Water footprint in milk agrifood chain in the subhumid and semiarid central region of Argentina

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Abstract

The high agricultural process of the Argentine humid pampas forces the intensification and relocation of cattle and dairy systems into subhumid and semiarid region to keep their competitiveness. In consequence, there is an increasing water demand scenario in these fragile areas in relation with this productive transformation process. Water footprints of UHT milk and cheese agrifood chain in La Pampa and San Luis provinces have been assessed using Life Cycle Assessment (LCA) methodology, including virtual water indicators. Milk chain of La Pampa presents high self-sufficiency water ratio and high primary production proportion in virtual water exports. Water footprint of San Luis milk chain is highly externalized with a low self-sufficiency water ratio.

Keywords: Life Cycle Assessment, Milk Agrifood Chain and Virtual Water

I. Introduction

The high agricultural process of the Argentine humid Pampas forces the intensification and relocation of cattle and dairy systems into subhumid and semiarid region to keep to their competitiveness. In consequence, there is an increasing water demand scenario in these fragile areas in relation with this productive transformation process.

For the period 1994-2007 the surface implanted with agricultural farming was duplicated at national level, reaching 22.8 million hectares (70% correspond to soybean) (SIIA, 2011). In the humid *"Pampas"*, this increase has occurred at the cost of land dedicated to the cattle ranch, which lost 8.8 million hectares but only 3 million heads were moved towards other regions of the country: 60% towards the northwest and 30% towards La Pampa and San Luis provinces (Rearte, 2007). Outside the "Pampa" region the agricultural surface has also increased at the cost of the clearing of native ecosystems (Cepal, 2005).

In general terms, San Luis and La Pampa provinces are inserted in the semiarid and sub humid region, where the high agricultural process relocates and increases the livestock stock in the cattle regions. Milk activity in both provinces has also been intensified in this process.

In La Pampa province the number of dairy farms grew by 15% during that period, with the consequent increase in milk production, reaching 140 million liter/year and reinforcing the expansive tendency of the activity (Iturrioz and Iglesias, 2009). It is remarkable that 16% of the dairy farms concentrate 55% of the provincial production and five mega dairy farms centralize more than 30% of it.

Although in San Luis the milk activity does not have still a significant dimension, it stands out the existence of two mega dairy farms in zones under irrigation. With 2,450 cows and a daily production of 43 thousand liters; both concentrate the 50% of the provincial production and reveal the potentialities that present those zones with underground water reserves for the development of highly intensified production systems (Manazza, 2009).

Particularly in semiarid zones the intensification processes are developed on the basis of water resources, being significant the incorporation of new surfaces with irrigation from superficial and underground sources. Only in San Luis province, the surface under irrigation by center pivot go from 14,940 has in 2002 to 33,216 has at the present time (Saenz et al., 2011).

Sustainability indicators of farming production in this region have been developed by Viglizzo *et al.* (2006). Different ecological footprints related to the sustainability of the agriculture expansion in the Pampas region were studied by Viglizzo *et al*. (2010). The use of water in milking processes of dairies in La Pampa province has been evaluated by Felice (2009). Nevertheless, the interactions between the productive activities related to the use of water resource throughout the entire life cycle of farming products (agrifood chain approach) have not been studied in this region.

The perspective of a developing new milk area in the semiarid zone with intensive use of water resource, and the greater pressures that exert the processes of intensification of the milk systems on this resource, motivate the election of this agrifood chain as a case of study.

A vision of supply chain is necessary for the assessment of environmental impacts of a product and the criteria of eco-efficiency must contemplate all the productive linkages that constitute the different phases of the products, from the primary production to the final consumption. Between the methodologies of environmental impact assessment, the Life Cycle Assessment (LCA) is the most commonly used (Mattsson and Sonesson, 2003). It is explicitly contemplated by the ISO 14040:2006, that provide international homologation (ISO, 2006), and it is a consistent tool to determine the eco-efficiency of systems (Van der Werf and Petit, 2002).

There are several LCA studies on dairy chains that focus on the assessment of the potential improvement of their environmental performance, analyzing the sensitivity of impact indicators such as: energy use, emissions of greenhouse gases, acidification, eutrophication, photo-oxidants and ecotoxicity. Eide (2002) compare different plant sizes, degree of automation and transport distances; Basset-Mens *et al*. (2009) assess different intensification scenarios of dairy systems and Hospido *et al.* (2003) alternative processes of milk production. Overall, the primary production of milk, specifically the agricultural phase, followed by the packaging, is identified as critical in the environmental impact of life cycle of milk[1].

Recently, the LCA methodology was used by FAO (2010) to develop estimates of Green House Gases emissions associated with milk production and processing of most regions and production systems in the world.

There is a vast inventory of water footprints of crops and animal products for many countries, including milk products of Argentina (Chapagain and Hoekstra, 2003; Mekonnen and Hoekstra, 2010). The first inventories were built with the aim of determine the volumes of virtual water flows from international trade in agricultural products (Hoekstra and Hung, 2002), animals (Chapagain and Hoekstra, 2003), and the analysis of water footprints of nations (Chapagain and Hoekstra, 2004).

Several papers of water footprint literature are focused on sustainable consumption of agrifood products in Europe in relation to trade policies of these countries, such as water

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1 *cf*. Cederberg, C. (2003). Life Cycle Assessment of animal products. 19-34. En: Mattsson, B., Sonesson, U. (Ed). *Environmentally-friendly food processing*. England: CRC Press. 94 p.

footprint of Spanish agriculture (Rodriguez *et al.*, 2008), or the consumption of pasta and pizza in Italy (Aldaya and Hoekstra, 2010).

The scope of this paper is to compare water use efficiency of different intensification dairy systems, valuate their eco-efficience heterogeneities, and monitor the water flow structure of milk chains in water scarcity regions. For that purpose, Water Footprints of UHT milk and cheese agrifood chain in La Pampa and San Luis provinces have been assessed using Life Cycle Assessment (LCA) methodology, including virtual water indicators.

II. Materials and methods

A simplified LCA of consumptive water use in bovine milk agrifood chain of La Pampa and San Luis provinces of Argentina has been developed, contrasting the efficiency of green and blue water for different scenarios of intensification of dairy farm systems, adapting the methodological criteria outlined in Hoekstra *et al.* (2009). The study focus on freshwater use in relation with resource depletion, analysis of other environmental impacts, such us eutrophication and acidification were not included.

Most common dairy systems of both provinces were selected from INTA dairy regional projects database (Ashworth, 2008; Felice, 2009). Three dairy systems with different degrees of intensification, scale and use of water resource were contrasted. The degree of intensification was determined based on animal density, and percentage of dry matter (DM) provided by supplements in relation to the total feed chain.

Water use in animal feeding corresponds to the sum of the evaporative demands of pastures and crops grown in farm and imported, considering both blue and green water origins. As a first approximation, losses that may occur in water distribution systems were not accounted, assuming that a high percentage can be reused. Only efficiency parameters of the irrigation system of the farm were considered.

For each system, the water consumption of the feed chain and production of grain for animal supplementation was determined according to the methodology developed by Allen *et al.* (1998), using AGROECOINDEX® model. The virtual water content of supplements was obtained from AGROECOINDEX® database, as well as the determination of the consumption of animal drinking water. The volume of water used in the process of application and pulverization of agricultural chemicals to crops was estimated by labels of products and average technical specifications used by local contractors (speed, flow, etc.), according to the technical report by Bogliani *et al.* (2005).

The water footprint of a product is defined as the total volume of freshwater used (directly or indirectly) to produce it; it is estimated taking into account consumption and pollution of water in all phases of the production chain. The accounting procedure is similar for all types of products derived from agriculture, industrial or service (Hoekstra *et al.*, 2009).

$$WF_{prod}(p) = \left[WF_{proc}(p) + \sum_{i=1}^{y} \frac{WF_{prod}(i)}{f_p(p,i)}\right] \times f_v(p) \quad (1)$$

Where $WF_{prod}(p)$ is the water footprint (or virtual water content) (m3/mass) of the product-output, $WF_{prod}(i)$ is the water footprint of the product-input (i) and $WF_{proc}(p)$ the water footprint (consumption of water) of the processing steps that transforms (y) imputs (raw material) in the final products (outputs), expressed in water use per unit of processed product (p) (m3/mass). In the case studies of this work, the use of water from the milking routine process for primary production of milk and total water consumption (not recovered) of all production processes of the two plants studied were determined, discriminating water consumption used in the transport phase of the raw material. The processes are specified in their respective inventories.

