Tap water vs. bottled water
in a Footprint Integrated approach

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ABSTRACT

A Footprint Integrated approach was used to assess and compare the impact on the environment and on the resources of tap water (TW) and pet-bottled natural mineral water (BW). A set of BW from six Italian companies was analyzed. This set covers about the 10% (by volume) of the total marketed bottled waters in Italy. TW is the public water available in Siena (Italy). The functional unit is a volume of water of 1.5 L.

An ad hoc Footprint methodology was defined, integrating Ecological Footprint (EF), Water Footprint (WF) and Carbon Footprint (CF). A Life Cycle Assessment (LCA) was performed, in order to derive the material and energy inputs and outputs of each upstream and downstream process required by the two ways of drinking water.

In the comparison based on *Ecological Footprint* and *Carbon Footprint*, tap water showed about 300 times lower values than bottled water. On the contrary, *Water Footprint* values were quite similar: TW displayed the same value of the average BW. The Footprint Integrated results were used to assess the Footprint savings allowed by tap water drinking. Water Footprint reduction chances were also discussed, including a comparison between PET, PLA (polylactic acid) and glass in bottling practice. Tap water seemed to be able to reduce his water consumption and withdrawal more than bottled water.

KEYWORDS

Bottled water; Tap water; Water Footprint; Ecological Footprint; Carbon Footprint.

INTRODUCTION

In the last 30 years, per capita consumption of plastic-bottled natural mineral water (BW) has grown worldwide without any interruption (IBWA, 2008). In Italy, which is the third BW consumer in the world, this growth was made possible in 1980s by the rise of private TV channels (widening advertising opportunities) and the introduction of polymers bottles (reducing transportation costs). These two elements enhanced the creation of a national BW market. In 1980 per capita consumption was 47 L, while in 2007 it was 202 L (Istat, 2008): Italians switched their drinking habits from tap water to bottled mineral water in less than 30 years. A different impact on resources and the environment may be connected to this switch.

The aim of this paper is to compare the environmental impact of tap water (TW) and pet-bottled natural mineral water (BW). A set of PET-bottled mineral water from six Italian companies was analyzed. The set covers about the 10% (by volume) of the total marketed bottled waters in Italy. The companies were selected in order to provide a true sample of the Italian market. Tap water is the one provided to the municipality of Siena (Italy). The functional unit is a volume of water of 1.5 L if TW is considered, while a pet-bottle of 1.5 L is the functional unit of BW, including all the packaging.

An ad hoc Footprint methodology was defined, integrating Ecological Footprint (EF), Water Footprint (WF) and Carbon Footprint (CF). The methodology is inspired by Life Cycle Thinking, which prescribes to evaluate the environmental burden of a product by considering each step of its entire life cycle, from cradle to grave. In order to get information on those steps and on any upstream and downstream process involved, a Life Cycle Assessment (LCA) of each way of drinking was performed.

Neither BW nor TW have been objects of any Footprint integrated analysis to date. EF calculation is usually applied at a territorial level, in order to assess the sustainability of different life styles (*e.g.* Bagliani *et al.*, 2008; Moran *et al.* 2008; Erb, 2004; Folke, 1997). Notwithstanding, some applications on processes or products have been preformed (*e.g.* Wada, 1993; Van der Werf *et al.*, 2007; Niccolucci *et al.*, 2008; Cuandra and Björklund, 2007; Thomassen and de Boer, 2005; Kautsky *et al.*, 1997).

In most cases, WF is used to calculate the consumption of water in big systems, such as nations (e.g. Allan, 1998; Erb, 2004; Hoekstra and Chapagain, 2008). More recently WF have been applied to the evaluation of the water needs of single products, mostly food and agricultural products such as meat, maize, tea or cotton (e.g. Chapagain et al., 2007; Chapagain and Hoekstra, 2007; Chapagain and Orr, 2008). Anyway, no WF applications to tap water or bottled water have been performed until now. The use of WF in the present study is necessary in order to provide a better account of water consumption and withdrawal of the life cycle of the two alternative goods than EF. Furthermore, WF of tap or pet-bottled water is characterized by the fact that water is at the same time one of the raw material inputs and the final product.

The Footprint Integrated approach required also a better evaluation of the greenhouse gas emissions than EF. Carbon Footprint accounts for any emission in each step of a life cycle, in terms of CO_2 equivalent tons.

This paper is organized as follows. In Section 1 the case study and the methodology are presented. Results of Life Cycle Inventory and of Footprint Integrated approach are shown in Section 2. A discussion of the results follows in Section 3, with an evaluation of the environmental burden reduction chances of the two ways of drinking water.

1. MATERIALS AND METHODS

1.1. The case study

The sample consists in a set of PET-bottled mineral waters from six Italian companies. The set covers about 10% (by volume) of the Italian bottled water market. The companies were selected in order to provide a true sample of the Italian market. As shown in Table 1, companies differed in: i) location, ii) farm size (*i.e.* bottled volume per year), iii) diffusion on national territory.

Data refer to the plant where water is bottled and the name assigned to each company refer to the main brand (if more than one is available) packaged in the plant. Cerelia® (BW1) and Lurisia®(BW2) are small companies (8 ML/yr and 40 ML/yr of volume bottled per year, respectively), with a small scale distribution (less than 500 km wide). Nerea® (BW3) and Montecimone® (BW4) are examples of an average Italian company, with an annual production in the range between 50 ML/yr and 150 ML/yr. Their market is national and BW4 bottles, in particular, with the brand of one of the major Italian supermarket chains. Sangemini® (BW5) and Gaudianello® (BW6) are two of the biggest companies in the market, with a production rate of 300 ML/yr and 400 ML/yr respectively. Their market is nationwide even if BW6 has a major diffusion in the south of Italy. The set of these companies covers all the Italian territory: BW1 and BW2 are located in the north, BW3, BW4 and BW5 in the centre and BW6 is one of the major bottling water companies of the south of Italy.

Bottled water is a product with a natural substitute that is tap water. The one available in Siena municipality (Italy) was also analyzed. It comes from 10 sources and it is provided by the company named Acquedotto del Fiora S.p.A®. It is abducted by 110 km of pipes and distributed to the final users by a web of pipes whose total length is 220 km. In 2007, the 60,000 inhabitants of Siena required about 7 GL of water.

1.2. Data collection and inventory

BW life cycle was assumed to be composed by 4 steps:

- B1. extraction of water from the source and raw materials production;
- B2. PET preforms production and transportation to the bottling water plant;
- B3. bottling and packing processes;
- B4. distribution to supermarkets and from there to final users

Conversely, TW life cycle was divided in 4 steps:

- T1. extraction of water from sources
- T2. abduction trough pipes
- T3. water storage
- T4. distribution trough a web of pipes to the final users

Data on each step of the two life cycles were either primary data or secondary data. These were collected in a preliminary inventory. Also a transportation scenario was elaborated.

