity, and equipped with mixer, live steam injection and cooling system. The procedure is called moulding. The next step consists in an enzymatic treatment followed by Heating (92 to 95 °C) → Cooling to 60 °C → pH correction → Enzymatic treatment → Cooling to 30 °C.

● Fermentation

The saccharified mash is transferred to the fermenting vessels where a culture of yeast transforms the fermentable sugars into ethyl alcohol and carbon dioxide. The fermenting vessels of different capacities (about 35 m^3) are equipped with a cooling system, live steam injection and carbon dioxide disposal. Carbon dioxide can be stored under pressure in tanks and transported easily by pipeline or released into the atmosphere.

● Distillation

Distillation is the operation through which the alcohol is separated from the fermented mash in a distillation column. The distillate contains beside the absolute alcohol, some impurities which include aldehydes, esters, higher alcohols, methyl alcohol, glycerin, furaldehyde, etc.), which have an unpleasant smell and taste, are opaque and pose health risks for human consumption.

● Refining

Refining is the operation that removes most impurities from raw spirits. Refined alcohol is obtained, without suspension, with a characteristic odor. The operation is based on successive evaporation and condensation. The refining plant is composed of a stainless steel vessel and a refining column. A quantity of raw alcohol diluted to approximately 50% is inserted into the vessel, which is equipped with a steam heating coil. Through heating, alcohol evaporates entering in the refining column where the concentration and purification processes occur.

- The **process steam** required in the production of ethyl alcohol is produced in a steam power plant with a capacity of 2 tons of steam per hour. The process steam is produced by combustion of liquid fuels.

- **The marc from distillation and washing waters** is sent to the pre-treatment plant, with a capacity of 130 m^3/d of wastewater. The marc from the distillation column is directed to two rotating filters with slots of 1 mm and 0.5 mm respectively that separate the flour from marc. The separated flour is stored in a 30 m^3 tank and then delivered to the livestock farmers.

- The liquid fraction of the marc is conducted in a 160 m^3 stainless steel tank called equalization basin. In this basin, pH adjustment is made with sodium hydroxide, solution 50%. The mash is acidic (pH = 3.5 ÷ 4) and it is brought to a pH approximately equal to 7. Also in the equalization basin, cooling is done to about 40 °C through a cooler plate and a cooling tower.

The equalization basin content is pumped periodically into the biological reactor (600 m^3) which is fed with flocculants (ferric chloride). The biological reactor is equipped with a programmable aeration system. In the biological stage, a culture of specialized bacteria reduces the organic load. The last treatment process is the ultrafiltration.

The water balance shows that the company uses 180,700 m^3 water in the production process, out of which approximately 40% is recycled for washing (67,100 m^3) and disinfection, therefore the effective consumption of the company is 113,600 m^3 water per year. Table 3 presents the main resources quantities required to produce one hectoliter of refined ethyl alcohol. Water is used (for one hectoliter of refined ethyl alcohol, 100% concentration) as process water (1.3 m^3 for molding) and cooling water (2 m^3), and for steam generation for heating and drying (0.2 m^3).

