Journal of Cleaner Production 88 (2015) 196–204

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Environmental impact of water supply and water use in a Mediterranean water stressed region

Javier Uche [a,*], Amaya Martínez-Gracia [a], Fernando Círez [a], Uriel Carmona [b]

[a] Natural Resources Area, CIRCE Research Institute, University of Zaragoza, María de Luna s/n, 50018 Zaragoza, Spain
[b] Cinara Institute – Engineering Faculty, Del Valle Cali University, Colombia

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form
28 April 2014
Accepted 28 April 2014
Available online 17 May 2014

Keywords:
Water supply
Water use
Water scarcity
Water LCA
Water stress index
Eco indicator 99

ABSTRACT

In this paper, the comprehensive approach provided by the Life Cycle Assessment (LCA) in water management is shown. It includes the LCA of the diverse water supply alternatives within a region but also the LCA of further water uses. The case study is the Segura Basin, a dry area in the southeast of Spain with important water demands. Thus, external alternatives like water transfers and desalination are required to partly balance the reduced natural water availability. The paper firstly shows the environmental impacts of water supply alternatives, depending on its contribution to the water balance in the watershed. Secondly, the LCA of water use in that water stressed area is also analysed, in order to compare both impacts. The target is to analyse if alternatives reduce the global impact of water supply and to compare that damage with that derived from water use. Both LCA approaches are integrated by using the Eco-Indicator 99 method.

Results show that seawater desalination has the highest impact, but external solutions as the Tajo-Segura water transfer are also impacting solutions when low water volumes are delivered. The lowest impacts are found for local natural resources. Regarding the freshwater use, highest impacts are due to agriculture, since water consumed exceeded its natural resources. It has been demonstrated that diversification of water supply alternatives considerably increases the environmental impact of the use of water in scarce areas. Consequently, water users and policy makers should be aware of hidden costs to guarantee the water supply in these regions.

1. Introduction

Energy consumed in the water cycle increases as seawater desalination and large transport infrastructures are required to supply fresh water. Through the water cycle, water is consumed and evaporated while its quality is degraded as well, and some additional energy to restore the former quantity and quality is required. Relevant figures could be reached: in Spain, water cycle is about the 7% of the consumed electricity (Hardy and Garrido, 2010). However, more aspects need to be included in the analysis in order to perform a complete analysis of the associated impacts of fresh water use (Stoeglehner et al., 2011). Life Cycle Analysis (LCA) is crucial if not only energy issues are compared from a global perspective in the water sector. Studies combining LCA with other water assessment methodologies such as water footprint (Jefferies et al., 2012) are being developed and present huge interest. Additionally, some other life cycle environmental impacts related to the construction of the water treatment plants (WTP) and distribution networks, land use, or impacts associated to further uses of water should also be considered (Igos et al., 2013).

If several water supply alternatives are feasible within a region, the interest could then be focused on the comparison among the different water alternatives. Additionally, in water scarce areas, the study of the environmental impacts associated to water uses (urban, industrial and farming) and local freshwater depletion could lead to a very weak sustainability. Thus, the reduction of the environmental impact could be found by two alternative and/or complementary ways: either introducing new "green" water technologies, or alternatively, drastically reducing the present water demands in the region. In this sense, different studies can be found in literature in relation to the use of renewable energies for water systems. As an example, possibilities of desalination driven by renewable sources has been analysed (Koroneos et al., 2007), as well as specific solutions for polluted water being cleaned by sanitation and supply technologies driven by solar energy (Jasrotia et al., 2013). Additionally, many analyses of strategies to minimize the use of water in industrial (Sans et al., 1998) and domestic

* Corresponding author. Tel.: +34 976 25 84; fax: +34 976 73 20 78.
E-mail address: javiuche@unizar.es (J. Uche).

http://dx.doi.org/10.1016/j.jclepro.2014.04.076
0959-6526/

Abbreviations

AGUA	Actuaciones para la Gestión y Utilización del Agua (Actions for the Management and Use of Water)
ED	Ecosystem diversity
ERWT	Ebro river water transfer
GW	Ground waters
HH	Human health
LCA	Life cycle assessment
LCA	Life cycle assessment
LCIA	Life cycle impact assessment
LSW	Local surface waters
MCT	Mancomunidad de los Canales del Taibilla
NPP	Net primary production
P	Precipitation
SEC	Specific energy consumption
SWDP	Seawater desalination plant
TSWT	Tajo-Segura water transfer
VF	Variation factor
WA	Water availability
WR	Water reuse
WSI	Water stress index
WTA	Ratio of total annual freshwater withdrawals to hydrological availability
WTP	Water treatment plant
WU	Water use
WWTP	Wastewater treatment plant

sectors have been performed (Beal et al., 2013), frequently introducing efficiency concerns (Willis et al., 2013).