With respect to phases B3, T1, T2, T3 and T4, material and energy input flows were collected either by personal communications with each company (e.g. BW3, BW4, BW5 and TW) or by company's environmental declaration when available (e.g. BW1, BW2 and BW5). In this way, data on tap water were entirely primary data, while B3 was the only bottled water phase of which entirely primary data were available. Primary data refer to one year of production or supply. This enabled an allocation on the functional unit by simply dividing each input for the total number of produced bottles or the total amount of water piped.

Phases B1 and B2 required secondary data to be completely accounted. When company's environmental declarations were missing, material and energy flows were taken either from the literature or from specific databases (*e.g.* EDIP; CPM). No 'capital energy' inputs were accounted. Capital energy is the energy associated with buildings and machineries involved in all the production processes in the life cycles (Baldo et al., 2005). In general, this omission is not thought to introduce any significant error, and its contribution is usually less than 1% of the total system energy (Boustead and Hancock, 1979).

Tables 2 shows the mass and energy inventories per functional unit for the bottling phase of BW life cycle (B3) and phases T1, T2, T3 and T4 of TW life cycle. The "water content" is the same for all the companies, because it's the volume of water that is bottled or provided to the final user. The "processing water" is the sum of two components. In the case of BW, it is the sum of the water used in the process (*e.g.* bottles are washed before the filling process) and the water wasted. In the case of TW, it is the sum of the water wasted by the system (*e.g.* lost during the transportation in the pipes) and the volume of water that the final user lefts flowing from the tap before drinking (that is assumed to be 0.5 L). Some material flows such as PET, paper (corrugated cardboard), glue and wood are used in BW packaging (i.e. caps, bottles, labels, films, pallets). Others, such as steel, fiberglass, cast iron, PVC, HDPE and PP are used in pipes maintenance and so they are typical of the tap water providing life cycle. Sodium chlorite and hydrochloric acid are used in tap water disinfection. Electric energy is used into the bottling plants for the machinery needs and also into the tap water providing system, mainly for water pumping. Also thermal power needs of the two life cycles are considered. These needs are mainly due to offices and administrative buildings heating.

Pet-bottled water requires three transportation phases. Each one was provided with suitable assumptions on transportation medium, distance covered and fuel consumption:

1. pet-preforms and raw materials transportation from producing sites to bottling plant:
    - by trucks
    - average distance: 200 km;
    - average fuel consumption (diesel): 3 km/L;
2. packaged bottles transportation from bottling plant to stores:
    - by train (18%) and by trucks (82%) (http://www.cargo.trenitalia.it);
    - average distance: based on each company's market and plant location;
    - average trucks fuel consumption (diesel): 3 km/L;

3. packaged bottles (18 each time) transportation from stores to final user's site:
- by gasoline car (50%) or diesel car (50%);
- average distance: 10 km;
- average fuel consumption: 12 km/L (gasoline) and 15 km/L (diesel)

Values in Table 2 are in km per functional unit. Tap water doesn't require any transportation of these. Pipes provide water transportation from sources to final users.

1.3. The Footprint integrated methodology

The Footprint Integrated methodology is inspired by Life Cycle Thinking, so every step in the life cycle of the two ways of drinking water was accounted by Life Cycle Assessments (LCA).

LCA is an evaluation of the environmental impacts of a product, a process or an activity, by the identification and quantification of both material and energy input and output in the entire life cycle. (SETAC, 1999). A product or a process is analyzed *from cradle to grave*: from the raw materials extraction and production to the wastes treatment.

According to ISO standards 14040-44 (2006) a LCA is composed by four steps:

1. Goal and scope definition
2. *Life Cycle Inventory,* (LCI)
3. *Life Cycle Impact Assessment,* (LCIA)
4. Life Cycle Interpretation

For the requirements of a Footprint Integrated methodology, the LCA was limited to the Life Cycle Inventory (LCI), in order to collect data on each material and energy input and output in the two life cycles. These were also limited *from cradle to gate*, where the gate is actually the consumer's home. The final steps of the two life cycles (waste collection, disposal and treatment) were omitted.

The Ecological Footprint of a population is the *ecologically productive surface* that is actually necessary to both sustainably supply the population with any energy and matter resource and sustainably adsorb any waste or rejection (Wackernagel and Rees, 1996, Kitzes *et al.*, 2007). This surface is measured in global hectare (gha) (Monfreda *et al.*, 2004; Galli *et al.*, 2007). The EF of a product is defined as the sum of the EF due to all the activities needed to extract the raw materials, create the product, use it and treat the wastes. For the case study of the present analysis, EF is defined as follows:

$$EF = EF_{materials} + EF_{energy} + EF_{transportation} \qquad (1)$$

where:

- $EF_{materials}$ is the EF due to the production of any material involved in a life cycle (*e.g.* raw materials, packaging, pipes and chemicals production);
- EF_{energy} is the EF due to the production of each energy carrier;
- $EF_{transportation}$ is the EF of any transportation step.

Each input of the LCI was firstly converted in the corresponding *ecologically productive surface* (ha) and then normalized into *global hectare* (gha), using the right equivalence factors (Global Footprint Network, 2009).

Water Footprint accounts for the total water demand of an activity or a product, measured in L or m^3 (Hoekstra and Hung, 2002). This accounting method is based on the 'virtual water' concept as proposed by Allan (1998). The virtual water content (VWC) of a product or a commodity is defined by the volume of freshwater either directly or indirectly involved in the production chain, measured at the place where the product was actually produced (*i.e.* production-site definition, as proposed by Hoekstra and Chapagain, 2008). To date, few Water Footprints of goods have been performed (mainly food and agriculture products *e.g.* Hoekstra and Chapagain, 2008; Chapagain and Hoekstra, 2007; Chapagain et al., 2006). Their production requires different types of water in different life cycle phases. Water Footprint calculation is generally based on three components (blue, green and gray) and each one accounts for a different type of water (precipitations, irrigation and polluted water respectively). The particularity of the present study is that water is at the same time the resource and the product and that the latter requires different water components than an agriculture product.

For the reasons mentioned above, the WF calculation is here defined as the sum of the real (RWC) and virtual (VWC) water content, as follows:

$$\mathrm{WF} = \mathrm{RWC} + \mathrm{VWC} \qquad (2)$$

where RWC is the functional unit of 1.5 liters, while the VWC is assumed to be the sum of four components:

$$\mathrm{VWC} = \mathrm{VWC}_{\mathrm{materials}} + \mathrm{VWC}_{\mathrm{energy}} + \mathrm{VWC}_{\mathrm{processing}} + \mathrm{VWC}_{\mathrm{transportation}} \qquad (3)$$

The terms of eq. (3) are defined as follows:

- $\mathrm{VWC}_{\mathrm{materials}}$ is the sum of freshwater volumes used to produce any material involved in the life cycle (*e.g.* raw materials, packaging, pipes and chemicals production);
- $\mathrm{VWC}_{\mathrm{energy}}$ is the sum of freshwater volumes used for the production of each energy carrier;
- $\mathrm{VWC}_{\mathrm{processing}}$ is the volume of freshwater worn out, but not bottled (e.g. for BW, the volume wasted, lost, used in the production chain; for TW, the sum between the freshwater volume lost during its run up to the tap and the water volume assumed to be left flowing by the final user before drinking);
- $\mathrm{VWC}_{\mathrm{transportation}}$ is the sum of freshwater volumes used to produce each transport fuel.