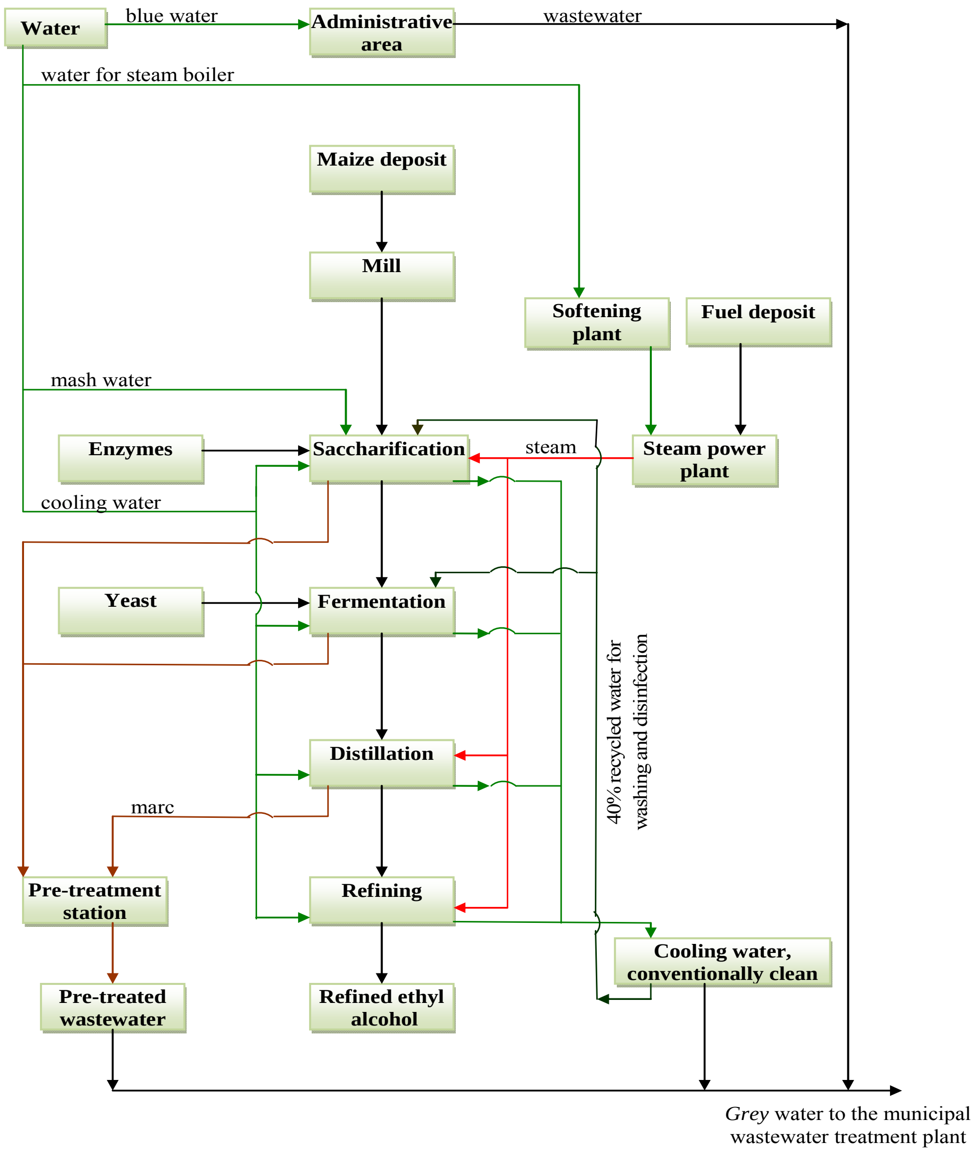

Fig. 1. Technological ethyl alcohol production processes

Table 3. Maximum consumption standards for one hectoliter of refined ethyl alcohol, 100% concentration

No. crt.	***Resources***	***UM***	***Quantity***
1	Maize	kg	350
2	Enzymes	kg	0.2
3	Yeast	kg	0.3
4	Fuel	kg	100
5	Water	m^3	3.5
6	Electricity	kWh	20

Water sources can include groundwater, surface water, and municipal water supplies. The annual water losses (approx. 20,000 L) occur through evaporation, drift, and blow down from the cooling tower; evaporation from the dryer; and incorporation into the product.

4. Water footprint assessment

4.1. Water footprint assessment of maize

Maize growing season begins on 15th May and ends on 11th October. The *effective rainfall* used by crop represents the *green* water use (evaporation of soil moisture supported by rainfall). Even if 2007 and 2008 appear to be the driest years, the efficiency of the rain reaches the highest values, 97.7% respectively 94.2%.

Irrigation is necessary when rainfall is insufficient to balance the water lost through evapotranspiration. No irrigation was applied for maize growth, so there is no blue evapotranspiration in the fields during 2005-2008 period in Botosani County.

The rainfall recorded the highest values in July and August, which are the most important months for maize growth. Even though 2007 was one of the driest years, the crop water requirement was fully met by the high values of the rainfall especially in the development and the middle stages of maize growth. Maize is a drought-tolerant plant, being mostly grown with *green* water; therefore irrigation was not needed for the period 2005-2008 in Botosani County. Reference crop evapotranspiration (Et_0) reaches its higher values in June and July, which correspond to the development stage of the crop; therefore, the effective rainfall (the rainfall that infiltrates into the soil) has lower values from June to August.

During the 2005-2008 period, the harvested area and maize yields fluctuated as it can be seen in Fig. 2. The harvested area of maize has decreased from 2005 to 2008 with more than 30000 ha. The yield has reached its maximum level in 2008, after its minimum in 2007. Yield reduction to 2.3 t/ha is due to soil moisture stress, 2007 being considered an excessive dry year.