The parameter $f_p(p,i)$ is called *product fraction* (or conversion factor) and is defined as the amount of output ($W\ (p)$, mass) obtained per unit of input ($W(i)$, mass):

$$f_p(p,i) = \frac{W\ (p)}{W(i)} \qquad (2)$$

The *value fraction* of an output product, $f_v(p)$ is defined as the ratio between the market value of the product (monetary units/monetary units) in relation to the aggregate market value of all outputs (p = 1 to z) obtained from the input products (raw material):

$$f_v(p) = \frac{price\ (p) \times W(p)}{\sum_{p=1}^{z}(price\ (p) \times W(p))} \qquad (3)$$

In this paper, for dairy systems the *value fraction* was estimated considering only two products of the cow: milk and meat, taking the total annual market value of both products.

Specifically, the water footprint of dairy milk can be expressed by equation (1), where $WF_{prod}\ (p = raw\ milk)$; $f_p(p,i) = 1$; $WF_{proc}(raw\ milk) = {}^{CRo}/_{Y^{R,S}}$; CRo: water consumption in milking processing routine (m3/year); $Y^{R,S}$: dairy milk production (L/year). $WF_{prod}(i)$ is given by the total virtual water consumption of animal feeding, $VWT^{R,S}$:

$$WF_{prod}(i) = \left(\frac{VWT^{R,S} \times f_v(raw\ milk)}{Y^{R,S}}\right) \qquad (4)$$

For industrial milk products, water footprint is given by equation (1) where: $WF_{prod}\ (p = Ind_i\ )$; $WF_{prod}\ (i = raw\ milk)$

$$WF_{prod}\ (Ind_i\ ) = \left[WF_{proc}\ (Ind_i) + \sum_{i=1}^{y} \frac{WF_{prod}\ (raw\ milk)}{f_p(Ind_i, raw\ milk)}\right] \times\ f_v(Ind_i) \qquad (5)$$

Where $WF_{prod}\ (Ind_i\ )$ is the water footprint of industrial milk products (for i = UHT milk, cheese, cream, ricotta); $WF_{prod}\ (raw\ milk)$ is the virtual water content of a unit of raw material (raw milk); ($\frac{1}{f_{p(Ind_i)}}$) is the industrial product (i), expressed as the amount of raw material per unit industrial product. $WF_{proc}\ (Ind_i)$ is the volume of water use in the industrial processing stages, expressed in m3 per unit of raw milk processed (m3/L milk). Processes are specified on their respective inventories (III.1.2.4).

The next step in determining the water footprint of a supply chain, is to calculate the virtual water flows entering and leaving the provincial limits, resulting from the import and export of primary products (raw milk) and industrial applications. This is done by adding virtual water content of each product in the chain: $WF_{prod}\ (Ind_i\ )\ and\ WF_{prod}\ (raw\ milk)$, identifying those that are exported, consumed or processed locally and those imported for final consumption. For La Pampa province, the flow of virtual water and water footprint of the dairy chain were estimated for 2005, based on the dairy chain 2005 flowchart by Iturrioz and Iglesias (2009). In the case of San Luis province, estimates of water footprints and virtual water flows for the year 2008 were made based on Manazza (2009). We determined the flow of virtual water imported by the consumption of milk products from the national consumption patterns by type of dairy product (kg / capita / year) using MAGyP (2011) database.

Thus, the total water footprint of the chain is given by HH_C $(Hm3)$:

$$HH_C\ (Hm3) = \left\{ \sum_{j=product}^{i=sector} W\ Fprod_j^i \times \mathrm{Q_j^i} \ - \sum_{j=raw\ milk}^{PP} WFprod_j^{pp} \times I_{rmilk} + AVM^{Cons}(Hm3) \right\} \quad (6)$$

For i = (primary production (PP), industry)

Where, $\mathrm{Q_j^i}$ is the total production volume of (j) product, of (i) sector; $WFprod_j^i$ is the water footprint of the dairy (j) product of (i) sector; I_{rmilk} is the volume of provincial primary product (raw milk) delivered to local industry of local. $WFprod_j^{pp}$ is the water footprint of raw milk and AVM^{Cons} the virtual water imports by external dairy products consumed in the local market.

Among the alternative economic criteria used in this study, the adequacy of Life Cycle Cost Analysis methodology was assessed. This approach is the methodological framework proposed by LCA for the integration of economic aspects of eco-efficiency and the assessment of cost-effectiveness of alternative production processes and products (Norris, 2000).

Inventories were built of effective water costs (CEf) based on the cost of extraction of it: direct costs (consumption of electricity or diesel fuel, maintenance and repairs), indirect costs (depreciation of equipment and well). Subsequently, the cost-effectiveness analysis was added with assessment criteria of economic aspects of water footprint, as the economic impact of a water footprint is related to water use inefficiency (Hoekstra, 2009).

In accordance with economic criteria proposed by Hoekstra (2009), for the analysis and discussion of results in the framework of a deductive theoretical model according to Young (2005), the Global Water Productivity index ($GWP^{\boldsymbol{S,R}}$) was built as the inverse function of the water footprint of the system:

$$\frac{\boldsymbol{Water\ use\ Intensity} \ = \ \frac{\boldsymbol{mm}}{\boldsymbol{ha}}}{\boldsymbol{Milk\ productivity} \ = \ \frac{\boldsymbol{L\ mikl}}{\boldsymbol{ha}}} = \frac{\boldsymbol{mm}}{\boldsymbol{L\ milk}} = \boldsymbol{WF_{prod}}\ (\boldsymbol{raw\ milk}) \quad (7)$$

$$\boldsymbol{GWP^{S,R}} = \frac{\mathbf{1}}{\boldsymbol{WF_{prod}}\ (\boldsymbol{raw\ milk})} \quad (8)$$

Returning to the equation (7), some global determinants of the value of WF indicator and their relationships can be identified.

The numerator of the fraction, the intensity of water use will depend, among other variables, on the consumption of water in the feed chain (production of DM within the system) and import of virtual water from external supplementation, which depends on the chain composition (type and acreage), effective precipitation, use of irrigation, feed chain balance (adjusted stocking efficiently, avoiding excess supply of MS).

Regarding the denominator, milk productivity will depend on DM production per mm of water per unit area (water productivity feed chain (kgMS / ha / mm), which allow systems with higher stocking rates, and thus, higher milk production per ha in a water efficient manner.

Finally, economic issues associated with eco-efficiency comparison between systems were approached by estimating the negative impact on the producers' economic surplus derived from not using the most efficient available technology, i.e., that increased global water productivity of the system:

$$CeH = P_{milk} \times (GWP^{p} - GWP^{c}) \quad (9)$$

Where CeH is the water cost-effectiveness or economic loss per unit of water; P_{milk} the commodity price (milk); GWP^{p} the global *potential* productivity of water in the system (Liter of milk / Liter of water); GWP^{c} the *current* global water productivity in the system (L milk / L water). Simplifying assumptions: (a) global potential productivity of the system is equivalent to the current productivity of the best system under study, (b) potential water productivity can be achieved at the same cost as current productivity, (c) the price of the product is homogeneous.

The Total Economic Cost (CET) as a criteria for determining the cost relative water efficiency of dairy production systems, is given by the sum of the Cost Effectiveness of extraction (CEf), and water efficiency cost (CeH), according to equation (10):

$$CET = CEf + CeH \quad (10)$$

III. Results

III.1 Inventory

III.1.1 Physical Inventory of Primary Production: feed phase and milking process

The results of calculations of total water consumption by the system, using AGROECOINDEX® model for animal feed, animal drink and farming pulverizations, are tabulated below (Table 1).

