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Water use performance of water technologies: the Cumulative Water Demand and Water Payback Time indicators

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ABSTRACT

The effective management of fresh water through the use of water technologies is central to international debate. However, available indicators used to measure the performance of water technologies have several limitations: they do not comprehensively assess the quantity and quality of water use; they are not able to measure the benefits of locally recovered resources; and they are not simple to apply in a life-cycle perspective.

The goals of this paper are to develop a set of indicators based on the Cumulative Energy Demand (CED) and Energy Pay-Back Time (EPBT) models used in the energy sector to compare the performances of water-use technologies in different locations and therefore measure their benefits in term of recovered water resources in different contexts.

The Cumulative Water Demand (CWD) and Water Pay-Back Time (WPBT) indicators were developed and tested in a case study of a water-collection system produced in Padova (Italy) and installed in Rovigo (Italy). To determine their effectiveness, a simulation of their application to the same technology in different Italian locations was performed.

The results confirmed the applicability of the designed set of indicators and the effectiveness of the WPBT in measuring their performance in different contexts. To obtain comprehensive information on the quantity and quality of water used, it is recommended that CWD and WPBT be used together.

1. Introduction

World population growth and economic development have put significant stress on the availability of natural resources such as fresh water (Bates et al., 2008; El Gohemy, 2012). Effective management of this resource is necessary to guarantee human wellbeing and a safe environment from a socio-political perspective and to obtain efficient production and brand competitiveness from a company perspective (Orr et al., 2007; EC, 2012). This topic has been debated at the international level (Dworak et al., 2007; Bates et al., 2008) and several institutional programs have been launched to address this issue (UN, 1992; EC, 2010; EC, 2012 UN, 2012). In this context, research on and investment in efficient water technologies (such as collection, treatment, purification, reuse, recovery) worldwide have grown rapidly in the last decade and are considered a priority area of intervention (EC, 2000; Dworak et al., 2007; El Gohemy, 2012).

At the same time, several studies confirmed the importance of assessing environmental impacts of water technologies (Foley et al., 2010; Hancock et al., 2012; Angrill et al., 2012; Bonton et al., 2012; Godskesen et al., 2012a,b, 2013). Recent methodological approach developments propose the integration of LCA with impact assessment indicators related to water (Berger and Finkbeiner, 2010; Hoekstra et al., 2011; Jeswani and Azapagic, 2011; Galli et al., 2012; Kounina et al., 2013; Mazzi et al., 2014; ISO, 2013); however only a few indicators have been specifically developed to assess the environmental performance of water technologies related to water. Angrill et al. (2012) developed a specific indicator of environmental performance for water-collection technologies based on the model of Hoesktra et al. (2011) that considered water consumption but not the quality of water entering the different life-cycle processes. Therefore, it is not sensitive to the improvement or degradation of water functionality (Kounina et al., 2013). Godskesen et al. (2012a,b) created an indicator of water withdrawal and applied it to water-collection and -treatment technologies, but this indicator presents the same limitations of the model of Angrill

Acronyms: CED, Cumulative Energy Demand; CWD, Cumulative Water Demand; CWU, Cumulative Water Use; DWU, Degradative Water Use; EPBT, Energy PayBack Time; HDPE, High Density Polyethilene; LCA, Life Cycle Assessment; V_{in}, volume of water entering the unit process; V_{out}, volume of water out of the unit process; WF, Water Footprint; WPBT, Water Pay Back Time; α, water quality coefficient.

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et al. (2012). Igos et al. (2013) stated that current indicators do not allow to measure the benefits of water technologies in terms of recovered water resources (quality and quantity) adopting a life cycle perspective. Chen et al. (2012) and Marìn (2012) underline how LCA studies integrated with water use and impact analysis (as in the above-mentioned studies) are expensive in terms of resources and show that there is a clear need to develop simplified tools that allow performance comparison of different technologies in the same location or evaluation of the same technology in different locations that are easy to understand.

Based on a literature review of performance indicators of water technologies, the following gaps emerge:

- indicators do not comprehensively consider water consumption and degradation;
- they are not able to measure the benefits in terms of recovered resources in a specific location; and
- they are too arduous to apply within a LCA.

In other contexts, such as renewable energy and energy recovery technologies, a set of performance indicators that respond to these needs have been developed and are widely used, including cumulative energy demand (CED) and energy pay-back time (EPBT) (Frischknecht and Jungbluth, 2007; EC-JRC, 2011; Scipioni et al., 2012). They consider the qualitative and quantitative aspects of used and recovered/produced energy, allow comparison of different technologies in the same location or evaluation of the same technology in different locations, are easy to assess and communicate compared to the results of a full LCA study, and measure the benefit derived from the exploitation of an energy technology (Brendt, 1982; Wilson and Young, 1996; Tahara and Atsushi Inaba, 1997; Knapp and Jester, 2001; Dixit et al., 2010; Raugei et al., 2012).

