Greenhouse gas costs and benefits from land-based textile production

by Dr. Marcia DeLonge

Preliminary findings from a life cycle assessment of wool garment production

Land-based fibers are the traditional basis for textile production, thus the ecological impacts of garments are fundamentally linked to land and land management. Globally, over 64 million tons of apparel fibers are milled each year; just under half of these are land-based natural fibers, including 23.3 million tons of cotton, 1.5 million tons of wool, 0.7 million tons of flax, and 2.7 million tons of other cellulosic fibers (FAO). Agricultural practices and production methods vary significantly between and among fibers, with consequences for greenhouse gas emissions. The objective of this life cycle study is to quantify the range and uncertainties of the net greenhouse gas emissions (including CO_2, CH_4, and N_2O) resulting from garment production, with an initial focus on wool garments.

Overview of rangeland science and management strategies

Wool production is based in rangelands, which cover over 22 million hectares in California, approximately 50% of the State's land area (Brown S. Dushku, 2004). Globally, rangelands cover roughly 3.3 billion hectares and store around 30% of the terrestrial soil C pool (Jobbagy, 2000). The spatial extent of rangelands and their propensity to store C in soils is suggestive of a significant potential for C sequestration opportunities. Rangelands also provide numerous ecosystem services that can be protected or enhanced by conserving or improving soils (Havstad, 2007).

Rangeland management practices that maintain or increase soil C stocks can help mitigate climate change. Thus, wool sourced from well-managed rangelands may be linked to maintenance or enhancement of soil C. Opportunities exist for increasing soil C through management practices across a range of soil textures, climates, and hydrologic conditions (Smith, 2008). Significant uncertainty currently exists regarding the potential sequestration rates from improved rangeland management practices, and more research is needed to identify the best opportunities.

Management practices often considered include (DeLonge M. O., In review), e.g.,:

- **Grazing** (physical and biological effects, grazer species, stocking rates)
- **Fire** (suppression, planned burns)
- **Soil amendments** (commercial fertilizers, manure, compost, organic matter)
- **Cultivation** (mowing, irrigation, aeration and tillage)
- **Plant community composition** (species removal, species introduction)

Carbon sequestration potential on California rangelands through compost additions

Recent research in Northern California rangelands has suggested that one promising management strategy for climate mitigation is amending grazed grasslands with compost. A 3-year field experiment at a coastal and a valley grassland demonstrated that a one-time ½" surface addition of compost increased C in soils but did not significantly increase greenhouse gas emissions from soils (Ryals R. &., 2013). The rate of C sequestration from this study was estimated to be 0.7-4.0 Mg CO_2eq ha^{-1} y^{-2}). Another study based on this field experiment but using the DayCent biogeochemical model has indicated that treating grasslands with compost can have a net mitigation potential of 1.3-1.6 Mg CO_2eq ha^{-1} y^{-1} for at least 10 years, even when accounting for a potential increase in N_2O emissions (Ryals R. H., 2013). These observed and modeled rates of C sequestration are comparable to findings from other studies looking at changes to soil C stocks following improvements to management (Conant, 2001).

Note: The CO2-equivalents unit (CO_2-eq) is used for reported values that consider the combined global warming potential (GWP) from CO_2, CH_4, and N_2O. Note that CO_2 has a GWP of 1 (1 g CO_2-eq = 1 g CO_2). To convert C from CO_2 into CO_2-eq, multiply by 3.67 (44.01 g CO_2 /12.01 g C). To convert C from CH_4 into CO_2-eq, multiply by 1.33 (16.04 g CH_4/12.01 g C in) and then by the GWP (1 g CH_4 = 25 g CO_2-eq on a 100 y timeframe, Solomon et al. 2007). To convert N from N_2O into CO_2-eq, multiply by 1.57 (44.01 N_2O/28.01 g N) and then by the GWP (1 g N_2O = 298 g CO_2-eq on a 100 year timeframe, Solomon et al. 2007).

An additional benefit of using compost can be achieved when compost is produced from materials diverted from high emission waste streams. A life cycle assessment for compost produced and applied to grazed grasslands found that when feedstock materials are diverted from high emission waste-streams, such as anaerobic manure storage systems or landfills, significant emissions can be avoided (DeLonge M. R.). Potential net savings were found to be 23 Mg CO_2eq ha^{-1} in a case study for cow-grazed grasslands in Northern California and about 4.3 Mg CO_2eq ha-1 in a broader uncertainty analysis.