Lack of data to perform the LCA inventory in water cycle is evident. Then, it has been usually focused into a single stage. Examples of the LCA application could be found in literature to a water treatment plant (WTP) (Bonton et al., 2012), with specific case studies such as those presented about three different water systems in Copenhagen (Godskesen et al., 2011), as well as to LCA of drinking water alternatives (Vince et al., 2008), seawater desalination (depending on energy sources) (Raluy et al., 2004, 2005a), water supply network (Filion et al., 2004) and wastewater treatment plants (WWTP) in specific locations such as Bologna in Italy (Tarantini and Ferri, 2001) or Bree in Belgium (De Gussem et al., 2011), even considering further water reuse (Ortiz et al., 2007). The LCA analysis of water supply alternatives to a region was firstly applied to California (Stokes and Horvath, 2006). In Europe, the first LCA approach was proposed by Estevan (2008), who included the predominant environmental impact of hot sanitary water use in Spanish dwellings. Afterwards, different studies have been focused on the environmental assessment of the urban water cycle (Lemos et al., 2013), especially in locations with some water stress such as the Mediterranean area (Amores et al., 2013). The work presented by Hospido et al. (2013) points out the difficulties of properly complete the water use in the life cycle assessment, since it presents several origins, irregular geographical distribution and diverse ecosystems functions. The urban wastewater reclamation and reuse alternatives in the Mediterranean area have been studied by Pascualino (2011) with the LCA methodology as well.

The Segura Basin is a water stressed region in Mediterranean Europe (southeast of Spain). Huge investments of water works historically tried to solve the water scarcity in Spain and especially in the Segura Basin (Albiac et al., 2007). The Ebro River Water Transfer (ERWT) was proposed but finally abandoned in 2005 because of the provoked regional conflicts and the refuse of the European Union (EU) to fund the works. The following alternative (AGUA programme), partially financed by the EU, was based on new 20 seawater desalination plants (SWDP). Both infrastructures, transfer and desalination, were already studied from the LCA perspective (Raluy et al., 2005b; Muñoz et al., 2010), and a small advantage to desalination against the ERWT was found because of the large path required (900 km) and the seasonal availability of natural water resources from the Ebro. Nowadays, the operating SWDP does not fully cover the water deficit of the region, and desalted water costs seem to be very expensive to farmers. Thus, water deficit is balanced by groundwater (uncontrolled) overexploitation, if natural local water resources are not available.

Two complementary main lines are considered in this work. Firstly, the LCA of the water supply alternatives within the Segura Basin includes the environmental comparison of local alternatives (natural surface resources and ground waters), as well as the external ones: Tajo-Segura water transfer (TSWT) and seawater desalination. Base case (scenario 1) corresponded to the 2009 water balance. Irrigation and drinking water were distinguished in the analysis, since they presente significant differences. Two additional stages are required for drinking purposes: water supply network and water treatment plants. Once the base situation was analysed, three additional scenarios (2–4) were included in order to know, from the LCA approach, the environmental impact in wet and dry years, or the dependence from the TSWT. The four scenarios maintained the overall water demands on the watershed. Secondly, apart from water cycle infrastructures, the environmental impact of water consumption in this water scarce area was also calculated for the four different scenarios. The main purpose of this paper is then to show the combined LCA of the water supply alternatives and the water use in this water-stressed region in order to compare the environmental consequences, from the LCA perspective, of widening (or not) the supply options in order to reduce the depletion of local water resources.

2. The case study: the Segura Basin

2.1. Water demands and water balance

Segura Basin (see Fig. 1) has a surface of 18,870 km^2 and stable population of 1,850,000 inhabitants (in 2001). Average rainfall is about 400 mm/year, but potential evapotranspiration rises up to 700 mm/year (SBWA, 2007a). The water balance and the supply alternatives are presented in Table 1. Detailed description of water supply infrastructures is supporting information not included in the paper, but it is available upon the request to the corresponding author.

As we can see, annual water demand in the Segura Basin totalizes 1483 Mm^3/y. Farming is, by far, the highest water consumer (1117 Mm^3/y), since profitable crops have been traditionally cultivated in large irrigation surfaces (around 250,000 ha). Annual natural water availability (local surface waters, LSW) is only about 318 Mm^3 for an average year (SBWA, 2007b). LSW are stored in several reservoirs (see Fig. 1 for location). Water demands are partially balanced by the water transfer from the Tajo River (TSWT), which delivered, on average, 368 Mm^3/y in the period 1998–2009, and seawater desalination (SWDP), which was used