Inventory data for milking routine process was built based on data collected by measurements in situ. In all the cases studied there are water reuse systems, mainly resulting from the process of cooling (plate cooler) where water is stored and managed to animal drink. These reused volumes are not counted as consumption, avoiding duplication.

Table 1-Inventory data for dairy systems: *Animal feeding and Milking process*								
	San Luis				*La Pampa*			
	Modal	**Extensive**	**Intensive S**	**Mega**	**Modal**	**Extensive**	**Intensive S**	**Mega**
Dairy cows -in production	65	140	98	1.180	196	500	66	2.185
Annual production, L/year	438.913	1.058.500	983.675	10.466.010	1.708.200	3.923.750	402.960	21.772.433
Milk production per ha, L/ha/year	**1.562**	**3.308**	**15.133**	**15.369**	**4.495**	**4.563**	**5.233**	**17.349**
Irrigation, total m3/year	1.442.448	no	700.920	5.280.000	no	no	no	no
Animal feeding								
On-Farm Pasture Water consumption , m3/year	**961.579**	**1.292.898**	**462.280**	**5.953.030**	**1.966.880**	**3.249.295**	**374.682**	**7.207.465**
Brought-in feed supplements Water Consum., m3/year	**107.800**	**586.986**	**584.584**	**5.748.895**	**0**	**1.606.000**	**456.250**	**10.647.416**
Drinking Water -total, m3/year	**3.395**	**7.254**	**2.861**	**36.956**	**2.592**	**15.513**	**2.592**	**67.425**
Water use for crop protection-Pulverizations, m3/year	**47**	**78**	**14**	**221**	**85**	**143**	**13**	**520**
Total Water consumption per ha, m3/ha/year	**3.818**	**5.898**	**16.150**	**17.238**	**5.183**	**5.664**	**10.825**	**14.281**
Milking process								
Water consumption in milking process , L/day	**2.655**	**1.159**	**2.884**	**152.601**	**6.209**	**31.391**	**3.246**	**310.500**
Total Water consumption in milking process, m3/year	**969**	**423**	**1.018**	**55.699**	**2.266**	**11.458**	**1.185**	**113.333**
Total W. cons. milking process, per milk unit, *Lwater/Lmilk*	**2,2**	**0,4**	**1,0**	**5,3**	**1,3**	**2,9**	**2,9**	**5,2**
Totals								
System Water consumption per milk unit, m3/L/year	**2,27**	**1,69**	**1,02**	**1,06**	**1,08**	**1,18**	**1,86**	**0,82**

* Corresponds to the weighted average of the mm actually applied to crops in the irrigated area. Efficiency parameter considered: furrow irrigation (60%); Spray-central pivot (90%)

Source: Own elaboration

The largest volumes of water consumption (m3/year) occur widely in the production of dry matter (DM) inside the system and on external animal feed. In less intensive systems, the share of water consumption of domestic food resources is higher (over 70% for cases Modal (M) and Extensive (E) in both provinces). In intensive systems more than 50% of water consumption is virtual water imported through external feed.

Systems that use complementary irrigation present water forage consumption per unit area (mm/ha) that is, on average, 39% higher than the average of the 5 cases studied without irrigation[2].

It is remarkable the high intensity of use of water by intensive systems in relation to the extensive system and Modal. The average volume of total annual water consumption per unit area (m3/ha/year) from Modal and extensive systems in both provinces (5.141m3/ha/year), represent 35% of the average volume of intensive systems (14.623 m3/ha/year).

III.1.2. Economic Inventory for Primary Production: Costs

The monetary values of m3 of water were determined based on extraction costs, computing: i) direct costs: electricity consumption or diesel fuel, maintenance and repairs, labor, ii) Indirect: amortization of equipment and wells.

2 The value of water consumption of the feed chain per unit area (mm / has), is a resulting weighted average value of the water consumption of each crop which made up the chain and its surface.

Table 2- Inventory data -Cost of water (withdrawal)-AR$/m3 water			
San Luis	**Feeding (Irrigation)**	**Feeding (Drinking)**	**Milking process**
Modal	0,100	0,860	0,860
Extensive	0,004	0,570	0,570
Intensive S	0,091	0,476	0,476
Mega	0,483	0,483	0,539
La Pampa			
Modal	0,000	0,275	0,275
Extensive	0,000	0,136	0,136
Intensive S	0,000	0,448	0,448
Mega	0,000	0,118	0,118

Source: Own

The high proportion of fix indirect costs in the actual cost of water extraction and its dilution associated with the increased extraction volume, explains that the unit cost ($/m3) decreases with the scale of the establishment (Table 2).

Similar situation is observed with the dilution of direct fixed costs in the unit costs of water for furrow irrigation systems, associated with application volumes (Modal and Intensive cases in San Luis).

III.1.3 Physical and financial inventory of Transport and Industrial Production

The inventory was built based on data collected through technical interviews made to production managers of both studied industries. Table 3 summarizes the volumes of total water consumption and costs for the case studies.

Processes surveyed in UHT milk firm: Cleaning / washing transport, tanks, UHT equipment (CIP), facilities. Water supply: public water network. Volume of water consumed (m3) and average water tariff for February-March 2011.

Processes revealed in Cheese firm: Cleaning / washing transport, tanks, Steam pasteurizing equipment, facilities. Water supply: groundwater-extraction. Value of m3 of water based on the calculation of the cost of extraction.

Table 3-Inventory data: Transport and Industry		
	San Luis	*La Pampa*
	Product: UHT Milk	**Product: Cheese**
Daily milk processing, L/day	93.000	20.000
Annual Production	25.896.000 litres	624.000 kg
Transport-water consumption (cleaning), m3/year	**4.380**	**1.332**
Industry-total water consumption (processing), m3/year	**42.828**	**17.027**
Transport-water consumption (cleaning), L water/L Milk	**0,13**	**0,16**
Industry-total water consumption (proc.), L water/L Milk	**1,70**	**2,08***
Cost of m3 water (average 2010), $/m3	**2,02**	**0,165**
Industry-Annual water expenditure in Plant, $/year	**86.513**	**2.799**
Transport-Annual water extenditure-(cleaning), $/year	**8.848**	**220**
**Correspond to milk processed for cheese production. Product value 0,9*		

Source: Own

The 60% of the volume of water consumption correspond to cleaning processes of facilities, transportation and tanks. The volume used for floors cleaning comes from reused sources.

III.2 Virtual Water from primary production: comparison between systems

In the study cases from San Luis, Intensive S and Mega dairy systems had the lowest value of Virtual Water (VW) per liter of raw milk: 1,025 Lwater/Lmilk and 1,065 Lwater/Lmilk, respectively. The biggest indicator corresponded to Modal dairy: 2,275 Lwater/Lmilk.

In La Pampa, the Mega dairy system had the lowest indicator of virtual water: 828 Lwater/Lmilk; the greatest value corresponded to the Intensive S system: 1,867 Lwater/Lmilk (Table 4).

In terms of averages, there is a greater indicator of virtual water and higher relative dispersion for dairy farms of San Luis (1,515 Lwater/Lmilk, CV = 39%); La Pampa: 1,241 Lwater/Lmilk, CV = 35.7%).

Table 4-Virtual Water of Dairy systems: case studies

	San Luis				*La Pampa*			
	Modal	Extensive	Intensive S	Mega	Modal	Extensive	Intensive S	Mega
Feeding, L water/L milk/year	2.273	1.694	1.024	1.060	1.084	1.184	1.862	823
Milking process, L water/L milk/year	2,21	0,40	1,02	5,32	1,33	2,92	2,94	5,21
Total Virtual Water -Dairy, L water/L milk/year	2.275	1.694	1.025	1.065	1.085	1.187	1.865	828

Source: Own

In relation with the intensity of resource use and productivity of the system per unit area, Modal and Extensive systems produced the lowest levels in both provinces (Figure 1).

For the intensive systems studied in San Luis, it is observed that productivity compensate their intensity of resource use, like what happens in the case of Mega dairy in La Pampa. This result is relevant, since the intensive systems studied in San Luis use complementary irrigation and present virtual water indicators below the average indicator of both provinces (Figure 1).