In Table 4 the values of the evapotranspiration (ET), crop water use (CWU), yield (Y) and the water footprint (WF) of maize crop production in Botosani County are presented for the 2005-2008 period 2005-2008.

The values were separated into the three water footprint components, *green, blue* and *grey*. The *grey* water footprint represents the volume of water needed to dilute pollutants discharged into water bodies. Essential for the crop growth, nitrogen fertilizer is also harmful if used excessively.

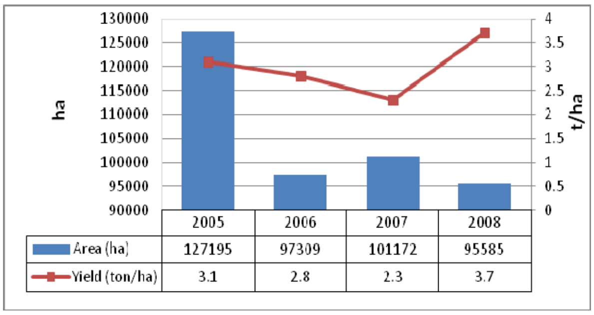

Fig. 2. Harvested area of maize and yield in Botosani County in 2005-2008 period

In 2006 and 2007, the application of nitrogen fertilizers was 17 kg N/y respectively 16.1 kg N/y which resulted in higher percentage of the grey water footprint (Fig. 3) in comparison with 2005 and 2008. The average *grey* water footprint for maize production for the analyzed period was 96 m^3/t and the *green* water footprint 1584 m^3/t.

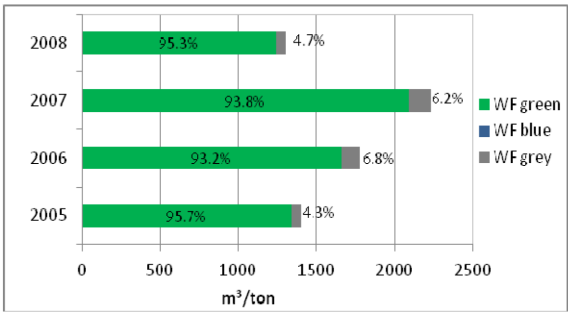

Fig. 3. Maize water footprint for the period 2005-2008 in Botosani County

The total average water footprint for maize production in 2005-2008 period was calculated and found to be 1680 m^3/t, with a maximum value in 2007 for both *green* and *grey* water footprints, with 2094m^3/t and respectively 140 m^3/t.

The water footprint calculations were affected by the low levels of maize yields that fluctuated during different precipitation regimes in the analyzed period, emphasizing a poor management of the water resources in Botosani County.

Table 4. Evapotranspiration, crop water use, yield and the water footprint of maize crop production

Period	ET_{green}	ET_{blue}	ET_{total}	CWU_{green}	CWU_{blue}	CWU_{total}	Yield	WF_{green}	WF_{blue}	WF_{grey}	WF_{total}
	mm/growing period			m^3/ha			t/ha	m^3/t			
2005	416	0	416	4160	0	4160	3.1	1341	0	61	1402
2006	463	0	463	4630	0	4630	2.8	1655	0	121	1776
2007	482	0	482	4820	0	4820	2.3	2094	0	140	2234
2008	460	0	460	4600	0	4600	3.7	1243	0	62	1305

Natural factors such as droughts or floods also influence maize production. In addition, old technologies usage or even no mechanical means at all in small size exploitations, result in low yields of the maize crops.

4.2. Water footprint assessment of the ethyl alcohol production

The production of the ethyl alcohol includes the following process steps: moulding, saccharification, fermentation, distillation and refining. Fig. 4 shows that most of the water (over 160,000 m^3/y) is used for cooling; therefore the water consumption for the other processes is relatively small. Due to the low water consumption, some of the components in the production process (labeling, packing, energy consumption, transportation) have been neglected.

