Journal of Cleaner Production 93 (2015) 318–329

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

A contribution to the environmental impact assessment of green water flows

Paula Quinteiro [a, *], Ana Cláudia Dias [a], Margarida Silva [b], Bradley G. Ridoutt [c], Luís Arroja [a]

[a] *Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

[b] *Forest and Paper Research Institute (RAIZ), Quinta de São Francisco, Private Bag 15, 3801-501 Eixo, Aveiro, Portugal*

[c] *Commonwealth Scientific and Industrial Research Organisation (CSIRO), Sustainable Agriculture National Research Flagship, Private Bag 10, Clayton South, Victoria 3169, Australia*

ARTICLE INFO

Article history:
Received 10 March 2014
Received in revised form
4 November 2014
Accepted 8 January 2015
Available online 17 January 2015

Keywords:
Characterisation factors (CFs)
Eucalyptus globulus
Green water flow
Life cycle assessment (LCA)

ABSTRACT

In recent years, numerous efforts have been made to include water-related issues in life cycle assessment (LCA) methodology. This study provides an overview of existing methods that address green water use in LCA. In this overview, we analyse the main features of existing LCA methods used to examine changes in long-term blue water availability caused by variations in green water flows, particularly with respect to inventory, the characterisation model and characterisation factors.

Moreover, we propose a method of assessing impacts on terrestrial green water flows (TGWI) and addressing reductions in surface blue water production (RBWP) caused by reductions in surface runoff due to land-use production systems. Both TGWI and RBWP are analysed, taking into account the green water use/atmosphere and green water use/soil interfaces.

In this proposed method, the life cycle inventory (LCI) phase considers the net green water flow that leaves the land-use production system, allowing the study of two alternative reference land uses: 1) quasi-natural forest and 2) grasslands/shrublands. In the life cycle impact assessment (LCIA) phase, regional- and species-specific characterisation factors (CFs) for the amount of green water evaporated or transpired are also proposed.

To illustrate the applicability of the proposed method, we employed a case study on *Eucalyptus globulus* stands (first rotation), located in Portugal. The results show that different impacts on terrestrial green water flows and on surface blue water production are obtained depending on the alternative reference land use. Moreover, the case study shows that the method developed can be a useful tool assisting in improved national *E. globulus* forest planning.

1. Introduction

Anthropogenic activities associated with land-use changes and current climate change trends have been increasing pressure on freshwater natural resources. Numerous efforts have been undertaken to include water-related issues in life cycle assessment (LCA) methodology. Over the last five years, consideration of water use in LCA has progressed rapidly, resulting in a complex set of methods for addressing different water types and sources, pathways and characterisation models at midpoint and endpoint levels, and with different spatial and temporal scales (Kounina et al., 2013; Tendall et al., 2013).

Studies have been carried out related to water abstraction and human appropriation (e.g. Boulay et al., 2011; Milà i Canals et al., 2009; Núnez et al., 2012; Pfister et al., 2009; Ridoutt et al., 2010), the potential impacts of blue water use on ecosystems (e.g. Hanafiah et al., 2011; Pfister et al., 2009; Tendall et al., 2014; Van Zelm et al., 2011; Verones et al., 2013) and water pollution, related to the discharge of eutrophying, acidifying and ecotoxic compounds into freshwater systems (e.g. Azevedo et al., 2013; Goedkoop et al., 2013; Helmes et al., 2012; Seppala et al., 2004; Struijs et al., 2011). However, less attention has been paid to green water use and green water flows. Green water use refers to precipitation on land that does not run off or recharge the

---

* Corresponding author. Tel.: +351 234 370 349.
E-mail address: p.sofia@ua.pt (P. Quinteiro).

http://dx.doi.org/10.1016/j.jclepro.2015.01.022
0959-6526/

groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. It also refers to the rainwater incorporated into harvested crops or wood (Hoekstra et al., 2011). Green water flow refers to the portions of green water used by soil and vegetation that is evaporated or transpired.

Both green water use/soil and green water use/atmosphere interfaces should be considered in assessing the potential environmental effects resulting from changes to green water flows due to land use. The methods developed for assessing green water flows have been more concerned with the interface between green water use/soil, i.e. how a change in green water affects the regional long-term availability of surface blue water (Fig. 1) (Milà i Canals et al., 2009; Núnez et al., 2012; Ridoutt et al., 2010). The water use/atmosphere interface assumes particular relevance because terrestrial evapotranspiration (ET) has been identified as a significant source of precipitation for land-use production systems (Ellison et al., 2012; Trenberth, 1999; Van der Ent et al., 2010). Recently, Berger et al. (2014) have taken the first steps in considering the water use/atmosphere interface in LCA, i.e. how land use affects the ET that is recycled to the atmosphere and then the precipitation that returns to the regional terrestrial ecosystem (Fig. 1). These authors examine the atmospheric evaporation recycling within watersheds and analyse their vulnerability to water depletion.