According to King and Webber (2008), two scenarios were provided. The account for the total water amount related to a life cycle implies a distinction between water consumption and water withdrawal (UNEP/GRID-Arendal, 2008). Water consumption relates to the water that is taken from the environment to be used in a process and not returned to the source. Conversely, when water is taken from a source, used in a process and returned to the source, it is available again. Water withdrawal accounts for closed circles of these. The first scenario measures only the consumed water consumed, whereas the second one measures also the withdrawn water.

Specific coefficients were used to convert each input into the relative virtual water content. LCA database by Plastics Europe (2009, http://lca.plasticseurope.org/index.htm) was used to get data on water consumption and withdrawal in polymers production processes. LCI database by CPM (2009, http://www.cpm.chalmers.se/CPMDatabase/) provided coefficients to convert cast iron and steel. FEFCO 2006 European database (2009, http://fefco.org) provided data on paper and dashboard. The water needs of pallet (wood) production were taken from EDIP database (2009, http://lca-center.dk). Water consumption for electricity was estimated according to the Italian 2008 energy mix (2009, http://www.terna.it) and converted with coefficients provided by Gerbens-Leenes *et al.* (2008). Other fuels were converted using data from Hoekstra and Chapagain (2008). King and Webber (2008) provided coefficients to assess water consumption in gasoline and diesel production processes.

While EF accounts only for CO_2 emissions, Carbon Footprint includes also any other greenhouse gases. Even if the debate on the greenhouse gases emissions is today very popular, neither a unique definition of CF nor a standard methodology are available (Wiedmann and Minx, 2007). The present study adopt the following definition: CF is a measure of the impact that humans have on the environment in terms of greenhouse gases emissions during the entire life cycle of a product or a service. Each greenhouse gas is accounted, even if it does not have a carbon content, by considering its global warming potential or GWP, as provided by the Intergovernmental Panel on Climate Change (IPCC, 2009, http://ipcc.ch). This is a coefficient that considers both the life time of the molecule in the atmosphere and its greenhouse power. Each emission is then converted in CO_2 equivalent mass (kg CO_2 eq).

CF is calculated as the sum of three components, as is shown in the following:

$$\mathrm{CF} = \mathrm{CF}_{\mathrm{material}} + \mathrm{CF}_{\mathrm{energy}} + \mathrm{CF}_{\mathrm{transportation}} \; (4)$$

The terms of eq. (4) are defined as follows:

- $\mathrm{CF}_{\mathrm{material}}$ is the CF due to the production of any material involved in the life cycle (*e.g.* raw materials, packaging, pipes and chemicals);

- CF_{energy} is the CF due to the production of each energy carrier;
- $CF_{transportation}$ is the CF of each transportation step.

The calculation of CF made possible a new calculation of EF (EFCF).

2. RESULTS

2.1. Bottled water mass and energy inputs and outputs

Life Cycle Inventory results showed that BW_1 requires the major mass inputs among the set of companies analyzed The mass demand decrease as the dimensions of the company considered increase. The two smallest companies (BW1 and BW2) required a material input per functional unit in the range between 8.5 and 7 kg; the two mean companies (BW3 and BW4) required 6.25 kg and the two biggest companies required the minor mass inputs (5.5 kg and 4.5 kg respectively). The differences among the six producers can be explained in terms of scale economies and plant efficiency: with respect to small producers, the most mass input requiring processes are related to the bottling procedures, whereas bigger producers' mass needs are mostly related to the dimensions of their markets (*e.g.* diesel for transportation production processes).

Mass output trends were similar: the smaller the producer, the bigger the mass output values. BW1, BW2, BW3 and BW4 showed a mass output in the range between 8 and 7 kg per functional unit and the most relevant processes were again related to the plant functioning. BW5 and BW6 mass outputs were 6.5 and 5.5 kg respectively and the most relevant processes were the industrial water cooling ones (which include water cooling in the diesel for transportation production processes). Again, the differences among the producers can be explained in terms of plant and market dimensions.

Energy inputs and outputs decrease as the plant dimensions increase. Per functional unit, biggest plants require less energy than the smallest ones. Energy outputs are due to the incineration of wastes (mainly the incineration of the wastewater treatment by-products).

2.2. Tap water mass and energy inputs and outputs

The entire life cycle of tap water required, per functional unit, 6.79 kg of material inputs and 5.44 MJ of energy inputs, while output flows were 8.23 kg of materials and 1.63 MJ of energy. The latter is made possible, as described above, by the incineration of wastes. The most mass requiring process was the one connected to the water distribution (53.43%), which includes the total drawn water, the water lost during the distribution and the water left flowing by the final user before drinking (0.5 L). The sum of these components was 3.63 kg per functional unit. Accordingly, the most mass outputs contributing process were the water drawing at the source (43.64%; 3.63 kg) and the water distribution process (50.01% and 4.16 kg, mainly due to the drawn water and the chemicals used for water disinfection).

The energy balance showed that the energy inputs and outputs were mostly related to the process of wastes treatment (5.41 MJ and 1.63 MJ respectively). Other processes contributed with less than 1% either to energy inputs or outputs.

2.3. The Ecological Footprint of bottled water (EF_{BW})

As can be seen in Table 3, the average EF_{BW} value was (0,536 ± 0,061) $g\text{m}^2$, which was the result of the contribution of each term of eq.(1). The major contribution (88.4 %) was due to materials (mainly packaging), with 0.474 $g\text{m}^2$. The energy flows required a surface of 0.056 $g\text{m}^2$ (10.4 %), while the contribution of transportation to EF_{BW} was very low (1.2%), with 0.006 $g\text{m}^2$.

Among the materials, the major contribution came from primary packaging, i.e. those components which are directly in contact with drinking water, such as bottle and cap (respectively made of PET-polyethylene therephtalate and PP-polypropylene or HDPE-high density polyethylene, depending on producers' choices). Polymers represented about 90% of all BW packaging materials and had a remarkable EF, which contributed to the enhancing of $EF_{materials}$.

