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Resource use and greenhouse gas emissions from three wool production regions in Australia

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ABSTRACT

Australia is the largest supplier of fine apparel wool in the world, produced from diverse sheep production systems. To date, broad scale analyses of the environmental credentials of Australian wool have not used detailed farm-scale data, resulting in a knowledge gap regarding the performance of this product. This study is the first multiple impact life cycle assessment (LCA) investigation of three wool types, produced in three geographically defined regions of Australia: the high rainfall zone located in New South Wales (NSW HRZ) producing super-fine Merino wool, the Western Australian wheat-sheep zone (WA WSZ) producing fine Merino wool, and the southern pastoral zone (SA SPZ) of central South Australia, producing medium Merino wool. Inventory data were collected from both case study farms and regional datasets. Life cycle inventory and impact assessment methods were applied to determine resource use (energy and water use, and land occupation) and GHG emissions, including emissions and removal associated with land use (LU) and direct land use change (dLUC). Land occupation was divided into use of arable and non-arable land resources. A comparison of biophysical allocation and system expansion methods for handling co-production of greasy wool and live weight (for meat) was included.

Based on the regional analysis results, GHG emissions (excluding LU and dLUC) were 20.1 ± 3.1 (WA WSZ, mean ± 2 S.D) to 21.3 ± 3.4 kg CO_2-e/kg wool in the NSW HRZ, with no significant difference between regions or wool type. Accounting for LU and dLUC emissions and removals resulted in either very modest increases in emissions (0.3%) or reduced net emissions by 0–11% depending on pasture management and revegetation activities, though a higher degree of uncertainty was observed in these results. Fossil fuel energy demand ranged from 12.5 ± 4.1 in the SA SPZ to 22.5 ± 6.2 MJ/kg wool (WA WSZ) in response to differences in grazing intensity. Fresh water consumption ranged from 204.3 ± 59.1 in the NSW HRZ to 393.7 ± 123.8 L/kg wool in the WA WSZ, with differences primarily relating to climate. Stress-weighted water use ranged from 11.0 ± 3.0 (SA SPZ) to 74.6 ± 119.5 L H_2O-e/kg wool (NSW HRZ) and followed an opposite trend to water consumption in response to the different levels of water stress across the regions. Non-arable grazing land was found to range from 55% to almost 100% of total land occupation. Different methods for handling co-production of greasy wool and live weight changed estimated total GHG emissions by a factor of three, highlighting the sensitivity to this methodological choice and the significance of meat production in the wool supply chain. The results presented improve the understanding of environmental impacts and resource use in these wool production regions as a basis for more detailed full supply chain analysis.

1. Introduction

Australia is the largest exporter of greasy wool in the world, trading over 289 thousand tonnes in 2011 (FAO, 2011), from a flock of 68.1 million wool sheep (AWI, 2011), though production has declined in the past two decades (Curtis, 2009). Australian wool production is based on the Merino sheep breed, which produces highly sought-after wool for garment manufacture. Meat

Abbreviations: ABARES, Australian Bureau of Agricultural and Resource Economics and Sciences; CSF, case study farm; dLUC, direct land use change; GHG, greenhouse gas; GWP, global warming potential; NSW HRZ, high rainfall zone; LCA, life cycle assessment; LU, land use; LW, live weight; NSW, New South Wales; RAF, regional average farm; SA, South Australia; SE, system expansion; SA SPZ, Southern Pastoral Zone; WA, Western Australia; WA WSZ, Wheat Sheep Zone; WSI, water stress index.

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production from lambs and cull-for-age (CFA) breeding animals also represents a valuable co-product.

With increased demand for information regarding the environmental credentials of fibre products from garment manufacturers, retailers and consumers (Kviseth and Tobiasson, 2011; BSI, 2014; Karim et al., 2014), the need for scientifically-sound whole of supply chain research addressing key environmental impacts and resource use issues is acute. Addressing this need for wool production is more complex than is generally the case for man-made fibres as the latter have relatively consistent and regulated systems for the raw material phase of the supply chain compared to wool.

Life cycle assessment (LCA) is the most widely used tool for reporting the environmental impacts and resource use of products (ISO 2006) and ideally assessment should report on all major environmental impact and resource use categories affected by a product across the full supply chain. A number of sheep studies have focussed on lamb production (Ledgard et al., 2011; Peters et al., 2010a, 2010b; Ripoll-Bosch et al., 2012; Wiedemann et al., 2015c; Williams et al., 2006) though few of these reported impacts for wool. A review by Henry (2011) demonstrated the limitations in data and methodology in past LCA studies, and, to date, only two detailed LCA studies have been published for wool produced in Australia and these reported only the single impact of greenhouse gas (GHG) emissions, excluding land use (LU) and direct land use change (dLUC), for cradle to farm-gate wool production, each from a single case study farm (Brock et al., 2013; Eady et al., 2012).