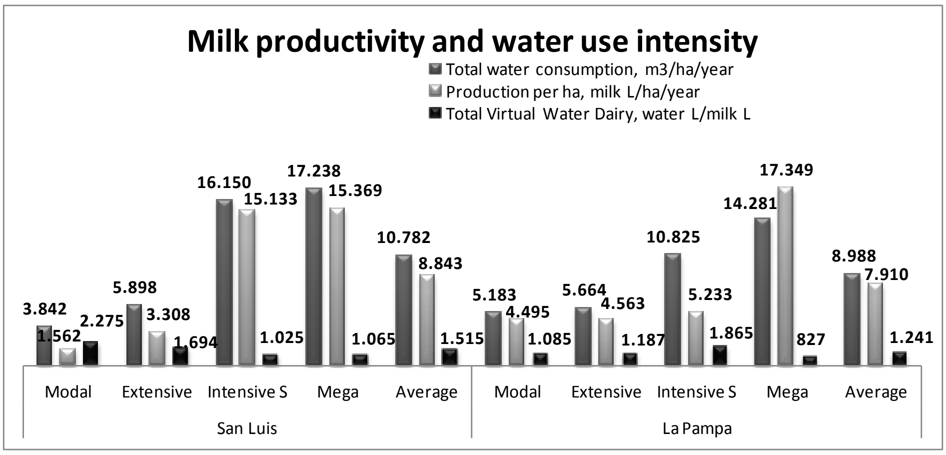
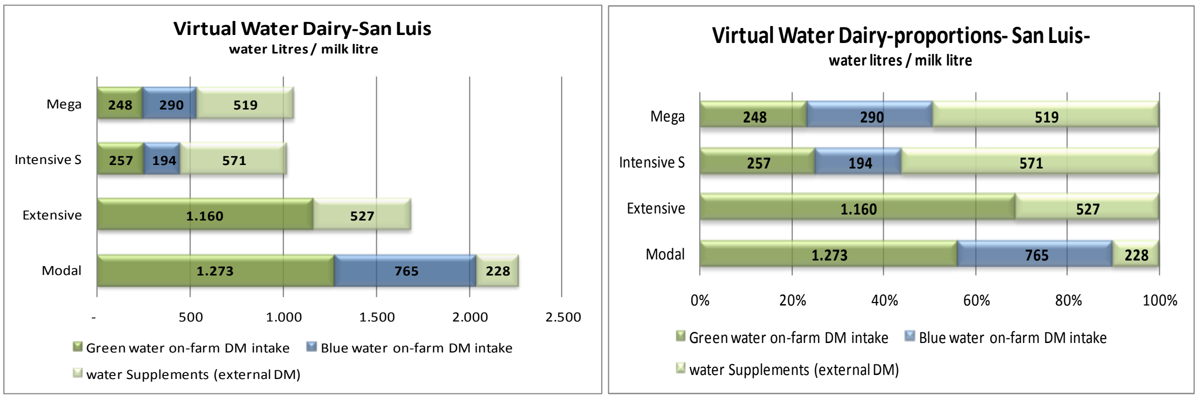


Figure 1 - Productivity of milk and intensity of water use by the system under study

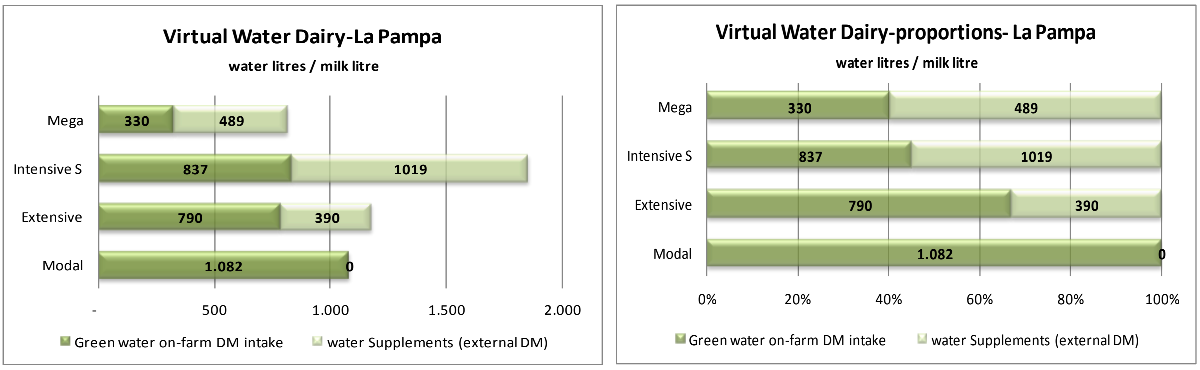
Separating Virtual Water indicator between green water and blue water, we observe that the Intensive S and Mega dairy systems present values and proportions of blue water relatively similar: 194 Lwater/Lmilk and 290 Lwater/Lmilk, respectively. In the case of the most intensified system (Mega dairy), blue water consumption is higher than on-farm green water, an aspect that reveals the reality of the need for complementary irrigation systems for dairy farming in the semiarid region (Figure 2).



(a) (b)

Figure 2 - Virtual blue and green water primary production by component: study cases from San Luis. (a) volume, (b) percentage share.

However, it is noteworthy that in the cases studied in both provinces, it is observed that further intensification of the system corresponds to a higher proportion of external virtual water incorporated into the basis of animal nutrition through supplementation (external DM). This source is the main contributing factor in the VW indicator for intensive systems, more than 50% in all cases[3] (Figures 2 and 3).



(a) (b)

Figure 3 - Virtual blue and green water in primary production component: study cases from La Pampa. (A) volume, (b) percentage share.

External feed involves green water, therefore, added to the green virtual water from internal DM production, determine its prevalence in the virtual water indicator for the systems under study (Figures 2 and 3).

III.3 Virtual Water determination for industrial production and supply relationships: UHT Milk and Cheese cases.

Primary production, in particular animal feeding, is largely the main determinant of Virtual Water indicator for both dairy products under study. Explains over 99% of its value (Table 5), and reveals the importance of consideration of the variants of dairy systems.

According to equation (5) (section II) virtual water content of the functional units of a liter of UHT milk and a Kg of cheese, packaged and ready for distribution, were determined.

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3 Modal case of La Pampa produces on-farm all the supplements used for feeding.

In both industrial dairy products analyzed, the lowest value indicator was introduced in Virtual Water supply variants of intensive systems. In the case of the dairy industry in San Luis, 990 liters of water per liter of UHT packaged milk under Intensive S System, and in the case of La Pampa, 7,476 liters of water per Kg. of cheese from the Mega dairy System (Table 5).

Table 5-Virtual Water of Industrial Products: UHT Milk and Cheese, by dairy system

	San Luis				*La Pampa*			
	Modal	**Extensive**	**Intensive S**	**Mega**	**Modal**	**Extensive**	**Intensive S**	**Mega**
Feeding, L water/L milk/year	**2.273**	**1.694**	**1.024**	**1.060**	**1.084**	**1.184**	**1.862**	**823**
Milking process, L water/L milk/year	**2,21**	**0,40**	**0,19**	**5,32**	**1,33**	**2,92**	**2,94**	**5,21**
Transport, L water/L milk /year			**0,13**				**0,18**	
Industry, L water/L milk			**1,70**				**2,32**	
Value product fraction			**0,96**				**0,9**	
Virtual Water per raw material unit processed, L water/L milk	**2.186**	**1.628**	**985**	**1.024**	**979**	**1.071**	**1.680**	**748**
UHT Milk -Product Factor, raw milk L/UHT milk*			**1,005**					
UHT Milk-Virtual Water, water L/UHT milk L.	**2.197**	**1.636**	**990**	**1.030**				
Cheese - Product Factor, milk L/Kg. Cheese*							**10**	
Cheese-Virtual Water, L water/kg. Cheese					**9.786**	**10.705**	**16.802**	**7.476**

* Corresponds to the inverse of the product fraction (1/fp) to express the virtual water indicator in units of final product (functional unit defined). The product fraction 1L UHT milk is 0.995. In the case of cheese, a product fraction of 0.1 is considered, average value for the three types of cheeses produced in the plant (soft cheeses, hard and semihard).
Source: Own

From the analysis of the value of virtual water per liter of raw milk processed, it is remarkable the low VW values in the large-scale intensive dairy farms in both provinces: 1,024 liters of water per liter of processed milk in San Luis and 748 liters of water per liter of processed milk in La Pampa (Table 5).