Among the producers, EF_{BW} was in invert proportion with bottled water volumes per year. Three ranges were observed: small producers (BW1 and BW2) with higher EF values (more than 0.6 gm^2); mean producers (BW3 and BW4) with a EF in the range between 0.5 and 0.6 gm^2; big producers (BW6 and BW5) with EF values lower than 0.5 gm^2. Differences were related to each term of eq. (1). Differences in $EF_{materials}$ were weaker and directly related to the differences in PET-bottles weight among the producers. $EF_{transportation}$ increased as producers sell their bottles in wider markets. The bigger the plant, the bigger the market, the longer the distance between the plant and the place where bottles were sold, the higher the $EF_{transportation}$ value. Anyway, EF_{energy} was the term of eq. (1) that was most influencing the differences among the producers and that make EF_{BW} to be in invert proportion to bottled water volumes per year. Scale economies enable more efficient energy usages (variable costs are usually in invert proportion with produced volumes) and enable the allocation of fixed costs among higher volumes of product. In this way, energy consumptions per functional unit are lower in bigger plants than smaller ones. Notwithstanding, higher volumes produced per year permit higher profits, that can be invested in advanced and more efficient technologies. In some cases, producers are well-aware of the opportunities that scale economies make possible. BW5 is not the bigger producer of the set, but it had the lower EF (0.469 gm^2). This excellence can be explained by the strong commitment of the company to best resource allocation and saving (as declared in the company's Environmental Declaration, 2008, http://www.sangemini.it).

Small producers showed higher EF, even if the distribution of their products is at a local scale (less than 500 km from the plant). In other words, $EF_{transportation}$, which was proportional to the volume of water bottled per year, was not enough to compensate EF_{energy}, which was in invert proportion to the volume of water bottled per year. From the Ecological Footprint point of view, the ideal market is made by few producers that bottle big volumes of water and sell them in a local monopolized market. The worst market is the one in which there are many small producers challenging in a national market.

2.4. Carbon Footprint (CF) and Ecological Footprint revision (EFCF) of bottled water

As shown in Table 4, the average CF_{BW} value was (0.26 ± 0.021) gm^2. The major contribution came from $CF_{materials}$ (0.198 CO_2 eq kg, 76% of CF_{BW}), which was mainly due to materials used in packaging. CF_{energy} followed (0.049 CO_2 eq kg, 18% of CF_{BW}), while $CF_{transportation}$ gave the weaker contribution (0.013 CO_2 eq kg, 6% of CF_{BW}).

Among the producers, higher CF_{BW} values were related with lower volumes of water bottled per year, even if the trend was not as evident as in the case of EF. No remarkable differences appeared between BW1 and BW6, the smallest and the biggest producers respectively. CF_{energy} was the only term of eq. (4) in respect of which there were some differences among the producers (0.058 CO_2 eq kg for BW1 and 0.033 CO_2 eq kg for BW6). These can be still explained in terms of scale economies as seen in the case of EF, but also in terms of latitude: BW1 plant is in the north of Italy, whose winter is usually colder and longer than the one of the south of Italy, where BW6 has his plant.

The calculation of CF made possible a recalculation of EF (EFCF), in order to provide EF with other greenhouse gases emissions than CO_2. Results are shown in TABLE 5. The average EFCF was (0.723 ± 0.058) gm^2 and the term of eq. (1) that undergone the major alteration was the transportation one, from 0.006 gm^2 to 0.036 gm^2. Anyway the contribution of $EFCF_{transportation}$ was still weak (5% of EFCF). Between EF and EFCF, the contribution of energy flows doubled, from 0.056 gm^2 to 0.137 gm^2 (19% of EFCF), while the increase of the packaging materials contribution was lower, from 0.475 gm^2 in EF to 0.551 gm^2 in EFCF and its relevance decreased from 88.4% (in EF) to 76% (in EFCF).

Among the producers, BW5 showed the lower EFCF value (0.662 gm^2), while BW2 showed the higher one (0.835 gm^2). Even if the highest value was not shown by the smallest producer (BW1) and the lowest value was not the one of the biggest producer (BW6), EFCF tended to decrease as the bottled volume per year increased. EFCF did not significantly subvert the EF ranking: even if some producers changed their position, the trend of EF in relation to plant dimensions was confirmed.

2.5. The Water Footprint (WF) of bottled water: consumption and withdrawal scenarios

The WF_{BW} results in the consumption scenario are shown in Table 6. The average WF_{BW} was (3.610 ± 0.251) L, which is the sum of the Virtual Water content (VWC) and the Real Water content (RWC), as stated in eq (2). The RWC was the same for all the producers (1.5 L), because it is the bottled volume. The VWC was 2.11 L and, as stated in eq (3), it is the sum of four terms: $VWC_{process}$ was 70% (1.468) of VWC; $VWC_{materials}$ was 17% (0.360 L); $VWC_{transportation}$ was 9% (0.197) and VWC_{energy} was 4% (0.085 L).

WF_{BW} showed a trend of invert relation with the volume of water bottled per year. Small producers (BW1 and BW2) had a higher WF; mean producers showed values that were similar to the average WF; BW5 and BW6 showed the lowest WF.

Among the producers, differences in $VWC_{transportation}$ can be explained by the different diffusion of each brand within the national market. The wider the diffusion, the higher $VWC_{transportation}$. Water needs in transportation were proportional to the distances that trains and trucks had to cover. No meaningful differences were found in $VWC_{packaging}$ and anyway they were directly related to the type of material used rather than to the bottled volumes. Companies choose different materials with different WF (e.g. LDPE instead of paper to make labels; PP or PE to make caps). Also bottles can be different in weight. A higher variability was observed in VWC_{energy}. In some cases differences among the producers can be explained in terms of different efficiency in the use of energy power. This efficiency is also related to scale economies, as in the case of EF_{BW}. In other cases, the geographical position of the plant can affect VWC_{energy}, because it affects the choice of the thermal power vector (e.g. LPG or diesel instead of methane). In $VWC_{process}$ the major differences resulted. Processing relates to a set of activities which take place in the bottling plant. These activities require water consumption (e.g. water employed to wash the bottles before filling and corking them) and a water loss. The water lost or wasted is a key point and it strongly depends on technical and marketing choices by the company. A higher number of bottle-size changes in the bottling phase involved more losses (this is the case for BW1). Nevertheless, strong differences were observed in presence of similar marketing choices but different plant sizes. An evident correlation was found between plant size and water losses: the bigger the company the lower the water losses. This correlation can be explained in terms of scale economies.

The WF_{BW} results in the second scenario, which accounts also for water withdrawal, are shown in Table 7. If compared to the first scenario, WF_{BW} more than doubled, increasing from 3.61 L to 8.14 L. Among the terms of eq (3), only $VWC_{process}$ did not increase if compared to the first scenario. This is due to the fact that the first scenario already accounted for the closed water circuits that are used for cooling the bottling machines. Instead $VWC_{materials}$, VWC_{energy} and $VWC_{transportation}$ remarkably increased. For it is essentially made of polymers, whose production requires a lot of cooling water, $VWC_{materials}$ affected WF_{BW} more than $VWC_{process}$ (43% of VWC and 36% of WF_{BW}). VWC_{energy} increased almost 12 times if compared to the first scenario, from 0.088 L to 1 L per functional unit (15% of VWC and 12% of WF_{BW}). These results were strongly related to the Italian national energy production mix. Also $VWC_{transportation}$ increased, from 0.197 L to 1.27 L (16% of WF_{BW}).

