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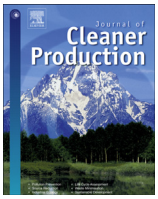

Carbon, water and land use footprints of beef cattle production systems in southern Australia

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ABSTRACT

For agri-food products, environmental impacts related to greenhouse gas emissions, water use and land use are all typically of high concern. Concurrent assessment is therefore important to report meaningfully on environmental performance and to avoid potential negative consequences of narrowly focussed environmental improvement strategies, such as carbon footprint reduction alone. In this study, land use footprints were calculated for six diverse beef cattle production systems in southern Australia (cradle to farm gate) using net primary productivity of potential biomass (NPP_0) as a means of describing the intrinsic productive capability of occupied land. The results per kg live weight, ranging from 86 to 172 m^2 yr-e (where 1 m^2 yr-e represents 1 m^2 of land occupation for 1 year at the global average NPP_0) represent between 1.3 and 2.7% of an average global citizen's annual land use footprint, and highlight the importance of land use in beef cattle production. These results were approximately 10 and 1000 times the normalised carbon and water scarcity footprint results. The diversity of land types supporting livestock production underscores the importance of taking into account land quality in the calculation of a land use footprint. While NPP_0 can be used to improve land use assessment beyond a simple measure of land area, further development of the land use footprint indicator is recommended and discussed.

1. Introduction

For agricultural and food products, environmental impacts related to greenhouse gas (GHG) emissions, water use and land use are typically of high concern. This means that the evaluation of alternative agri-food production systems and products is not straightforward as options frequently involve tradeoffs between one source of impact and another. For example, land can be used for biodiversity conservation and carbon sequestration or it can be used for food production, and some forms of agriculture conserve more soil carbon, perennial biomass and biodiversity than others. Alternatively, actions to reduce GHG emissions in agriculture might require greater water use, and interventions to achieve water efficiency and water quality objectives might necessitate greater use of energy and consequently increase GHG emissions (Heller and Keoleian, 2011; Pfister et al., 2011; Ridoutt et al., 2011; Stoessel et al., 2012). Furthermore, a small area of irrigated cropland might produce as much food as a much larger area of non-irrigated land and thereby be considered land use efficient and beneficial in terms of minimising pressure on land resources – so-called land sparing (Balmford et al., 2005; Egan and Mortensen, 2012; Phalan et al., 2011).

This complexity highlights the futility of comparing the environmental performance of food production systems or products using any single footprint indicator. While carbon footprinting of products has been influential in raising awareness about GHG emissions and has even been described as a catalyst for life cycle thinking and management (Weidema et al., 2008), concern has also been raised that the practice violates the core principle of life cycle assessment (LCA) known as *comprehensiveness*, meaning that consideration should be given to all relevant environmental impacts (Finkbeiner, 2009). Similar concerns could also be raised in relation to water footprints, which consider only water use impacts (Ridoutt, 2011). As such, it is possible to discern in recent years a progression toward multiple footprint indicator studies (Bernardi et al., 2012; Čuček et al., 2012; Díaz et al., 2012; Ewing et al., 2012; Galli et al., 2012; Hammond and Seth, 2013; Hanafiah et al., 2012; Kanakoudis et al., 2012; Niccolucci et al., 2010; Nijdam

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et al., 2012; Page et al., 2012; Schaefer and Blanke, 2012; Steen-Olsen et al., 2012) and the concept of an integrated family of footprint indicators is emerging (Galli et al., 2012; Ridoutt and Pfister, 2013). The multi-indicator approach is important because the objective of a life cycle based environmental assessment should not only be to avoid problem shifting from one part of the product life cycle to another, but also from one form of environmental burden to another.

In previous research, the carbon footprints (cradle to farm gate) for six diverse beef cattle production systems in southern Australia were assessed and found to range from 10.1 to 12.7 kg CO_2e kg^{-1} live weight (Ridoutt et al., 2011). The corresponding LCA-based water scarcity footprints were 3.3–221 L H_2Oe kg^{-1} live weight for these same systems (Ridoutt et al., 2012), calculated using the Water Stress Index (WSI) of Pfister et al. (2009). Following Ridoutt and Pfister (2010a, 2012), the reference unit 1 L H_2Oe represents the burden on freshwater systems from 1 L of consumptive freshwater use at the global average WSI. The purpose of the research now being reported was to complement these case study findings for beef cattle with novel land use footprint indicator results. The concurrent assessment of GHG emissions, water use and land use is considered necessary for products in the agriculture and food sectors, and this multi-footprint indicator approach might be considered sufficient for environmental labeling for products in this consumption domain. To assist in the interpretation of the environmental profile for each livestock production system, the indicator results were also assessed after normalisation relative to the average annual environmental impact of a world citizen.