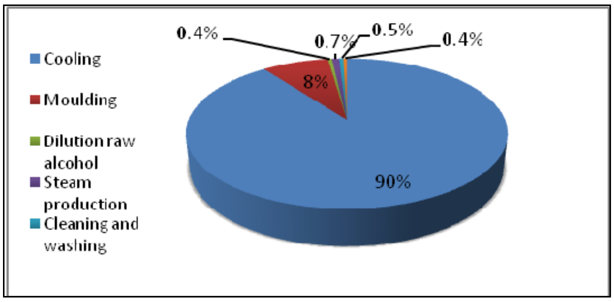

Fig. 4. The operational blue water used in the alcohol company

The alcohol company abstracts annually over 180,000 m^3 of water out of which 113,600 m^3 is embedded into the product, so that it does not return to the hydrologic system from where it was withdrawn. There is no use of *green* water in the operational stage; therefore the *green* water footprint is zero. The wastewater flow of 16,335 m^3 is treated in the municipal wastewater treatment plant, so the *grey* component of the operational water footprint is effectively zero.

Annually, 1620 m^3 of water is consumed for domestic purposes and cleaning activities within the business, which represent the overhead operational water footprint.

The supply chain water footprint is related to the product inputs, ingredients other than water, labeling and packing materials. The company uses 3.3 kg of maize to produce 1 liter of ethyl alcohol; therefore approximately 4800 tons of maize are used per year for the entire production, which require after summing up the supply chain water footprint and the operational water footprint, a total water footprint of the business exceeding 8,000,000 m^3 of water per year. Fig. 5 presents the variations of the total water footprint of 1L ethyl alcohol in 2005-2008 periods, which fluctuated due to different values of maize water footprint.

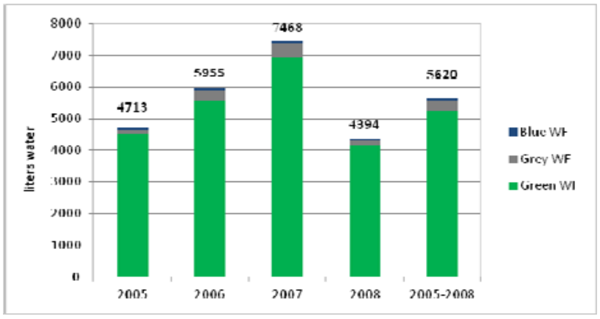

Fig. 5. The water footprint for the production of 1L ethyl alcohol in the period 2005-2008

Therefore, by adding the *green*, *blue* and *grey* components, results a total water footprint for 1L of ethyl alcohol varying between 4713 L of water in 2005 to 7468 L in 2007 (Fig. 6).

The overall results, including all components, are shown in Fig. 7. The resulted water footprint for the ethyl alcohol production industry reveals that 98.6% of the total water footprint is linked to the *indirect* water use in the supply chain, and only 1.4% belongs to the *direct* water use in the industry's operational stage. The total water footprint of ethyl alcohol production is distributed as follows: 93% *green* water, 5.6% *grey* water and only 1.4% *blue* water.

The *green* and *grey* water footprints are associated with the supply chain. Maize is one of the crops that is mostly grown with green water. The operational water footprint is associated with *blue* water that is used in the production processes, mainly for the cooling towers.