In the absence of detailed studies based on Australian production practices and performance data, the environmental credentials of wool have been modelled using inventory data (i.e. Made-by, 2011) that do not accurately reflect Australian production methods. Given this, and the narrow focus of the case studies to date, the present study aimed to produce a benchmark analysis of water, energy, land and greenhouse gas emissions for three types of Australian Merino wool, produced in three different production systems across the country using a broader farm dataset. Detailed aims are provided in the following section.

2. Materials and methods

2.1. Goal and scope

The study investigated impacts from major Australian wool production regions to provide information to the wool industry, wool fabric users and the general public. The study specifically aimed to i) quantify resource use for energy, water and land, ii) to estimate GHG emissions and removal associated with land use and direct land use change (LU and dLUC) from wool production, and iii) to identify impact hotspots in the production system. The system boundary included all supply chain processes associated with the primary production of wool to the farm-gate (Fig. 1). The functional unit was ‘1 kg of greasy wool at the farm gate’.

Impact assessment included global warming using Global Warming Potentials (GWPs) based on the IPCC (Solomon et al., 2007). Fossil fuel energy demand was assessed from an inventory of energy demand throughout the system, and was reported in mega-joules (MJ) with lower heating values (LHV). Stress-weighted water use was assessed using the water stress index (WSI) of Pfister et al. (2009) and reported in water equivalents (H_2O-e) after Ridoutt and Pfister (2010). Inventory results were also presented for fresh water consumption and land occupation with methods described in the following sections.

2.1.1. Regions and farming systems

Wool is produced in three broadly defined Australian agro-climatic zones; the high rainfall zone (>600 mm average annual rainfall or a.a.r), the wheat-sheep zone (300–600 mm a.a.r) and the pastoral zone (<300 mm a.a.r) (Hassall & Associates Pty Ltd, 2006). The largest numbers are located in the wheat-sheep and high rainfall zones (~53% and 39%) with smaller numbers in the pastoral zone (Hassall & Associates Pty Ltd, 2006). This study selected farms from geo-spatially defined regions within each zone (see Supplementary material). The defined regions were located in the western wheat-sheep zone (WA WSZ), the eastern high-rainfall zone (northern NSW HRZ) and the southern pastoral zone (central SA SPZ).

The western wheat-sheep region is classified as temperate, with a winter dominant rainfall pattern of 400–550 mm a.a.r. Within this region, the case study farms were located at an elevation of ~250–300 m above sea level in flat to undulating terrain, near the town of Darken. Temperatures range from an average minimum monthly average of ~6 °C in winter, to a maximum monthly average of ~30 °C in summer. Farms produced wheat and other grains on arable land, and typically grazed sheep on non-arable land, or land being used for pasture leys within the cropping cycle. Grazing is supported by native pastures with introduced clover, predominantly *Trifolium subterraneum*, and supplied with annual or bi-annual applications of super-phosphate and lime as required. Supplementary feeding and forage crops are used to manage annual feed deficiencies in summer. Wool is produced from large-bodied Merino sheep, producing fine wool (20 μm) and lambs for meat production.

The eastern high rainfall region is a cool temperate environment with a summer dominant rainfall pattern of 700–900 mm a.a.r. Temperatures range from an average minimum monthly average of ~0 °C in winter, to a maximum average of ~27 °C in summer. Within this region, the case study farms were located at an elevation of ~950–1000 m above sea level in undulating to hilly terrain, near the town of Armidale. Farms are typically mixed grazing enterprises, producing wool, lamb and beef with only small areas of crop land used for forage. Grazing is supported by native pastures with introduced clover, or sown pastures, and is typically supplied with applications of superphosphate every 2–3 years. Small amounts of supplementary feed are used in lower rainfall years and annually during winter. Wool is typically produced from smaller bodied Merino sheep, producing super-fine wool (17 μm) and smaller lambs for meat production.

The southern pastoral region contains large sections of arid (<250 mm) desert lands, with smaller areas of semi-arid (>250 mm, winter dominant) native grasslands or savannas, which support low densities of sheep and cattle, with no cropping and few alternative farming systems available. Supplementary feed is not typically used. Temperatures range from an average minimum monthly average of ~4 °C in winter, to a maximum average of ~34 °C in summer. Within this region, the case study farms were located at an elevation of ~300–350 m in flat to to hilly terrain, near the town of Hawker. Because of the low grazing density, the farms studied from this region were very large (>15,000 ha) and management inputs were low. Sheep on the farms studied were typically set-stocked in large paddocks (>2000 ha) and were handled infrequently. Wool is produced from large-bodied Merino sheep, producing medium micron wool (21–22 μm) and lambs for meat production.