The greatest VW indicator per liter of processed milk corresponds to Modal dairy farm of San Luis (2,186 Lwater/Lmilk), followed by Intensive S dairy farm of La Pampa (1,680 Lwater/Lmilk) (Table 5).

The heterogeneity between systems magnifies the differences in the Virtual Water indicator for Cheese in La Pampa, by the fact of the conversion factor of raw material in the final product (liters of milk / kg. Cheese). The lowest VW indicator for cheese Kg. was the Mega dairy farm with 7,476 liters of water per kg. of cheese, while the Intensive S system showed the highest water indicator with 16,802 L water/kg. cheese (Table 5).

Alternatively, virtual water content of two additional dairy byproducts for both industries were calculated, such us the case of Cream (42.8% fat) in San Luis, and “Ricotta”, resulting from the cheese processing in La Pampa.

The lowest value of virtual water per liter of Cream corresponds to the case of the Intensive S System in San Luis: 1,983 liters of water per liter of Cream. VW for Ricotta, by Mega dairy farm supply, reach 1,628 liters of water per kg. of product (Table 9).

Table 6-Virtual Water Industrial sby-products: Cream y Ricotta, per dairy system

	San Luis				*La Pampa*			
	Modal	**Extensive**	**Intensive S**	**Mega**	**Modal**	**Extensive**	**Intensive S**	**Mega**
Feeding, L water/L milk/ year	**2.273**	**1.694**	**1.024**	**1.060**	**1.084**	**1.184**	**1.862**	**823**
Milking process, L water/L milk/ year	**2,21**	**0,40**	**0,19**	**5,32**	**1,33**	**2,92**	**2,94**	**5,21**
Transport, L water/L milk/ year			**0,13**				**0,18**	
Industry, L water/L milk			**1,70**				**2,32**	
Value product fraction			**0,04**				**0,1**	
Product factor*, raw milk proc. (L)/product unit (L)			**48,3**				**19,6**	
Cream -Virtual Water, L water/ L Cream	**4.400**	**3.277**	**1.983**	**2.062**				
Ricotta-Virtual Water, L water/kg. Ricotta					**2.131**	**2.331**	**3.659**	**1.628**

* Corresponds to the inverse of the fraction product (1/fp) to express the virtual water indicator in units of final product (functional unit defined). The product fraction is 0.02 for 1L of Cream and 0.05 for 1kg of Ricotta.
Source: Own

IV. Discussion

IV.1 Virtual Water and comparison of system water eco-efficiency

A first remarkable aspect is the strong positive relationship between intensity of water use (water use m3/ha/year) and system productivity (milk production / ha / year). This relationship suggests that, on average, each additional liter of milk per hectare of the system corresponds to 0.79 m3 of virtual water added (Figure 4). This fits with the results presented on section III.3, as noted, the main determinant of VW indicator is water consumption at animal feeding stage (production or import of DM).

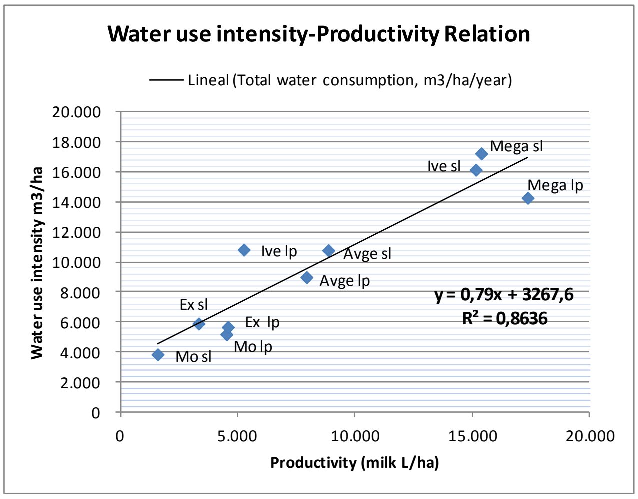

Figure 4 - Intensity of water use, m3/ha/year - Productivity of the system, L milk / ha / year Relationship

The second relationship, represented in Figure 5, shows that low Virtual Water indicators are related to higher productivity of the systems. Note that the lower values of VW in both provinces correspond to Mega dairy farms and San Luis-Intensive S system (Ive SL).

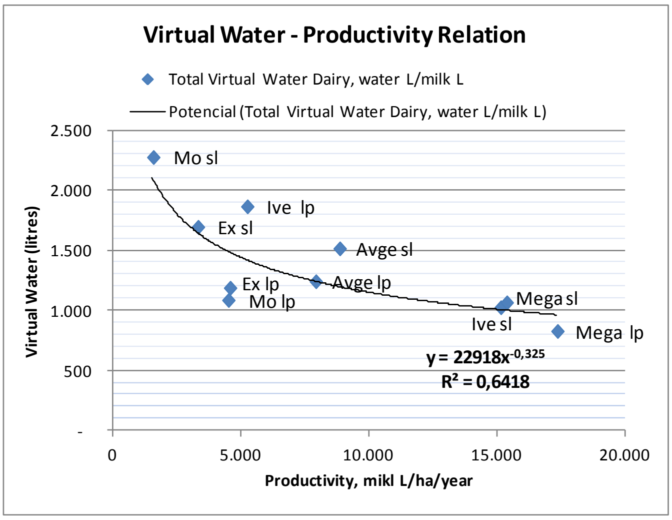

Figure 5 - Virtual Water, Lwater/L milk / year - Productivity of the system, Lmilk/ ha / year Relationship

The most water efficient dairy systems are those in which their productivity compensate the intensity of resource use. This brings to the conceptualization of the inverse function of Virtual Water, expressed in liters of milk per mm[4], as a proxy of the Global Water Productivity of the dairy system -equation (8) of Section II[5]-; driving to the approach of the analysis of its determinants for the considered systems, to explain aspects of the heterogeneity of eco-efficiency of such water use.

As noted in Results III.3and in consistency with Mekonnen and Hoekstra (2010) results:

i. intensive systems with high productivity (Mega and Intensive S dairy farms) had the lowest indicators of total VW.
ii. main contributing factor to total VW was the green water from external feed.

These results suggest that:

a) While virtual water productivity of external feeds is less than the observed for other sources of feed within the system, its existence in the animal feed ration contributes significantly to the global water productivity of the system as a whole -Table 7-.
b) However, if it is technically possible (nutritional equivalence) the replacement of external feed by internal feed sources with more water productivity (higher kg DM/mm), maintaining the same conversion efficiency, it would be possible to reach further reductions on VW value, increasing water eco-efficiency of the system.

These two points are visible, examining the productivity of complementary irrigation from San Luis study cases.

Table 7- Water Productivity of feeding: on farm DM intake and supplements-San Luis study cases.

		Mega		Extensive		Intensive S		Modal	
		Value	Metabolization average	Value	Metabolization average	Value	Metabolization average	Value	Metabolization average
On-farm water productivity	*Kg MS/mm*	12,73	0,474	11,72	0,481	12,21	0,455	9,80	0,454
Brought supplements w productivity	*Kg MS/mm*	4,94	0,682	6,09	0,682	4,55	0,682	4,54	0,682
On-farm DM average production	*kgMS/ha*	11.201		5.695		8.130		4104	
External DM average import	*kgMS/ha*	3.259		1.118		4.088		174,4	
Total DM per ha	***kgMS/ha***	**14.460**		**6.813**		**12.218**		**4.278**	
Irrigation		yes		No		yes		yes	

Source: Own

The average productivity of internal water (green and blue) of -On farm DM production- in Mega dairy is 12.73 kgDM/mm, and the average productivity of external water (green) of External feed is 4.94 kg. DM/mm. Extensive system has similar values of internal productivity per mm (11.7 kg DM / mm).