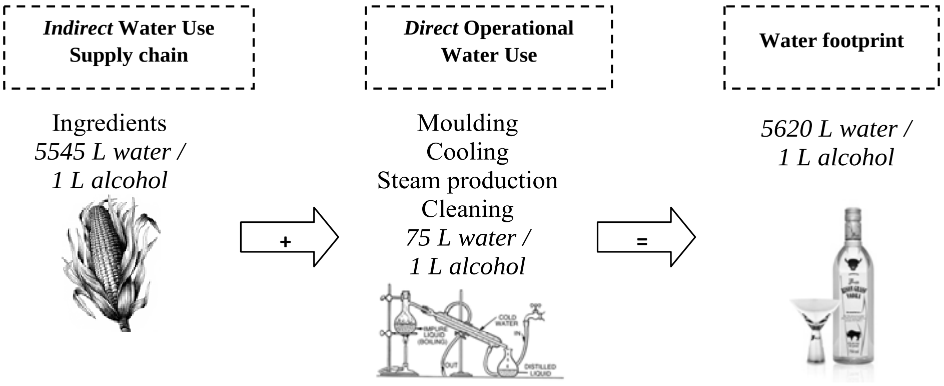

Fig. 6. Indirect and Direct Water Footprint Components

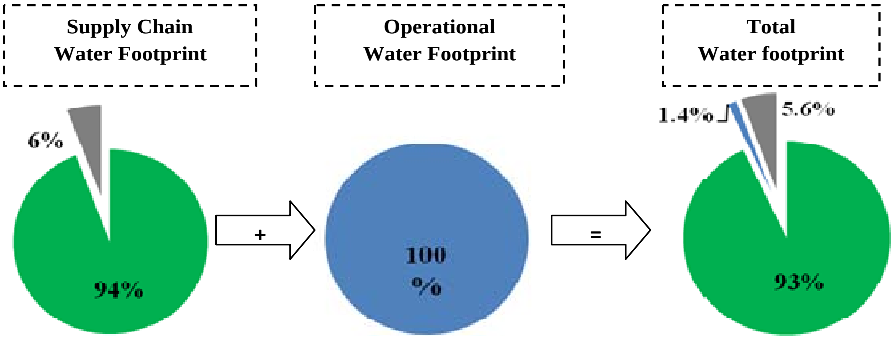

Fig. 7. Water Footprint Components of 1 L ethyl alcohol production in Botosani County

The water footprint assessment has identified *where* the water was used in the ethyl alcohol production and *what type* of water was used. The water footprint assessment proves to be a useful method for businesses in providing valuable insight within the production chain. In addition, it provides strategic information required to understand the water-related risks and vulnerabilities of the business.

5. Recommendations for a sustainable water management in the alcohol industry

Within any business, water consumption occurs upstream as well as downstream, so the business needs to incorporate the supply chain accounting into its management processes. The water minimization strategy may also involve a marketing plan for changing the consumers' behavior.

Water use efficiency (WUE) is quantified by the ratio of crop yield to water supply, which includes the available water in the soil profile for plant growth during sowing, as well as rainfall and irrigation during the growing season.

The maize water use efficiency in 2005-2008 period, in Botosani County (Table 5) was 0.66 kg/m^3 which is below the globally measured average which ranged between 1.1 - 2.7 kg/m^3, reported by Zwart and Bastiaanssen (2004). The variability of WUE and its low values can be attributed to a poor management of water resources, soil (nutrient) management, as well as natural factors like droughts and floods. In addition, the use of old technologies in small size exploitations, results in low yields and low water productivity of crops (maize).

Table 5. Yields, crop water use (CWU) and water use efficiency (WUE) of maize production in Botosani County for the period 2005-2008

Year	*Yield (ton/ha)*	*CWU (m^3/ha)*	*WUE (kg/m^3)*
2005	3.1	4156	0.75
2006	2.8	4634	0.60
2007	2.3	4815	0.48
2008	3.7	4600	0.80
2005-2008	3	4551	0.66

To accomplish optimum water conservation and improved water use efficiency is required a water conservation enabling environment that includes:

(1) *Education and training, improvement of systems and public incentives*: measures that might allow the increase of the production potential for additional 20 % than the current practices;

(2) *Irrigation management*, *supply infrastructure management* and an *optimized resource policy* to reach 60 % of the production potential;

(3) *Involvement of the private sector* for the complete use of the available production capacities.

The consideration of sustainable practices in the field of the ethyl alcohol production industry refer usually to the components of sustainability addressed at the level of economically feasible, environmentally-friendly technology and socially equitable processes (for both maize growing and ethyl alcohol production). Such practices may contribute to savings in water, energy, raw materials, diminished emissions and waste generation and a more efficient use of personnel time, with benefits for the decrease of business costs, the increase of profit and competitiveness.

5.1. Reducing the water footprint through the supply chain

When it comes to reducing the *indirect* water footprint, the industry needs to work with suppliers and influence them to improve quality standards and to reduce the indirect water footprint by installing effluent treatment plants and engaging in rainwater harvesting. If necessary, that may require changing to other suppliers who are more responsive to water conservation.

At the farm level, it is important to implement *water conservation measures* in order to obtain an efficient use of water. Water conservation in agriculture implies measures designed to:

(1) improve the availability of water for agricultural purposes ("*Supply Management*"),

(2) reduce the water demands through efficient use of water ("*Demand Management*") and

(3) preserve the quality of water resources by avoiding pollution or wastes (Prinz and Malik, 2004).

Rainwater is an essential resource for growing food; therefore eighty percent of the world's agricultural land is rain-fed and contributes to about 60 percent of the global food production (Wani and Ramakrishna, 2005).