Life cycle assessment overview and boundaries

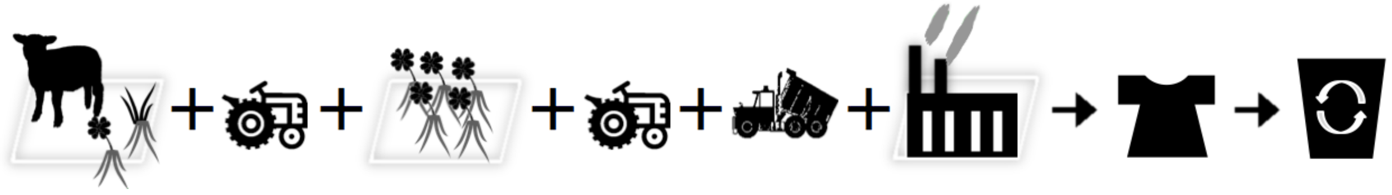
The goal of this study is to quantify and contrast the ecological impacts of garment production using a land-focused approach, focusing initially on wool production. Greenhouse gas fluxes (CO_2, CH_2, and N_2O) associated with all life cycle phases were estimated based on available literature or common industry values. Levels of uncertainty and variability in these initial case study values will be assessed in future analyses. The model currently considers:

- Land management practices (fertilizers/amendments, stocking rates, etc.)
- Animal productivity (wool production per year)
- Animal emissions (enteric fermentation, manure management)
- Transportation of raw and processed materials
- Employee commute transportation
- Fiber/fabric processing based on renewable or conventional energy sources, including facility heating and cooling and water heating for scouring.
- Fabric maintenance (washing/drying)

The model does not currently consider:

- Dye (natural or synthetic) production or application
- Byproducts from wool production (i.e., lanolin, meat, dairy)
- Fabric lifetime
- Fabric disposal
- Future work will include other fibers (i.e., cotton) and land-uses for comparison

Figure 1: Conceptual diagram highlighting key phases in the lifecycle of wool garments. The life cycle of fibers begins with land management and includes maintenance, lifetime, and disposal. The focus of this study is to identify differences and uncertainties in the environmental impacts that arise from agricultural practices and land use and how these fit into the broader context of fabric production



Life cycle assessment case studies

Several scenarios were defined to represent a broad range of potential cases of land management and wool garment production. The scenarios were chosen to represent a range from low to high net greenhouse gas emissions based on available management choices at all phases of the life cycle of garment production. Significant uncertainties exist within many parameters, and the impacts of these on the study outcomes will be addressed with an uncertainty analysis in future research. The first scenario (scenario 1; “optimistic”) represents a case where greenhouse gas emissions are minimized using best available practices based on literature and industry values. Additional cases explore the greenhouse gas impacts as higher emission practices are assumed within various phases of the life cycle, progressing towards a case that is designed to represent a likely higher emission scenario (scenario 7; “conventional”). The set of scenarios is intended to illustrate a range of possible carbon footprints that may be associated with garment production depending on land, animal, and production management.

Preliminary results have suggested that garment production may be associated with a carbon footprint exceeding 30 kg CO_2e per garment, but that a net sink of greenhouse gases may be possible if best land and production management practices are adopted.

The cases are built with the following assumptions, with some variability depending on the specific scenario:

Production facility & employee commute: A production facility 85,000 square feet that processes 2 million pounds of wool a year for a total of 8 million garments (using 0.25 lb = 113.5 g wool per garment). We assume that the facility has 2302 heating degree-days and 2656 cooling degree-days (U value = 0.04), which is used to estimate energy needs for heating and cooling the building. The facility operates 7 days a week with 3 shifts per day of 24 people. We assume an average commute of 20-40 miles roundtrip and 21-35 miles per gallon of fuel efficiency. Greenhouse gas emissions from gasoline consumption are 8887 g CO_2 gallon-1 (EPA).