Among the producers, some novelties arose from the calculation of the second scenario. BW2 showed the highest value (8.37 L) while BW6 showed the lowest one (7.81 L). BW1 had the highest WF in the consumption scenario, and a lower WF than the average one in the withdrawal scenario. $VWC_{process}$ was the term that made BW1 the producer with the highest WF value in the first scenario. In the withdrawal scenario, $VWC_{process}$ did not change, while the other terms increased. Since BW1 is a less energy and transportation intensive company, his WF increased less than the other producers.

2.6. The Carbon Footprint of tap water (CF_{TW})

As presented in Table 4, the Carbon Footprint of tap water was 9.10E-04 CO_2 eq kg. CF_{energy} was the term of eq (4) that mostly affected CF_{TW} (97.19%). The production of electricity was the most CF_{energy} influencing component (95.93%), while the other components had a marginal role (e.g. diesel and LPG production processes). $CF_{materials}$ was 2.8% of CF_{TW}. The other flows were insignificant.

2.7. The Ecological Footprint of tap water ($EFCF_{TW}$)

The Ecological Footprint of tap water was directly calculated on the basis of the CF_{TW} results. In this way, as shown in Table 5, the EFCF of tap water was 2.40E-03 *g*m^2. $EFCF_{energy}$ was the most influencing term (97.05%). The electrical component was the main one and it reached almost 100% of $EFCF_{energy}$.

$EFCF_{materials}$ was 2.95% of the entire $EFCF_{TW}$. The main components of $EFCF_{material}$ were again steel (65.77%) and cast iron (30.98%), that are used in the maintenance of pipes.

2.8. The Water Footprint of tap water (WF_{TW}): consumption and withdrawal scenarios

The Water Footprint of tap water was 3.63 L if only water consumption was accounted (Table 6). The RWC was 41% and the VWC was 59%. The water used in the process of water providing (2.14 L) was the major contributor to VWC. It is the sum of two parts: the amount of resource lost by the aqueduct (1.64 l) and the water the final user lets flowing before drinking (0.5 L).

When also water withdrawal was accounted, the WF_{TW} resulted 3.65 L (Table 7). No meaningful differences arose between the two scenarios and also the role of each single component was anyway invariant. This is due to the fact that water withdrawal was more relevant in those processes (energy, transport and materials) with a low relevance to tap water. (e.g. WF_{energy} increased 10 times, but its contribution to WF_{TW} remained under 0.8%)

3. DISCUSSION

3.1. Comparing the results of the Footprint Integrated approach

Tap water showed lower values than bottled water in Carbon Footprint and Ecological Footprint (in both EF and EFCF forms). The Water Footprint values were instead quite similar in the water consumption scenario. More different values were found in the water withdrawal scenario.

CF_{TW} was almost 285 times lower than CF_{BW}. This means that per functional unit of 1.5 L, drinking tap water in Siena enables to avoid 259 CO_2 eq g of greenhouse gases emissions. The first difference between tap water and bottled water was the absence of the term $CF_{transportation}$ in tap water. This absence means 12.9 CO_2 eq g of greenhouse gas emissions saved. The difference of the two $CF_{materials}$ terms was remarkable: the materials used in the life cycle of tap water caused a total greenhouse gas emission that was almost 7700 times lower than the emission caused by the materials used in the life cycle of bottled water. Tap water does not require a packaging and his material needs are only due to pipes maintenance and water disinfection. This difference means that per functional unit almost 198 CO_2 eq g are not emitted if tap water instead of bottled water is drunk. Minor differences were found in the comparison between the two CF_{energy} terms. The average bottled water had a 55 times lower CF_{energy} than the tap water provided to Siena municipality. In terms of avoided emissions, this difference is about 48 CO_2 eq g.

From the Ecological Footprint (EFCF) point of view, drinking tap water may also permit an ecologically productive surface saving, with a difference of 0.72 *g*m^2 per functional unit with respect to bottled water. The latter, and all the processes that involves, required a 300 times wider surface. As in the case of Carbon Footprint, the first difference was the absence of $EFCF_{transportation}$ term in $EFCF_{TW}$. This absence may drive to a reduction of ecologically productive surface of 0.04 *g*m^2. Again, the difference between $EFCF_{materials}$ was significant. The materials flows needed by tap water required a 7750 times narrower surface than the material flows in the life cycle of bottled water (with an average surface requirement reduction of 0.55 *g*m^2). Differences in $EFCF_{energy}$ were not so evident (tap water was almost 60 times lower than bottled water). Anyway tap water required 0.13 *g*m^2 less than bottled water if energetic needs were considered.

The comparison between tap water and bottled water from the Water Footprint point of view showed that the two values were almost analogous (3.63 L and 3.61 L respectively) if only water consumption was considered. The RWC was obviously the same, since it is the volume of water that is furnished to the final user. Both results were heavily influenced by $VWC_{process}$, but for tap water this influence was stronger (2.12

L and 58.7%) than for bottled water (1.46 L and 40.44%). This means that the other VWC terms had a stronger influence to WF_{BW} than to WF_{TW}. Again, the absence of the transportation term in tap water led to a footprint saving of 0.197 L per functional unit. This saving and all the other savings enabled by the differences in $VWC_{materials}$ and VWC_{energy}, were all absorbed by $VWC_{process}$ term, which was higher in tap water than in bottled water. $VWC_{materials}$ in WF_{TW} was almost 45,000 times higher than in WF_{BW} (with a saving of 0.36 L per functional unit). Minor differences were found in the comparison of the two VWC_{energy} values. The energy flows needed by tap water required a 36 times lower water consumption than bottled water. This means a saving of 0.08 L per functional unit.

In the withdrawal scenario some important novelties arose. WF_{BW} more than doubled his value while WF_{TW} remained almost the same. This means that drinking tap water may lead to save about 4.5 L per functional unit. Tap water was not very influenced by the transition between the two scenarios, essentially because its $VWC_{materials}$ $VWC_{transportation}$ and VWC_{energy} terms were very low if compared to bottled water. These terms were the ones that mostly affected the increasing of WF_{BW} between the two scenarios, because they were made of withdrawn water intensive processes.

Differences between tap water and bottled water in terms of Ecological Footprint and Carbon Footprint were remarkable, while Water Footprint values were almost the same. Next paragraph will be dedicated to discuss in deep the latter indicator and the chances of its reduction for the two ways of drinking water.

3.2. Water Footprint reduction chances

The Water Footprint of the tap water provided to the municipality of Siena was similar to the one of a bottle of water produced by a mean company (e.g. BW3 or BW4). Differences appeared only comparing single terms of eq (3). $VWC_{process}$ term of tap water was higher than $VWC_{process}$ of bottled water. Nevertheless, tap water had lower $VWC_{materials}$, VWC_{energy} and $VWC_{transportation}$ values. These terms compensated $VWC_{process}$ and the final result was the same of the average bottled water.

Water Footprint is a very important indicator in the present analysis, because it allows the calculation of the volume of water that is consumed (or withdrawn) in order to provide a certain volume of drinking water to the final consumer. There is a substantial equivalence between the provided resource and the resource that is mainly required in the life cycle of the first. This is an exceptional case among all the consumer goods and it is so obvious that it is often overlooked. Only Water Footprint makes this exceptionality clear and manifest.