Rainwater management can be whether *in-situ moisture conservation* (rain and surface runoff management serves also the purposes of soil conservation and flood control) or *water harvesting* (the collection and concentration of rainfall and its use for the crops irrigation).

Regarding the water conservation measures, there can be distinguished three groups of measures:

1. Measures that are practicable only under rain-fed conditions;
2. Measures relevant for saving water in the rain-fed and in irrigated agriculture;
3. Measures applicable only for irrigated agriculture.

In–situ water conservation (Fig. 8), often combined with water harvesting measures, can contribute significantly making better use of the rainfall. Company's supply chain water footprint was calculated and found to be 94% green, so further will be described the best proven measures for in-situ moisture conservation. *Agricultural water conservation* consists in the increasing of crop water use efficiency, improving irrigation application efficiency, increasing the rainwater collection and use, decreasing crop consumptive use, reducing water use through the embracement of conservation measures and the use of new technologies for water management.

5.2. Reducing the operational water footprint in alcohol industry

For the ethyl alcohol production facility, water is the basic ingredient for its operations and a water saving policy is crucial in managing risk factors like threat of increased regulatory control and damage of the corporate image, financial risks caused by pollution and insufficient freshwater availability for operations. The water saving options for decreasing water withdrawal and water consumption within the ethyl alcohol production facility will be presented below.

5.2.1.Recycling of cooling water

Within the ethyl alcohol production facility, the cooling tower consumes 90% of the total water and at the same time represents the largest opportunity for greater water efficiency.

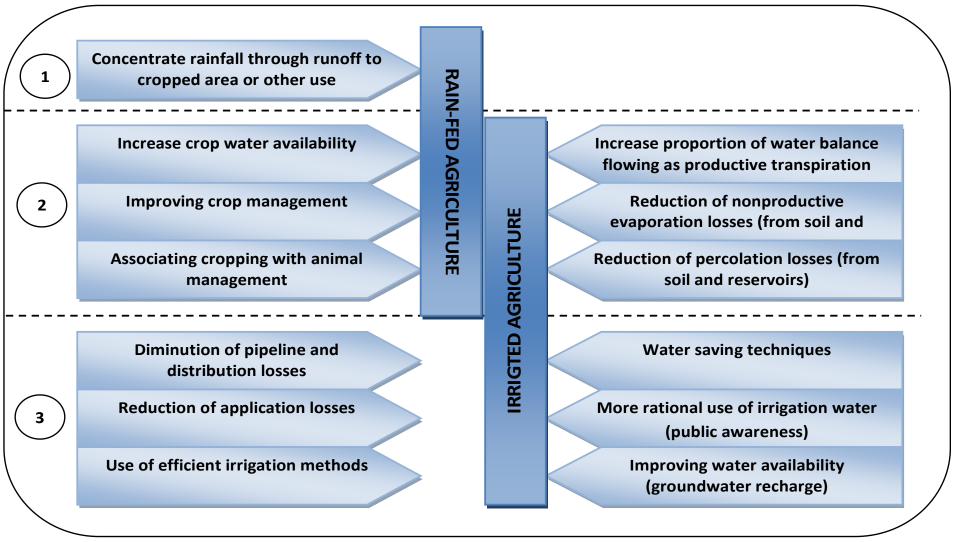

Fig. 8. Water conservation measures applied in (1) rain-fed agriculture, (3) irrigated agriculture and (2) in both sectors (adapted after Prinz and Malik, 2004)

The company already recycles 40% of the cooling water, but increasing this rate will result in multiple savings, from water to sewer costs to savings on the purchase of chemicals used to treat both incoming and discharged water.

Water withdrawal can be reduced by replacing single-pass cooling systems with a cooling loop. In a closed loop cooling system, the heat is transferred to the closed loop by typical heat exchange equipment and is removed from the closed system by a heat exchanger from the closed loop to a secondary cooling water cycle. The secondary loop could use either evaporative or once-through water cooling, or air cooling.

5.2.2. Using alternative water resources-condensate recovery and rainwater harvesting

Rainwater harvesting and condensate reuse are effective methods of reducing water withdrawal, by using both the natural environment and engineered systems, while avoiding problems due to excessive runoff.