Human-induced vegetation can significantly change the volume of water that is evaporated or transpired into the atmosphere in comparison to potential natural vegetation (PNV) (Ridoutt et al., 2010; Rost et al., 2008; Scanlon et al., 2007). Precipitation depends on the evaporation from oceans and recycled moisture from terrestrial surfaces. Van der Ent et al. (2010) have demonstrated that 40% of global terrestrial precipitation on average originates from terrestrial surfaces and 60% comes from oceans. Moreover, these authors suggest that 57% of all terrestrial evaporation returns as precipitation to land surfaces. The external forcing and climatic parameters, such as solar radiation, aerosols and greenhouse gases, affect sea surface temperature and therefore influence ocean evaporation. On the other hand, terrestrial evaporation is strongly influenced by climatic parameters (e.g. precipitation, air temperature, daily solar radiation and relative humidity), as well as by nonclimatic parameters for soil and vegetation (e.g. soil-root zone water holding capacity, canopy conductance and leaf area index). The growth and resilience of vegetation is largely precipitation-dependent and the recycled moisture contributes to regulation of the hydrological cycle (Foley et al., 2003; Jung et al., 2010) as well as to regulation of biomass/food production (Falkenmark and Rockstrom, 2004; Rockstrom et al., 1999). For instance, deforestation reduces the surface roughness and leaf area, which in turn limits the green water flows recycled into the atmosphere, thereby contributing to a decrease in precipitation levels (Pielke et al., 2006; Van Dijk and Keenan, 2007).

In this study, an overview of methods addressing ET is conducted in order to understand how green water flows have been and should be considered in LCA. Furthermore, we propose a method for assessing impacts on terrestrial green water flows (TGWI) and addressing reductions in surface blue water (river) production (RBWP) caused by reductions in surface runoff due to a land-use production system. This method encompasses the life cycle inventory (LCI), which accounts for green water flows recycling into the atmosphere due to specific types of land use, and proposes regional- and species-specific characterisation factors (CFs) in the life cycle impact assessment (LCIA) phase.

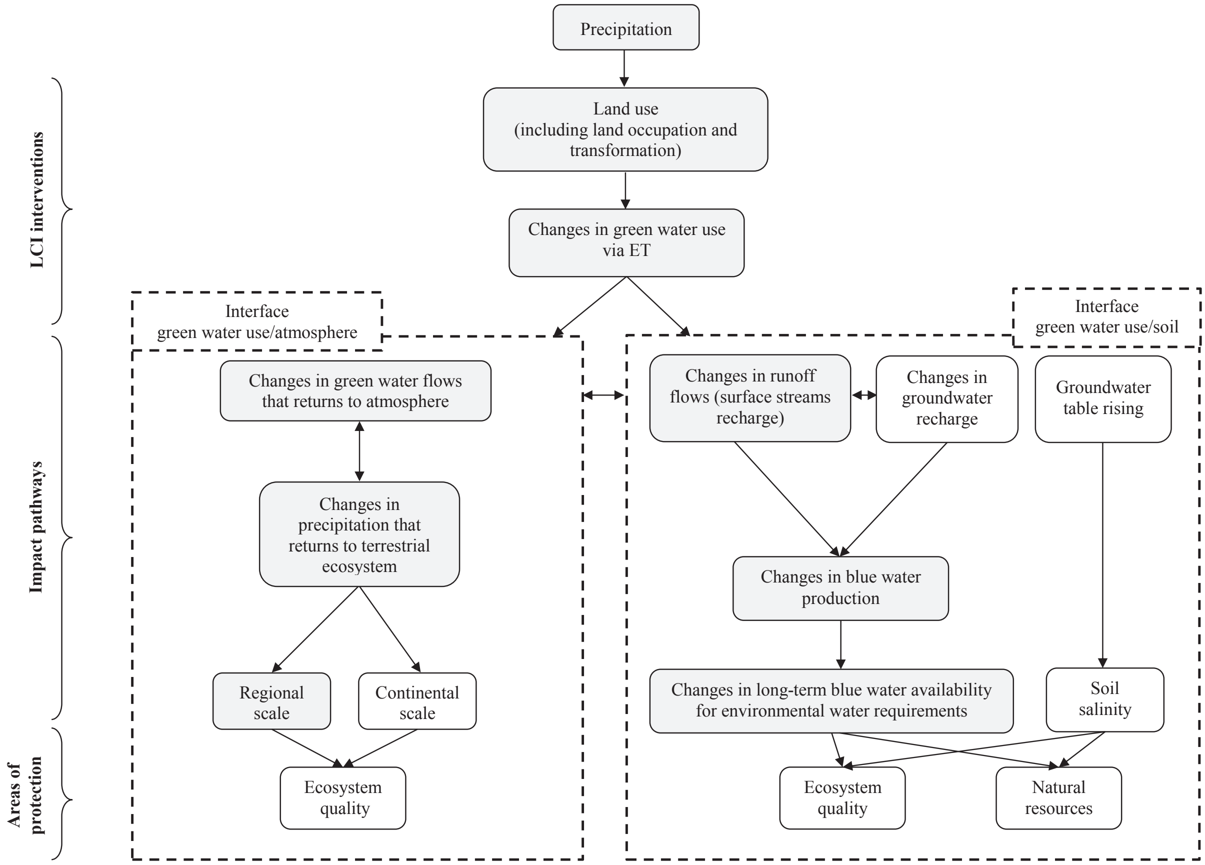

Fig. 1. Potential environmental impact pathways related to changes in green water flows. The shaded boxes are related to the pathway focused on this study.