It was also peculiar that the results of such a significant indicator were so similar. Nevertheless, an important dissimilarity should be noticed. The term $VWC_{process}$ is the most relevant to the Water Footprint of TW, but it is also the most reducible. It is made of two components: the water lost in piping and the water that the final user lets flow from the tap before drinking. The second component has been an assumption of the model and it can be omitted in a different consuming scenario or in presence of more responsible consumers. On the other hand, TW providers are committed to water losses reducing. In the municipality of Siena, these losses are estimated by the provider in 52% of the total volume taken from the environment. This value is quite typical for all Italian aqueducts as the average Italian value is 40% (Co.Vi.Ri, 2003). In order to reduce $VWC_{process}$ of tap water, as provided for Italian law (D.M. 08/01/1997, n°99), an accurate maintenance of pipes and other structures (e.g. pumps and tanks) in the supply system and an accurate monitoring system are strongly required. Losses would be easily reduced from 52% to 25%. If the losses in the aqueduct could be reduced from 52% to 25% and if consumers were more responsible, total life cycle losses would be 0.50 L, instead of 1.6 L.

Conversely, losses in BW life cycle are not so easy to reduce. $VWC_{process}$ is the sum of two parts: the water lost and the water used in the bottling chain. Among the analyzed companies, BW5 has been committed to material and energy saving practices for several years. Although it has reached some important goals (Sangemini SpA, 2008) its $VWC_{process}$ is 1.29 L, which is less than the average value but more than BW6, which does not declare any saving policy. Beyond a certain level, further savings seem to depend on other factors than on saving strategies. These factors may be the scale economies that can be achieved with bigger plant (and company) sizes. Assuming that BW6 could reduce it to 90%, its $VWC_{processing}$ would be 0.9 L.

If the targets mentioned above were reached, the Water Footprint of TW and of BW6 would be 2 L and 3.07 respectively. In other words, the first would be 33% lower than the second, allowing 1 L of water to be saved per functional unit. So a quite significant difference can be achieved in terms of VWC. This difference is even bigger in the withdrawal scenario, which affects more bottled than tap water. Under the same hypothesis mentioned above, tap water would show a VWC of 2.1 L while the one of BW6 would be 7.6 L.

Water consumption savings in TW are made possible by the fact that the entire life cycle takes place in the same company, which can supervise every single process that is implemented and every single L of water that is used. In BW life cycle, many companies are involved. This means that the bottling company can supervise and monitor only the processes and the material and energy usages that take place under its control. In this way, the different nature of the two life cycles has some consequences on the allocation of the responsibility to reduce the consumption of resources. In tap water life cycle all the responsibility belongs to the same company, while in PET-bottled life cycle the bottling company shares the responsibility with other companies.

The other bottled water VWC terms (energy, materials and transports) are not easy to reduce, because they do not depend only on bottling company strategies. Nevertheless, a water use reduction policy can be the use of materials whose production is less water intensive. At the present in Italy two materials are used in water packaging: PET (70%) and glass (30%) (Beverfood, 2008). The first is mainly addressed to supermarkets and food shops while the latter is sold in restaurants and cafes. Nevertheless, in the last years new materials such as bioplastics (*e.g.* PLA) were presented. Bottling companies state the environmentally friendliness of these materials. The kind as well as the weight of the materials used for packaging is a marketing issue due to company choices rather than to external factors.

PET, PLA and glass were compared on the basis on Ecological Footprint (EFCF), Water Footprint (withdrawal scenario) and Carbon Footprint. The withdrawal scenario in Water Footprint was the only one, because of the kind of data available on the life cycle of PLA (Vink *et al.,* 2002). Results, regarding 1 kg of product, are shown in Table 8. PLA has lower values than PET, but glass is the best material on the basis of the three indicators. PLA (5.05 $g\mathrm{m}^2$) requires less than half the ecologically productive surface that PET requires (13.11 $g\mathrm{m}^2$). Conversely, PLA requires a surface that is approximately twice the surface of glass (2.15 $g\mathrm{m}^2$). CF results reflect the same trend: PLA may permit to save 2.9 CO2 eq. kg with respect to PET, per 1 kg of product. Anyway glass greenhouse gases emissions are half the emissions caused by the life cycle of PLA. The latter shows a WF value of 58.67 L per 1 kg of product, which is the sum of the material (50 L) and the energetic (8.67 L) components. PET production requires 82.73 L of water, which is the sum of 16.63 L for the energy production and 66.1 L for the material production. Definitely lower is the water withdrawal required by the production of 1 kg of glass: 26.33 L.

On the basis of the Footprint Integrated approach, glass is the best material among the three. Although bottling companies already use them, glass bottles are mainly addressed to restaurants and cafes and are rare in supermarkets or food shops. 70% of the Italian mineral water production is in PET and almost all the production that is sold in supermarkets or food shops is in PET (Beverfood, 2009). That is, almost all the mineral water drinking families buy PET-bottled mineral water. Since the 1980's glass has been almost totally substituted by polymers, whose use and transportation costs are undeniably lower. That is why glass use is not expected to grow in next years.

The comparison between PET and PLA shows that the latter would be a good substitute of the first. From the Water Footprint point of view, the improvement would be strong, with 24 L of water saved per 1 kg of material produced and 0.86 L per bottle. Anyway there are still some problems with PLA in terms of producing costs and material treatment. Furthermore, there may be some ethic doubts on the use of food crops (*e.g.* maize) to make non-food products such as bioplastics in a context of global hunger.

4. CONCLUSIONS

The confrontation based on a Footprint Integrate methodology between a set of Italian bottled waters and the tap water provided to the municipality of Siena (Italy) showed remarkable differences in Carbon Footprint and Ecological Footprint. Tap water values were about 300 times lower than the average bottled water. Also the recalculation of Ecological Footprint that accounted greenhouse gas emissions other than carbon dioxide, based on Carbon Footprint results, confirmed the same trend. Drinking 1.5 L of tap water in Siena enables to prevent the emission of 259 CO_2 eq g of greenhouse gases and to reduce the use of ecologically productive surface of 0.72 $g\mathrm{m}^2$ with respect to an average bottle of mineral water.

Water Footprint values, when only water consumption was accounted, were instead almost analogous. Tap water has quite the same Water Footprint of an average Italian company, which bottles between 50 and 150 ML per year. This result was unexpected because water consumption in bottled water life cycle was taught to be extremely lower than tap water one. The inefficiency of Italian tap water providing systems is well known and this was expected to cause higher Water Footprint values than bottled water. The novelty of the present study is undoubtedly the demonstration that bottling 1.5 L of water requires the consumption of about 2.11 L of water that will not be available to the consumer. This volume is mainly needed by bottling operations and processes, but also the packaging and the transportation phases play a significant role. Bottling companies declare an average 0.1 L of process water per 1 L bottled. The present study has shown that this value is underestimated. Actually, it is 10 times higher, if an average company is considered. In the water withdrawal scenario this value is even higher. The Water Footprint of bottled water increases from 3.61 L to 8.14 L while the tap water one remains approximately the same (3.65 L).