5.2.3. Using less water for cleaning purposes

Annually, 1620 m^3 of water is consumed for domestic purposes and cleaning activities within the alcohol company. Below some alternatives for decreasing water usage in this sector are presented:

- use high-pressure, low-volume sprays as washing equipment in place of wash down hoses;
- install automatic shut-off devices where taps are used regularly and self-closing trigger nozzles to hose pipes, to control the flow of water;
- install and locate drains and sumps so that water and wastes enter;
- use detergents and sanitizing chemicals that are easily removed with minimum water.
- ***good housekeeping practices*** *such as metering, leak detection and maintenance may also be used*

By using the above outlined methods, benefits such as water conservation, preservation of water quality, reducing or eliminating drainage problems, conserving energy, often increases production, and save money. The stress of droughts, higher expenses and low commodity prices will continue to make efficient water management practices a necessary tool for farmers who wish to remain competitive in today's market. Efficient agricultural water conservation practices are essential to ensure the viability of Romania's agricultural industry.

6. Conclusions

Water footprints accounting is essential for the product and business transparency, which is requested nowadays by consumers. Since 70 percent of the world water use is located in the agricultural sector, which is part of the supply chain of many industries, the water footprint of a business that has agricultural products as input is likely to be dominated by the supply chain water footprint. The contribution of the operational water footprint is relatively small in such a case.

The main objective of this study is to evaluate a water-intensive industry from a water footprint perspective. The case study approached in this paper is developed onto an alcohol-production facility for which all water footprint components have been calculated for both direct and indirect water uses. For this, after the description of the technological processes involved in the alcohol production the water footprint for the ethyl alcohol production industry has been calculated and assessed by identifying the *blue*, *green* and *grey* water components. This study is the first assessment of its kind that considers the water footprint approach in a maize based ethyl alcohol production facility. However, in our case study, the inputs needed to calculate the water footprint for the maize production and for the production of ethyl alcohol from maize was performed based on real data obtained from the alcohol production facility, representing the reality of the production system.

The total average water footprint for maize production was calculated using the CROPWAT software, and found to be 1680 m^3/t, with the maximum value in 2007 for both *green* and *grey* water footprints, with 2094 m^3/t and respectively 140 m^3/t. The specifications of the water footprints related to both operational and supply chain within the ethyl alcohol production facility have been performed and according to the results, recommendations for an efficient use of water resources in the alcohol industry have been developed. The general results of the study are the following:

● The total water footprint of the business, after summing up the *indirect* water use in the supply chain and the *direct* water use in the operational stage, exceeds 8,000,000 m^3/y.

● The largest part of the product water footprint comes from the field, not the factory. As expected for any business that has agricultural products as input, the supply chain water footprint accounts for 98.6% while the operational water use forms only 1.4% of the total water footprint.

● The operational water footprint is entirely *blue* water, used in the production processes, mainly for cooling. The *green* and *grey* water footprints are associated with the supply chain, being divided into 94% and respectively 6%.

● The total water footprint of the studied beverage is 5620 L of water per 1L alcohol, being distributed in 93% *green* water, 5.6% *grey* water and only 1.4% *blue* water.

The consideration of sustainable practices in the field of the ethyl alcohol production industry refer usually to the components of sustainability addressed at the level of economically feasible, environmentally-friendly technology and socially equitable processes (for both maize growing and ethyl alcohol production). Such practices may contribute to savings in water, energy, raw materials, diminished emissions and waste generation and a more efficient use of personnel time, with benefits for the decrease of business costs, the increase of profit and competitiveness.

The water footprint accounting helps companies in providing a good overview of the water use in the value chain. In addition, it provides strategic information needed for the understanding and assessing the water-related risks and vulnerabilities.

Acknowledgments

This work was supported by a grant of the Romanian National Authority for Scientific Research, CNDI–UEFISCDI, project no. 60/2012, "*Integrated System for Reducing Environmental and Human-related Impacts and Risks in the Water Use Cycle*" (WATUSER).

The support of the PERFORMERA Project "*Postdoctoral Performance for Integration in the European Research Area*" (ID-57649), financed by the European Social Fund and the Romanian Government is also acknowledged.

References

Allen R.G., Pereira L.S., Raes D., Smith M., (1998), Crop evapotranspiration: Guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization, Rome.

Barjoveanu G., Cojocariu C., Robu B., Teodosiu C., (2010), Integrated assessment of wastewater treatment plants for sustainable river basin management, *Environmental Engineering and Management Journal*, **9**, 1251- 1258.