Hence, in terms of dairy system productivity, the use of complementary irrigation in Mega dairy allow to maximize DM production per unit area, making two annual crops of grass silage. This increase of dry matter production per unit area allows for greater stocking rate that results in an increase in milk production per hectare, ceteris paribus the rest of the variables that determine the system milk productivity. This explains most of the greater global

4 *Cfr* similar conceptualizations of water productivity in agriculture in Hoekstra (2009) and particular argentine crops in Caviglia and Andrade (2010).

5 $GWP^{S,R} = \frac{1}{WF_{prod}(raw\ milk)}$; Section II.

water productivity in efficient intensive systems (such as Mega or IveS in San Luis-Figure 5-), that is, a lower water footprint of the system and its enhanced eco-efficiency of water use.

IV.2. Economic evaluation and comparison between systems

As presented in the results section, the explicit cost inventory of water (accountant) was built from the extracting cost and tariff value (in the case of San Luis Milk Industry). Table 8 presents the actual cost of water (in AR $) per unit of raw material (liter of milk).

Table 8-	***Effective cost of water (withdrawal)- AR $ per liter of processed milk***					
San Luis	**Feeding**	**Milk Processing**	**Total Dairy**	**Transport**	**Milk Ind.**	**Total VW Cost**
Modal	0,23541	0,00190	**0,2373**			**0,2410**
Extensive	0,00169	0,00023	**0,0019**	0,00026	0,00344	**0,0056**
Intensive S	0,03861	0,00009	**0,0387**			**0,0424**
Mega	0,24501	0,00287	**0,2479**			**0,2516**
La Pampa					**Cheese Ind.**	
Modal	0,00069	0,00037	**0,0011**			**0,0014**
Extensive	0,00038	0,00040	**0,0008**			**0,0011**
Intensive S	0,00162	0,00132	**0,0029**	0,00003	0,00034	**0,0033**
Mega	0,00026	0,00058	**0,0008**			**0,0012**

Source: Own

It highlights the high cost of water in systems with irrigation, and among these, the higher cost of center pivot irrigation system (4.8$/mm), transferred to the explicit economic cost of Virtual Water (0,25 $/ L milk)-Table 8- which represents 17.5% of the raw material price, and 12% of the final product[6]. However, among the case studies of San Luis, despite the difference in the cost of mm applied, the cost of Virtual Water are similar for Modal and Mega dairy systems, precisely because of the higher global system productivity of Mega dairy farm (less VW)-Table 8-.

According to the methodological development (section II), approximating the economic cost of environmental water inefficiency (cost water efficiency $\boldsymbol{CeH}$ -), valuing indirectly the green water by the difference in the value of the global water productivity of system -Table 9- , we obtain:

Tabla 9- Economic value of Water estimates, systems comparison.										
	San Luis					La Pampa				
	Modal	**Extensive**	**Intensive S**	**Mega**	**Average**	**Modal**	**Extensive**	**Intensive S**	**Mega**	**Average**
Global Water Productivity (average), L water/L milk	0,0003	0,0006	0,0008	0,0008	0,0006	0,0009	0,0008	0,0005	0,0012	0,0008
Value of water productivity*, $/water liter	0,0005	0,0008	0,0012	0,0012	0,0008	0,0012	0,0011	0,0007	0,0017	0,0011
Enviromental cost of Water** $/water liter (1)	0,0007	0,0004	-	0,00003	0,0004	0,0005	0,0006	0,0010	-	0,0006
Liters of Virtual Water exceeded (2)	1.250	669	-	40	490	258	360	1.038	-	414
Econ. Cost of hydric inefficiency (CeH) $/L milk (1)x(2)	**0,88**	**0,26**	**0,000**	**0,001**	**0,19**	**0,13**	**0,21**	**1,08**	**0,00**	**0,27**
Effective Cost of water $/milk liter	0,241	0,006	0,042	0,252	0,135	0,001	0,001	0,003	0,001	0,002
Total Económic Cost of Water $/milk (Liter)	**1,12**	**0,26**	**0,042**	**0,25**	**0,33**	**0,13**	**0,21**	**1,08**	**0,00**	**0,27**

*Average water productivity multipy by the value of one liter of raw milk (AR$ 1,45)

**Differencial of average global productivity value from the most efficient system (unitary Cost of hydric inefficiency-CeH-).

Source: Own

6 Average prices november-march 2010: $AR 1,45 per liter of raw milk on dairy; $AR 2,10 average price 2010 UHT milk liter on plant.

i. In San Luis, the total economic cost of the VW under a Mega dairy system (0.25 $ / L milk), is almost equivalent to the Extensive system (0.26 $ / L milk).
ii. In San Luis, it highlights the low cost of water inefficiency of small-scale intensive system (Ive S) with irrigation, it has the lowest total economic cost (0.042 $ / L milk), followed by the Mega system of La Pampa.
iii. Among the study cases of La Pampa, it is remarkable the high negative impact of lack of productive efficiency in the small scale intensive system, involving the high cost of water inefficiency.

In relation to the expansion of present results at local or regional level, there are some necessary aspects to be considered.

The potential economic productivity of water in a region will exceed the current situation, if the water can be redistributed among sites or productive activities with greater value added (Hoekstra, 2009).

Hoekstra (2009) notes that high-value crops such as intensive, provide greater economic productivity of water, so it would seem attractive the relocation of water to its favor, especially in areas where water is relatively more scarce. However, the redistribution of water over large scales need to recognize that there are other factors to be considered in addition to those that are purely economical, for example, factors related to a desirable degree of food self-sufficiency (cereals) or availability of local raw materials in certain regions.

Therefore, the aspects related to the analysis of the allocation of water between productive activities should be complete and not partial. It must involve not only the economic aspects derived from the value and productivity of water, but also all those other economic issues that are not involved in productivity, as well as social and environmental (Hoekstra, 2009).

IV.3. Determining the flow of virtual water and water footprint of La Pampa and San Luis Dairy chain and its main products.

The purpose of this discussion is to deploy conceptually the water footprint indicator in milk agrifood Chain of a province and its main links –equation (6) Section II-, identifying the virtual water flows between them. An approximation of the possible implications of considering water eco-efficiency heterogeneities on systems, for determining the water footprint of primary production is made.

La Pampa Province

Water footprint of dairy chain products of La Pampa province for 2005 annual chain flow was estimated at 178.3 million m3 (178.3 Hm3), 55% is exported in raw milk to other provinces, 43% correspond to Cheeses (predominantly soft), and the remaining 2% belong to Pasteurized Milk, caramel candy, ice cream, yogurt and chocolate milk.

Considering the source of Virtual Water in the chain, 92.5% comes from provincial origin, explained by the water footprint of local primary production. The remaining 7.5% (13.3 Hm3 of VW) is contained in the supply of raw milk imported from other provinces.