Furthermore, the Water Footprint of tap water is more reducible than the one of bottled water. This is because the entire life cycle of tap water is controlled by the same company, while bottling companies manage only one phase on four of the life cycle of bottled water. Also, in order to reduce the water losses, bottling companies have to well organize their production and this is possible only in presence of scale economies, i.e. if the bottled volume per year is big enough, even if a certain level of losses reduction is reachable by monitoring the production chain and making the suitable changes if needed. Packaging requires also high water consumption levels. The substitution of PET with PLA (or other bioplastics) to make bottles is still to come. Some problems in the life cycle of PLA as a bottle are still not solved. Nonetheless, the comparison between PET and PLA showed that PLA enables the reduction of 0.86 L of water consumption per bottle produced. Anyway, in general water losses are not felt as a problem to face by bottling companies, with some exceptions (e.g. BW5). Instead, Italian tap water systems inefficiency is well known. The reduction of losses requires big investments but a well organized maintenance and monitoring system could be a helpful and not so expensive way to start preventing losses. This is what the Italian law on this issue prescribes.

The Water Footprint of tap water could be easily reduced to 2 L, while the biggest company among the set of analyzed could reduce it to 3.07 L. So a considerable difference can be achieved in terms of virtual water content. This difference is even bigger if also water withdrawal is considered, whose account affects more bottled (7.6 L as minimum) than tap water (2.1 L).

The use of a Footprint Integrated methodology in order to compare tap water and bottled water led to observe strong differences in Carbon Footprint and Ecological Footprint in favor of tap water. Also drinking tap water is recommended from the Water Footprint point of view, even if results are very similar (especially when only water consumption is accounted): tap water seemed to be able to better reduce its Water Footprint than bottled water.

Next step on this research path would be the increasing of the number of tap water providing companies considered, in order to verify the data provided by the tap water company analyzed here. A tap water provider committed to losses prevention (for some years) would be extremely important to compare with.

Also a direct knowledge of transportation practices in bottled water life cycle would be very useful. In the transportation scenario adopted by the present analysis, distances were calculated as the shortest highway path from the plant to a certain supermarket. Actually, these paths are not so direct. Bottling companies (and bigger ones in particular) use logistics hubs to stock their production (Dallari and Market, 2005). Even if these hubs are localized in strategic places, the way from the plant to the supermarket is surely longer than the one hypothesized here. This means that the role of the transportation term in every Footprint indicator is expected to increase. The present analysis tells that the bigger the volume of water bottled per year, the lower the Footprint values. Bigger bottling companies have also wider markets, which imply longer distances to be covered. A different transportation scenario, that may account the material and energy inputs and outputs of those complex logistic systems, might provide different results.

The life cycle of the two ways of drinking water was also limited *from cradle to gate*, where the gate is actually the consumer's home. The final steps of the two life cycles (waste collection, disposal and treatment) were omitted. In Italy companies are still not allowed to recycle PET bottles to make new PET preforms (and then new PET bottles), but law is expected to change in conformity with other European countries. So the final steps of bottled water life cycle can be included in order to verify Footprint reduction chances. Also different waste treatment technologies can be compared by using the Footprint Integrated methodology.

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EPD. Environmental Product Declaration. http://www.environdec.com

FEFCO. European Federation of Corrugated Board Manufacturers. http://www.fefco.org

Ga.Bi. http://www.gabi-software.com

Monticchio Gaudianello SpA. http://www.gaudianellomonticchio.it

Nerea SpA. http://www.acquanerea.com

IPCC. Intergovernmental Panel on Climate Change. http://www.ipcc.ch

Istituto Nazionale di Statistica. http://www.istat.it

LCA Center Denmark. http://www.lca-center.dk

Plastics Europe. Association of Plastics Manufacturers. http://www.plasticseurope.org

Regione Toscana. http://www.regione.toscana.it

Sangemini SpA. http://www.sangemini.it

TERNA. Rete Elettrica Nazionale SpA. http://www.terna.it

United Nations Environmental Programme. UNEP/GRID-Arendal. http://grida.no

TABLES

Table 1: The sample of six Italian bottling companies

COMPANY (MAIN BRAND NAME)	**ACRONYM**	**PLANT LOCATION**	**BOTTLED VOLUME PER YEAR**	**MARKET**
Cerelia®	BW1	North Italy	8 ML	Macro-regional
Lurisia®	BW2	North Italy	40 ML	Macro-regional
Nerea®	BW3	Centre Italy	50 ML	National
Montecimone®	BW4	Centre Italy	150 ML	National
Sangemini®	BW5	Centre Italy	300 ML	National
Gaudianello®	BW6	South Italy	400 ML	National (Southern Italy)

Table 2: Inventory of the primary Material and Energy inputs of the six bottled water companies and the tap water company (values are per functional unit of 1.5 L; NA = not available)

	unit	**BW1**	**BW2**	**BW3**	**BW4**	**BW5**	**BW6**	**TW**
Material flows								
Water content (functional unit)	L	1.500	1.500	1.500	1.500	1.500	1.500	1.500
Water (processing)	L	1.880	1.690	1.468	1.290	1.015	1.468	2.130
PET	kg	3.70E-02	3.70E-02	3.88E-02	3.52E-02	2.74E-02	3.79E-02	NA
PP	kg	2.50E-03	2.74E-03	2.71E-03	1.83E-03	5.15E-04	NA	1.83E-09
HDPE/LDPE	kg	4.17E-03	5.36E-03	4.64E-03	5.83E-03	3.31E-02	9.40E-03	2.03E-09
Steel	kg	NA	NA	NA	NA	NA	NA	5.83E-06
Glass fiber	kg	NA	NA	NA	NA	NA	NA	1.03E-08
PVC	kg	NA	NA	NA	NA	NA	NA	3.55E-09
Cast iron	kg	NA	NA	NA	NA	NA	NA	3.21E-06
Hydrochloric acid	kg	NA	NA	NA	NA	NA	NA	5.37E-07
Sodium chlorite	kg	NA	NA	NA	NA	NA	NA	4.29E-07
Corrugated cardboard	kg	4.12E-03	3.10E-03	3.83E-03	3.10E-03	7.46E-03	3.10E-03	NA
Glue	kg	3.00E-04	2.59E-05	5.51E-05	0.00E+00	0.00E+00	0.00E+00	NA
Wood (pallet's waste)	kg	6.35E-04	4.40E-04	3.50E-04	3.42E-04	3.34E-04	4.40E-04	NA
Lubricating oil	kg	2.80E-06	5.29E-05	NA	NA	NA	NA	NA
Additives (O_3, O_2, CO_2, N)	kg	6.47E-03	4.29E-03	4.20E-03	5.94E-03	4.49E-03	4.97E-03	NA
Energy flows								
Electric power	kWh	4.33E-02	6.94E-02	6.26E-02	7.73E-02	5.28E-02	7.11E-02	1.75E-03
Gas	kg	1.02E-02	1.80E-02	1.17E-03	5.23E-04	0.00E+00	1.00E-03	3.98E-08
Fuel oil	kg	6.59E-04	5.36E-06	NA	NA	2.04E-03	NA	8.84E-06
Transport processes								
PET preforms (by trucks)	km	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	2.00E+02	NA
Bottled waters (by trucks: 82%)	km	1.18E+02	1.41E+02	4.05E+02	3.52E+02	4.07E+02	3.80E+02	NA
Bottled waters (by rail: 18%)	km	2.59E+01	3.10E+01	8.88E+01	7.74E+01	8.93E+01	8.33E+01	NA
To consumers (by diesel cars: 50%)	km	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5.00E+00	NA
To consumers (by gasoline cars: 50%)	km	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5.00E+00	5.00E+00	NA