Chapagain, A.K, Hoekstra, A.Y., (2004), *Water Footprints of Nations.* Vol. I: Main Report and Vol. II: Appendices, UNESCO-IHE Institute for Water Education, *Value of Research Report Series* No. **16**, Delft, The Netherlands.

, (2003), Europe's Water: An indicator-based assessment, Topic Report No 1/2003, European Environment Agency EEA, Copenhagen, Denmark.

EC, (2012), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Blueprint to Safeguard Europe's Water Resources, November 2012, European Commission, Brussels, Belgium.

Ene S.A. and Teodosiu C., (2009), Water footprint and challenges for its application to integrated water resources management in Romania, *Environmental Engineering and Management Journal*, **8** , 1461-1469.

Ene, S.A. and Teodosiu C., (2011), Grey water footprint assessment and challenges for its implementation, *Environmental Engineering and Management Journal*, **10**, 333-340.

Ene S.A., Teodosiu C., Robu B., Volf I., (2013). Water footprint assessment in the wine making industry: a case study for a Romanian medium production plant, *Journal of Cleaner Production*, **43**, 122-135.

FAO, (2001), *Crops and Drops: Making the Best Use of Water for Agriculture*, Food and Agriculture Organization, Rome, Italy.

FAO, (2004), Crop evapotranspiration: Guidelines for computing crop water requirements, *Irrigation and Drainage Paper* **56**, Food and Agriculture Organization, Rome, Italy.

FAO, (2011), CROPWAT 8.0 Review Online at: http://www.fao.org/nr/water/infores_databases_cropwat.html.

Gerbens-Leenes, P.W., Hoekstra, A.Y., (2008), Business water footprint accounting: a tool to assess how production of goods and services impacts on freshwater resources worldwide, *Value of Water Research Report Series* No **27**, UNESCO-IHE.

Gerbens-Leenes P.W. and Hoekstra A.Y., (2012), The water footprint of sweeteners and bio-ethanol – review, *Environment International*, **40**, 202–211.

Hoekstra, A. Y. and Hung, P. Q., (2002), Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade, *Value of Water Research Report Series* No **11**, UNESCO-IHE, Delft, Netherlands.

Hoekstra, A. Y. and Chapagain, A. K., (2008), *Globalization of Water: Sharing the Planet's Freshwater Resources*, Blackwell Publishing, Oxford.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. and Mekonnen, M. M., (2009), *Water Footprint Manual: State of the Art 2009*, Water Footprint Network, Enschede, the Netherlands.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M. and Mekonnen, M. M., (2011), The *Water Footprint Assessment Manual: Setting the Global Standard*, Earthscan, London, UK.

INS, (2010), National Institute of Statistics, Romania, TEMPO-Online Series at http://www.insse.ro/cms/rw/pages/index.ro.do/.

NIMH, (2010), Regional Meteorological Center Moldova, Iasi, National Institute of Meteorology and Hydrology, Romania.

Prinz D., Malik A.H., (2004), More yield with less water - How Efficient Can be Water Conservation in Agriculture?, *European Water,* **5**, 47-58.

Teodosiu C., Cojocariu C., Musteret C.P., Dascalescu I.G., Caraene I., (2009), Assessment of human and natural impacts over water quality in the Prut River Basin, Romania, *Environmental Engineering and Management Journal*, **8**, 1439-1450.

Teodosiu C., Bârjoveanu G., Robu B., Ene S.A., (2012). Sustainability in the water use cycle: challenges in the Romanian context, *Environmental Engineering and Management Journal*, **11**, 1987-2000

Teodosiu C, Robu B., Cojocariu C, Bârjoveanu G. (2013), Environmental impact and risk quantification based on selected water quality indicators, *Natural Hazards,* DOI: 10.1007/s11069-013-0637-7.

Zwart S.J., Bastiaanssen W.G.M., (2004), Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize, *Agricultural Water Management*, **69**, 115–133.

Wani S.P and Ramakrishna Y.S., (2005), *Sustainable Management of Rainwater through Integrated Watershed Approach for Improved Rural Livelihoods*, In: *Watershed Management Challenges Improving Productivity, Resources and Livelihoods*, Sharma B.R., Samra J.S., Scott C.A., Wani S.P., (Eds.), International Water Management Institute, Colombo, Sri Lanka.

WFN, (2008), *Water Footprint Network*, Enschede, The Netherlands, Online at: www.waterfootprint.org.