The goals of this study are to develop a set of indicators that are applicable to water technologies based on the CED and EPBT models to compare the performances of same technology in different locations and therefore measure the benefits of the application of water technologies in terms of recovered water resources in different contexts.

2. Materials and methods

2.1. Criteria used to define the water-use indicators

CED and EPBT were used as model to define the set of indicators applicable to water technologies.

CED is an inventory indicator used within the framework of LCA studies (ISO, 2006a, 2006b; EC-JRC, 2011) that measures the direct and indirect use of energy from a quantitative and qualitative perspective (e.g., renewable or non-renewable) (Frischknecht and Jungbluth, 2007). It reports the different quantity of energy carriers in a single comparable unit, with primary energy expressed in MJ (Huijbreghts et al., 2006; Frischknecht and Jungbluth, 2007). EPBT measures the time needed for an energy production or recovery technology to pay back the CED required in its life cycle. It is defined as the ratio between the CED and the net energy recovered or produced by the technology while in use. Like CED, it is used within the context of LCA studies (Wilson and Young, 1996; Tahara and Atsushi Inaba, 1997; Knapp and Jester, 2001; Gagnon, 2008; Gagnon et al., 2009; Nishimura et al., 2010; Fthenakis et al., 2011; Raugei et al., 2012).

The key issues in defining the performance of water technologies are the following:

- Fresh water use can be degradative (Fig. 1) and consumptive (Fig. 2); the first results in the degradation of water quality, and the second accounts for water that is not returned to the original water basin because of evaporation, product integration or the return of the water to a different watershed or the sea (Bayart et al., 2010; Boulay et al., 2011).
- System approach (Brunner and Rechberger, 2004): the water technology is represented and analyzed through its processes, flows and stocks; other aspects such as the origin and the destination of the resource (e.g., surface water, groundwater, rainwater etc.), the geographical location and time span of the water use (Bayart et al., 2010; Boulay et al., 2011) also need to be considered.
- Mass Balance (Brunner and Rechberger, 2004); water flows, so the quantity and quality (physical, chemical and biological parameters) of inputs and outputs should be considered and mass balanced (Falkenmark, 2000; Berger and Finkbeiner, 2010; Boulay et al., 2011).

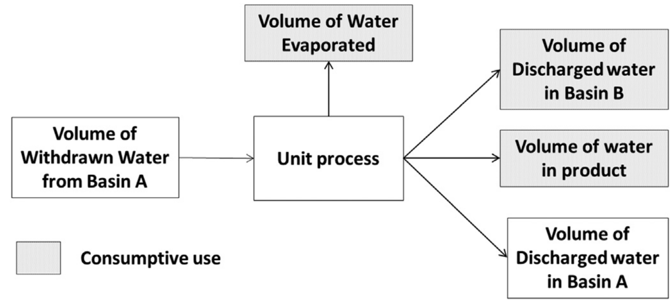

Fig. 1. Degradative water use.

To develop water-use indicators of water technologies the following criteria are adopted:

- Resource use focus (Frishcknet et al., 2007; EC-JRC, 2011; Scipioni et al., 2012): the indicators should focus on the direct and indirect use of the resource. Other environmental aspects (such as climate change or eco-toxicity) should not be considered;
- Type of assessment (VDI, 1997; Frischknet et al., 1998, 2007): the indicators should report on the quantity and quality of the resource used;
- Life-cycle perspective (Frishcknet et al., 1998; 2007; EC-JRC, 2011; Scipioni et al., 2012): the indicators should consider the life cycle processes of the water technology understudy;
- Inventory analysis level (Frishcknet et al., 1998, 2007; EC-JRC, 2011; Mazzi et al., 2014): the indicators should be related at the inventory level. The goal and scope of the study must be defined, and inventory analysis must be performed. Impact assessment should not be included in the study.

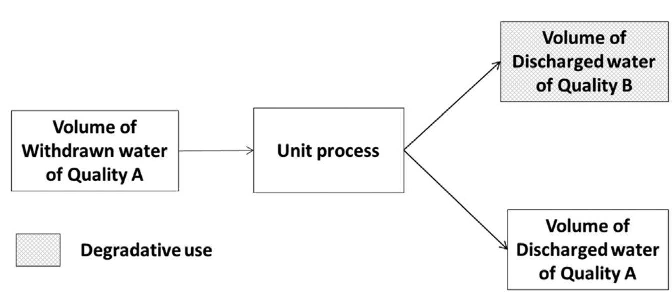

Fig. 2. Consumptive water use.