Table 3: EF results for bottled and tap waters per EF terms (values in *g*m² per functional unit)

ECOLOGICAL FOOTPRINT (EF)							
	BW1	**BW2**	**BW3**	**BW4**	**BW5**	**BW6**	**average BW**
Transportation	2,81E-03	3,23E-03	7,46E-03	7,91E-03	6,98E-03	7,94E-03	6,05E-03
Materials	4,70E-01	4,72E-01	4,86E-01	4,90E-01	4,48E-01	4,84E-01	4,75E-01
Energy	1,39E-01	1,44E-01	1,70E-02	1,24E-02	1,42E-02	7,03E-03	5,56E-02
total	**6,13E-01**	**6,19E-01**	**5,11E-01**	**5,10E-01**	**4,69E-01**	**4,99E-01**	**5,37E-01**

Table 4: CF results for bottled and tap waters per CF terms (values in CO_2 eq kg per functional unit)

CARBON FOOTPRINT (CF)								
	BW1	**BW2**	**BW3**	**BW4**	**BW5**	**BW6**	**average BW**	**TW**
Transportation	1,16E-02	1,18E-02	1,34E-02	1,36E-02	1,32E-02	1,36E-02	1,29E-02	0,00E+00
Materials	1,94E-01	1,95E-01	2,02E-01	2,03E-01	1,86E-01	2,10E-01	1,98E-01	2,56E-05
Energy	5,76E-02	9,36E-02	3,78E-02	3,43E-02	3,92E-02	3,34E-02	4,93E-02	8,85E-04
TOT	**2,63E-01**	**3,00E-01**	**2,53E-01**	**2,51E-01**	**2,38E-01**	**2,57E-01**	**2,60E-01**	**9,10E-04**

Table 5: EFCF results for bottled and tap waters per EFCF terms (values in *g*m^2 per functional unit)

ECOLOGICAL FOOTPRINT (EFCF)								
	BW1	**BW2**	**BW3**	**BW4**	**BW5**	**BW6**	**average BW**	**TW**
Transportation	3,22E-02	3,27E-02	3,76E-02	3,71E-02	3,66E-02	3,77E-02	3,57E-02	0,00E+00
Materials	5,39E-01	5,42E-01	5,64E-01	5,61E-01	5,16E-01	5,83E-01	5,51E-01	7,10E-05
Energy	1,60E-01	2,60E-01	9,50E-02	1,05E-01	1,09E-01	9,27E-02	1,37E-01	2,33E-03
TOT	**7,31E-01**	**8,35E-01**	**6,97E-01**	**7,03E-01**	**6,62E-01**	**7,13E-01**	**7,23E-01**	**2,40E-03**

Table 6: WF of bottled and tap waters (consumption scenario) results (values in L per functional unit)

WATER FOOTPRINT (CONSUMPTION)									
		BW1	**BW2**	**BW3**	**BW4**	**BW5**	**BW6**	**average BW**	**TW**
VWC	Transportation	1,90E-01	1,91E-01	2,01E-01	2,02E-01	1,99E-01	2,02E-01	1,97E-01	0.00E+00
	Materials	3,51E-01	3,22E-01	3,27E-01	3,52E-01	3,10E-01	4,99E-01	3,60E-01	8.10E-06
	Energy	5,93E-02	9,24E-02	9,46E-02	8,47E-02	1,03E-01	7,51E-02	8,48E-02	2.35E-03
	Process	1,88E+00	1,69E+00	1,47E+00	1,47E+00	1,29E+00	1,01E+00	1,47E+00	2.13E+00
RWC	Bottled/provided	1,50E+00	1,50E+00	1,50E+00	1,50E+00	1,50E+00	1,50E+00	1,50E+00	1.50E+00
	TOT	**3,98E+00**	**3,79E+00**	**3,59E+00**	**3,61E+00**	**3,40E+00**	**3,29E+00**	**3,61E+00**	**3.63E+00**

Table 7: WF of bottled and tap waters (withdrawal scenario) results (values in L per functional unit)

WATER FOOTPRINT (WITHDRAWAL)									
		BW1	**BW2**	**BW3**	**BW4**	**BW5**	**BW6**	**average BW**	**TW**
VWC	Transportation	1,23E+00	1,23E+00	1,29E+00	1,30E+00	1,29E+00	1,30E+00	1,27E+00	0.00E+00
	Materials	2,82E+00	2,84E+00	2,91E+00	2,96E+00	2,70E+00	3,15E+00	2,90E+00	2.46E-03
	Energy	7,02E-01	1,11E+00	1,14E+00	1,00E+00	1,23E+00	8,48E-01	1,00E+00	2.80E-02
	Process	1,88E+00	1,69E+00	1,47E+00	1,47E+00	1,29E+00	1,01E+00	1,47E+00	2.12E+00
RWC	Bottled/provided	1,50E+00	1,50E+00	1,50E+00	1,50E+00	1,50E+00	1,50E+00	1,50E+00	1.50E+00
	TOT	**8,13E+00**	**8,37E+00**	**8,31E+00**	**8,23E+00**	**8,01E+00**	**7,81E+00**	**8,14E+00**	**3.65E+00**

Table 8. Ecological Footprint, Water Footprint and Carbon Footprint of PLA, PET and glass (functional unit: 1 kg of final product)

		EF_{CF} (gm2)	**WF_C (L)**	**CF (kg CO2 eq)**
PLA	gross energy requirement	-	8,67E+00	-
	global water requirement	5,13E-02	5,00E+01	-
	carbon footprint	4,99E+00	-	1,80E+00
	TOT	**5,05E+00**	**5,87E+01**	**1,80E+00**
PET	gross energy requirement	-	1,66E+01	-
	global water requirement	6,79E-02	6,61E+01	-
	carbon footprint	1,30E+01	-	4,70E+00
	TOT	**1,31E+01**	**8,27E+01**	**4,70E+00**
GLASS	gross energy requirement	-	1,64E+01	-
	global water requirement	1,02E-02	9,91E+00	-
	carbon footprint	2,14E+00	-	7,73E-01
	TOT	**2,15E+00**	**2,63E+01**	**7,73E-01**