For industrialized dairy products in the province, 83.3% of its VW content comes from provincial origin (67 Hm3 by provincial milk supply), and 16.7% outside the province (Figure 6)

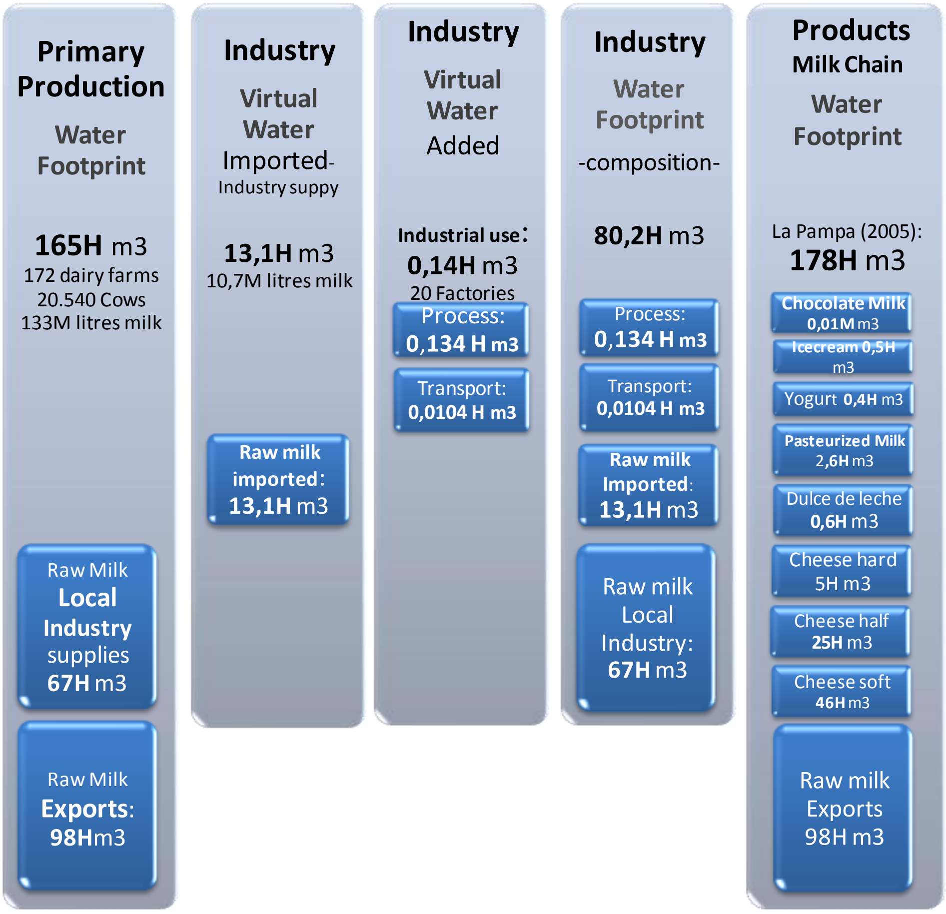

Figure 6-Water Footprint of the dairy chain products of La Pampa, by component. Year 2005

Virtual Water Flow of La Pampa milk chain (2005) was determined according to the developed methodology -equation (6), Section II-. The total water footprint of the chain was estimated at 224.4 Hm3, finding that the local consumption of dairy products added 46.1 Hm3 of water to the Virtual Water Footprint of Chain Products (178,3 Hm3), through the importation of dairy products from other provinces (Figure 7).

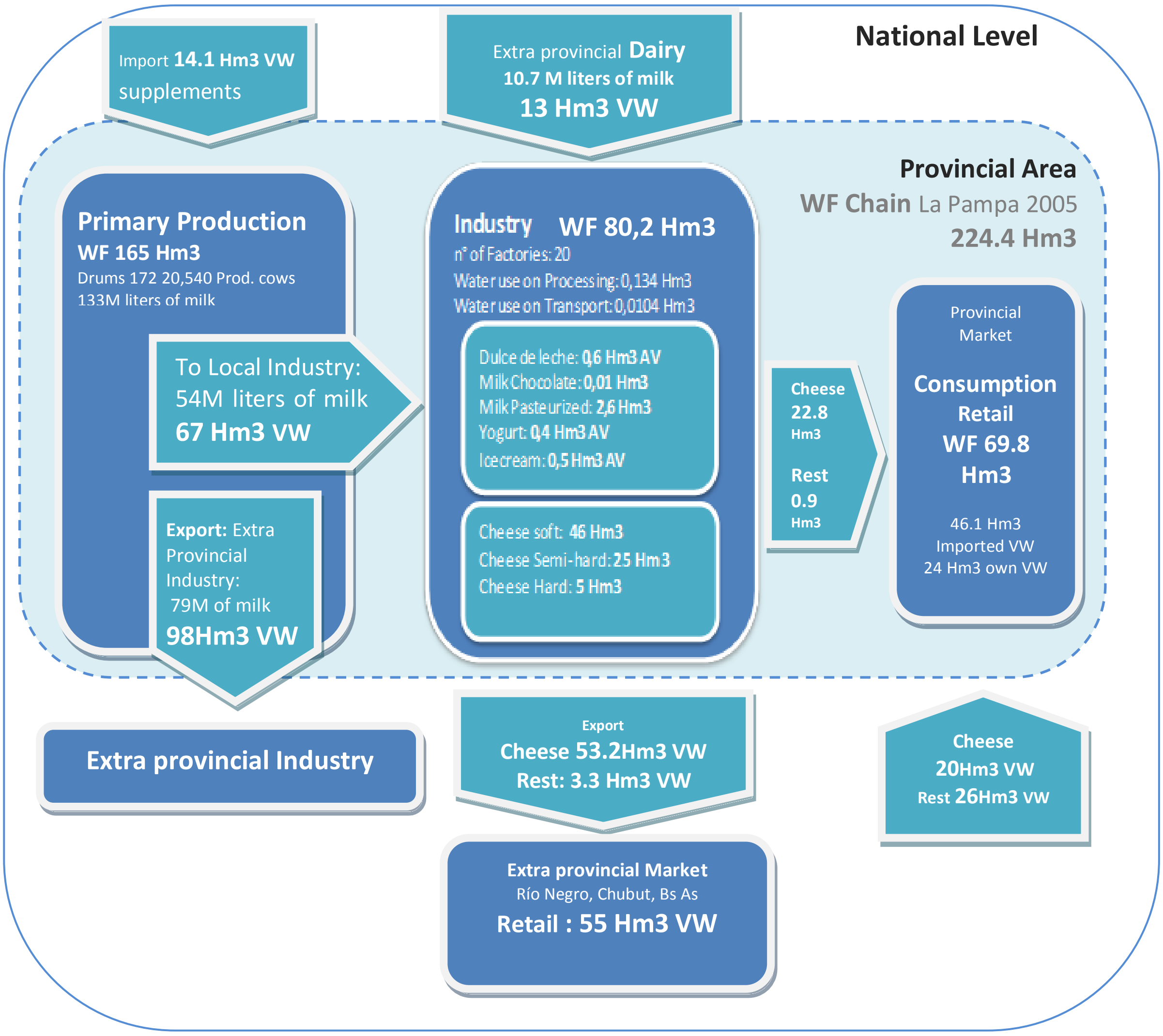

Figure 7 - Virtual Water Flow of Milk Chain of Pampa, year 2005

The dairy chain of La Pampa is a net Virtual Water Primary Production exporter in an estimated value of 84 Hm3 (export minus import flow). Only 40% of its virtual water flow is added to the local industry.

For 2005 annual chain production and trade flow volumes, the provincial Industry is also a net exporter of virtual water, estimated at 42.2 Hm3 (mainly Cheese). The 83% of the total water footprint of the Industry (80.2 Hm3) comes from local origin, and exports 53.2 Hm3 of virtual water by cheese sales outside the province (Figure 7).

The provincial water footprint of Consumption of dairy products, estimated at 69.8 Hm3, comprises 66.1% of virtual water imported from other provinces.

At the aggregate level, provincial milk chain is a net exporter of virtual water, with a value of 80.1 Hm3.

These values let to identify certain structural features of the flow:

1. **Primary production:**

   The high primary production share on total milk chain water footprint (74%) and its prevalence of VW content in the supply of local industry (83.5%), highlights the importance of optimizing productivity levels of dairy farmers, increasing water productivity in these systems.

2. **Industry**

   The water footprint is determined almost entirely by the VW content of the raw material incorporated into their products.

3. **Consumption:**

   The pattern of consumption estimates for the province of La Pampa and the particularities of the dairy market, show a high dependency ratio of external water for consumption of 66.1%, defined as the ratio between the virtual water content of imports for consumption and the total water footprint of provincial consumption.