In this study, a resource-based approach to land use footprinting was developed and tested. This approach recognises that productive land is a scarce resource and that the demand for land for the production of any particular goods or services adds incrementally to the pressure on global land resources and the associated wide ranging environmental impacts (e.g. loss of habitat for biodiversity conservation, loss of ecosystem services, local food production deficits). In essence, a global market for land is envisaged to exist, with the possibility that land use in one region may contribute to intensification and expansion of land use in other parts of the world through the agency of trade in agricultural and related commodities (Schmidt et al., 2012). In describing land as a resource, a simple quantitative measure (e.g. m^2 yr) is insufficient as land is not uniform in its productive capability. Land use footprinting must therefore incorporate the quality dimension of land used. At the present time, the modelling of land use in LCA is an emerging field (Finnveden et al., 2009; Milà i Canals et al., 2007) lacking consensus approaches (Hauschild et al., 2013; Mattila et al., 2012). Much of the recent focus, led in part by a project group working under the auspices of the UNEP/SETAC Life Cycle Initiative, has been on the development of methods which assess impacts of land use on biodiversity (de Baan et al., 2013; de Souza et al., 2012), individual ecosystem services such as erosion regulation, freshwater flow regulation and purification (Bos et al., 2012; Núñez Pineda, 2011; Saad et al., 2011; Saad and Margni, 2012), as well as biotic production potential and soil health (Brandão and Milà i Canals, 2012; Garrigues et al., 2012). However, at this point in time, these methods have not generally reached an operational stage of development, lacking normalisation factors and coherence with established impact assessment methods which would allow interpretation and the evaluation of tradeoffs relative to other well established impact category indicators. The exception is the modelling of climate impacts of land use associated with carbon dioxide transfers between vegetation, soil and the atmosphere (Müller-Wenk and Brandão, 2010). Impact assessment methodologies which address individual ecosystem services and which lead to a profile of impact category indicator results relating to land use will be rich in detail and most beneficial in contexts where the LCA practitioner is reporting within the LCA expert community or where they have the opportunity to provide detailed explanation and interpretation to the decision maker (e.g. Milà i Canals et al., 2013). On the other hand, a simplified resource-based approach to land use footprinting, if it can be shown to be environmentally meaningful, could be beneficial in contexts where a single land use footprint indicator, reported using an intuitively meaningful unit, is preferred - such as in the situation of Type III eco-labeling (ISO 14025, 2006).

2. Methods and data

2.1. System description

This case study concerns six geographically defined beef cattle production systems in the southern Australian state of New South Wales (NSW) where cattle are predominantly raised in mixed (i.e. livestock and cropping) farming systems. The six systems (Table 1) were selected in order to be diverse in farm practice (grass and feedlot finishing), product (12–15 month old yearling cattle to 24–36 month old heavy steers), environment (high-rainfall coastal to semi-arid inland) and local water stress (as defined by the WSI of Pfister et al., 2009). The system boundary was from cradle to farm gate and included all of the direct farming inputs (including replacement heifers and bulls), but excluded capital items such as machinery, buildings and other infrastructure. The functional unit

Table 1
Summary of the six geographically-defined beef cattle production systems[a].

Production system		Main product[b]	Location	Mean max Temp[c] (°C)	Rainfall (mm yr^{-1})	WSI[d]
Japanese ox – grass-fed steers	JOS	24–36 month old steers, 340 kg DW	Scone	24.1	644	0.032
EU cattle	EUP	24–30 month old steers, 280–300 kg DW	Parkes	23.4	584	0.815
Inland weaners, grass fattened and feedlot finished	IGF	24 month old steers, 585 kg LW	Walgett	26.9	477	0.021
			Gunnedah	26.0	619	0.021
			Quirindi	24.6	683	0.021
North coast weaners, grass fattened and feedlot finished	NGF	24 month old steers, 585 kg LW	Casino	26.7	1096	0.012
			Glen Innes	19.4	849	0.021
			Rangers Valley	19.4	849	0.021
Yearling	YG	12–15 month old yearling, 185–205 kg DW	Gundagai	22.3	713	0.815
Yearling	YB	12–15 month old yearling, 185–205 kg DW	Bathurst	19.8	635	0.021

[a] Based on data presented in Ridoutt et al. (2012).

[b] DW: dressed weight or dressed carcass weight after removal of hide, head, feet, tail and internal organs; LW: live weight; For beef cattle in New South Wales, Australia the DW is typically 50–55% of LW.

[c] Average daily maximum air temperature as an annual statistic.

[d] WSI: Water Stress Index (Pfister et al., 2009).

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