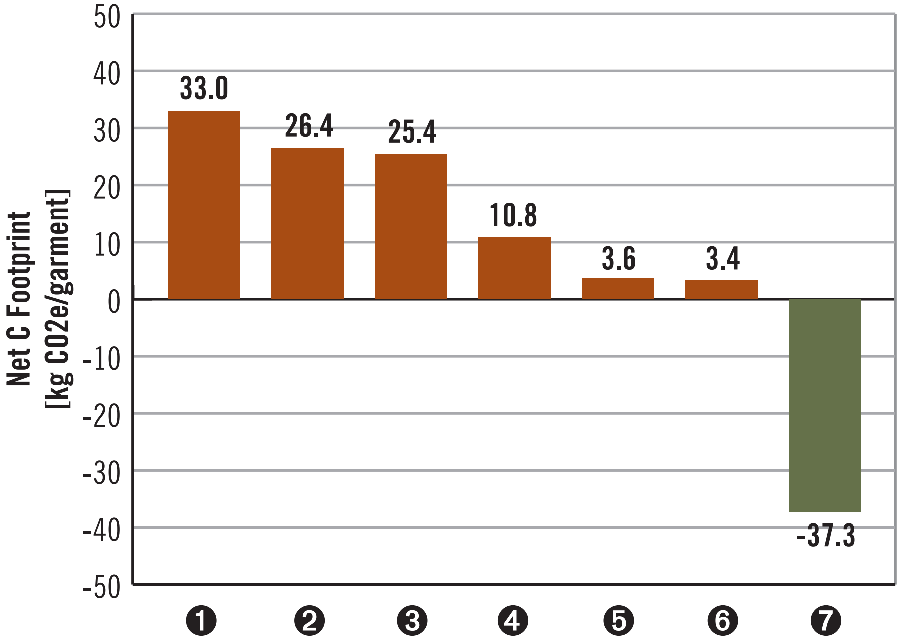
Animals: Wool is sourced from sheep that produce an average of 7.5 lb wool per head per year and graze on rangelands at an average stocking rate of 3-4 head per acre. The yield of dry scoured wool is 50% of raw wool. Of that, 10% of wool is lost during processing. Sheep are sheared once per year in 6.5 minutes using a 0.3 kW shearing tool. Enteric fermentation from sheep is 7-8 kg CH_4 head^{-1} y^{-1}. Manure production from sheep leads to both CH_4 and N_2O emissions. Methane emissions from manure occur at a rate of 0.2-0.3 kg CH_4 head^{-1} d^{-1}. Nitrous oxide emissions are based on the N excretion rate, assumed to be 0.4 kg N per 1000 kg animal mass per day, where sheep are assumed to have a live weight of 65 kg. The conversion rate of manure N to N_2O is 1.5-2%.

Electricity: For the sake of simplicity, we assume that the source of energy for electricity is constant throughout the entire life cycle of the garment, from production to home use. The source of energy varies among the different scenarios (Energy, 2013). We assume that the life cycle emissions are: 0.040 kg CO_2e kWh^{-1} from solar power, 0.082 g CO_2e kWh^{-1} from geothermal power, and 0.300 kg CO_2e kWh^{-1} from the California grid (based on the average public utility energy mix. For heating water (e.g., for scouring raw wool), we assume that ground water is heated from 50-60 degrees F to 110 degrees F using the same energy source applied throughout the scenario (where 1.1 -1.5 gallons of water are needed per pound of raw wool).

Material transportation and production: We assume that the distance from the farm to the mill is 50-60 miles and that the distance from garment production to the consumer is 10 miles in most cases. The exception is case 7 where we assume a total of 660 miles of transportation throughout the production and sales process. Diesel fuel use is calculated based on total truckloads and gas mileage factors from the EPA (EPA, 2013). In addition to wool scouring, we assume that fiber preparation require 2.2 kWh/lb TOP, spinning requires 1.4 kWh per pound, and knitting requires 0.3 kWh/yd (where the fabric weight is 113.2 g per yd).

Garment lifetime & maintenance: We assume that all garments are worn 29 times/year (1 time every 2 weeks), need to be washed once for every 10 days they are worn, and have a usable “lifetime” of 29 washes. At these rates the garments are considered have a 10 year useable life. Based on standard washing machine equipment, we assume that 0.9 kWh are used per load of wash, and that each load is 8 pounds of clothing (equivalent to 32 garments). For drying we assume a rate of 0.3 kWh per pound of dry garments, but that garments are air dried (0.0 kWh per lb) in the optimistic scenario.

Life Cycle Assessment of Fibershed & Conventional Fabric Production



❶ **Conventional Realistic:** CA grid-derived energy, slightly higher C footprint relative to other cases due to loss in soil C, synthetic fertilizer use, higher transportation costs

❷ **Conventional Optimistic:** CA grid-derived energy, but no increase in soil C

❸ **Fibershed Neutral Soil:** geothermal-derived energy, but no increase in soil C

❹ **Fibershed Conservative:** geothermal-derived energy, good land management increases soil C at a more conservative rate than Case7

❺ **Fibershed Realistic:** geothermal-derived energy, conservative compost credit, good land management increases soil C at a more conservative rate than Case7

❻ **Fibershed Possible:** solar-derived energy, conservative compost credit, good land management increases soil C at a more conservative rate than Case7

❼ **Fibershed Optimistic:** solar-derived energy, optimistic compost credit, good land management increases soil C at optimistic rate, minor reductions in C footprint relative to other cases at several steps (transportation distances, commuter mgp, animal emissions, air-dried clothes, etc.)