4. **General**

   a. The pattern of supply of the dairy industry and the nature of provincial net exporter of virtual water, revels the high total water self-sufficiency ratio for the milk Chain: 67.2%, defined as the ratio between internal virtual water and the total Chain water footprint.

   b. On the supply side: Economic valuation of net exports flow, where a high proportion of its total VW has less economic value (raw material), provides an additional reason for the importance of adding value to primary production source (i.e. adding value to water), apart from the reduction of idle capacity in industry on average 33% as is noted by Iturrioz and Iglesias (2009).

   c. The maximization of the value of water productivity also implies minimizing the economic cost of water use inefficiency in a milk chain.

   d. On the demand side / consumption: as an environmental objective would focus on minimize their water footprint, it would be relevant for the dynamic of consumption to address the substitution of imported virtual water only if the water footprints of imported goods are lower than local ones.

San Luis Virtual Water Flow

Virtual Water Flow Chain of San Luis for the year 2008 was determined according to equation (6), Section II. The total water footprint of the chain was estimated at 151 Hm3, noting that local consumption of dairy products add 84.9 Hm3 of water through imports of dairy products from other provinces to the 66.2 Hm3 content of Virtual Water Footprint of local chain products (Figure 8).

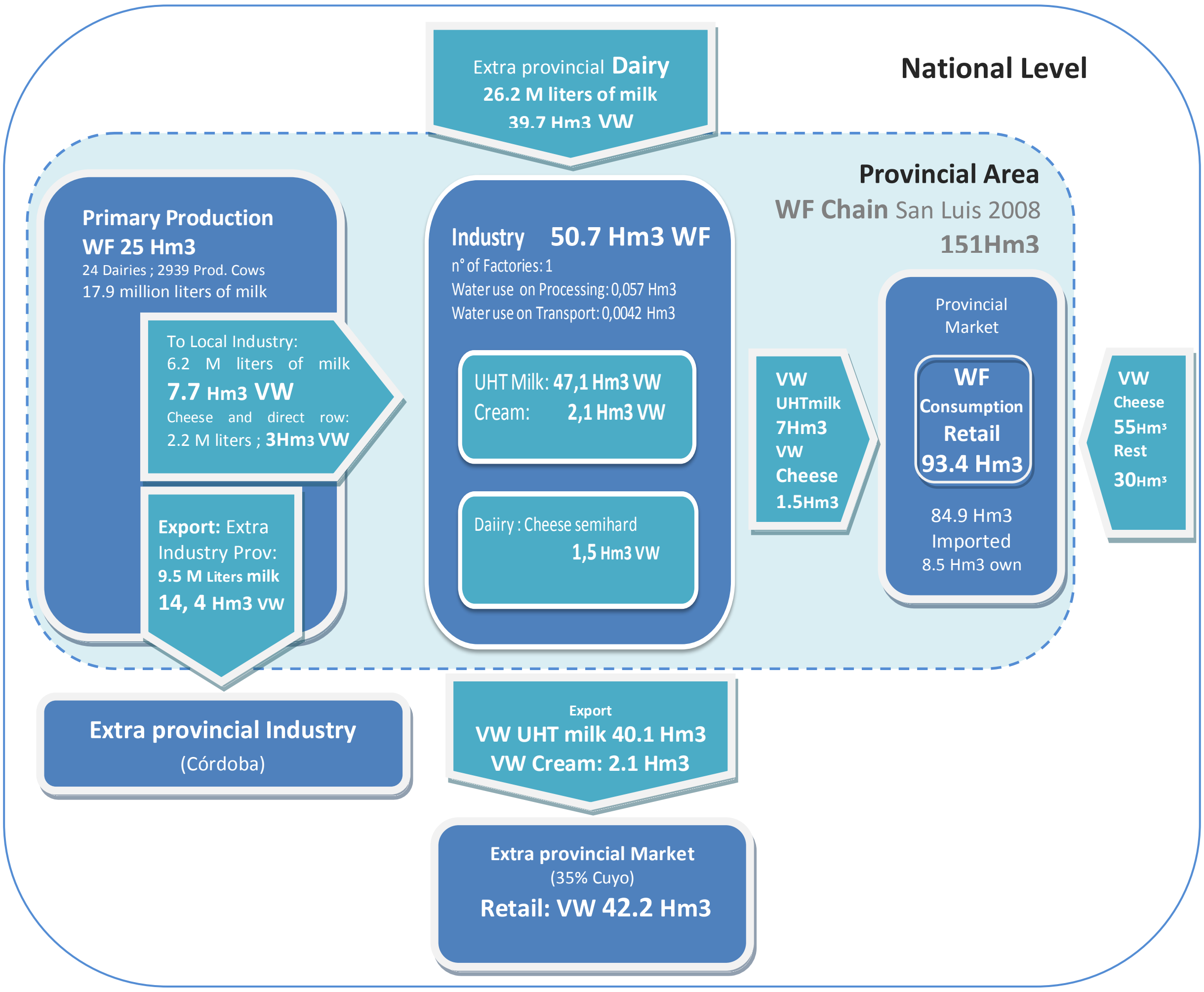

Figure 8 – Virtual Water Flow of San Luis Milk Chain, year 2008

San Luis milk chain is slightly net exporter of Virtual Water in its Primary Production with an estimated value of 7.4 Hm3. From the total Water footprint of primary production of 25Hm3, only 37% is added to the local industry.

For the volumes of production and trade flows of specific products in the considered period, the provincial Industry is net export of virtual water, with an estimated value of 42.2 Hm3, explained almost entirely by the exports of UHT milk.

Virtual water imports of raw material supply equate this value, so the resulting balance of net exports is only 2.2 Hm3. Only 18% of the total water footprint of the industry, estimated at 50.7 Hm3, is rooted in local VW, revealing a high dependency ratio of external water supply.

The provincial water footprint of Consumption of dairy products, estimated at 93.4 Hm3, is 90% externalized, this is, consist on virtual water imported from other provinces.

At the aggregate level, the provincial milk chain is a net importer of virtual water of 75.3 Hm3.

It highlights that 54% of primary milk production is concentrated in the two Mega dairy farms, their relative more eco-efficiency water use is reflected by their lower participation in the water footprint of primary production: 37.5% (Table 10).

Table 10-Water Footprint of Primary Production of San Luis-2008					
Stock	n° dairy	Cows average	Daily average production (L)	Total Production (L)	Water Footprint (Hm3)
less 20	8	12	87	159.049	0,4
20-50	4	37	628	916.789	2,1
50-100	6	74	1.327	2.905.856	6,6
100-200	4	162	2.916	4.257.360	5,8
Mega dairy	2	840	13.250	9.672.500	10,3
total	**24**	**2.939**	**Annual Production**	**17.911.554**	**25,2**

Source: own based on Manazza (2009).

The particular structure of the milk chain in San Luis, characterized by its small size in primary production and a predominant flow of external supply by the provincial milk industry, show the low total water self-sufficiency ratio for the Chain: 13%, defined as the ratio of internal virtual water to the total water footprint of the Chain. A further reading of the supplement mentioned ratio, reflects the high degree of externalization of the water footprint by this provincial agrifood chain through virtual water imports.

VI. Conclusions

- One value of this work is to make contributions to the convergence between the LCA methodological framework and the implementation of virtual water and water footprint indicators for environmental impact assessments and economic development.
- Primary production and particularly the animal feed, is largely the main determinant of Virtual Water indicator for both dairy products analyzed, accounting 99% of its value. In the dairy systems studied, the green water is the main contributing factor to the Virtual Water indicator.
- The results obtained from the analysis of cases in both provinces provide evidence of a negative relationship between productivity per hectare and water footprint, revealing the importance of considering system heterogeneities on water footprint estimates.
- The high values of water costs per unit of output (liter of milk) on dairy systems that use irrigation, show the significant importance of optimizing water use efficiency and maximizing the productivity of the system.
- The analysis of the flow of virtual water and water footprint Dairy Chain in both provinces, identified certain structural characteristics in relation to the use of water resources. Water Footprint of San Luis milk chain is highly externalized, while La Pampa milk chain has a high water self-sufficiency ratio, but strategies for adding value to water productivity are required.
- Further analysis is necessary regarding the redistribution of water between different productive activities to focus on eco-efficiency analysis in a complete and not partial sense. It must involve not only the economic aspects derived from the value and productivity of water, but also all those other things that do not involve strictly socioeconomic productivity like social and environmental factors in all dimensions of impact.

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