

1st Edition

The Green Book

*Guide to wool sustainability issues
& supply chain integrity standards*

06.2026





Executive Summary

Wool is a bio-fibre with a host of natural sustainability characteristics. Yet it is currently characterised as environmentally detrimental by various environmental footprint tools. The IWTO Green Book aims to set the record straight.

Wool is a biogenic fibre, grown from sunlight, water and grass through the process of photosynthesis, and forming part of nature's own carbon cycle. Every kilogram of clean wool embodies approximately 1.7 kilograms of biogenic CO₂ equivalent, stored in a durable, recyclable and ultimately biodegradable form. Wool garments are worn more times before washing than any other fibre type, washed at significantly lower temperatures, and kept in active use far longer. A commercially profitable wool recycling industry has existed for over 200 years. At end of life, wool biodegrades readily in soil and water, returning nutrients to the earth. These are not marketing claims. They are documented, peer-reviewed findings.

The broader ecological picture reinforces this. The world's grasslands cover 40% of the terrestrial land surface, and the sheep that graze them play an active role in soil health, water retention and carbon drawdown. Responsible grazing is one of the few genuinely scalable responses to the global carbon crisis - one that simultaneously produces food and fibre while sustaining the photosynthetic systems on which all life depends.

WHY THE NUMBERS HAVE BEEN WRONG – AND WHAT NEXT?

Despite this evidence, dominant product environmental footprint tools consistently rank wool as more damaging than synthetic fibres derived from fossil fuels. The reason is methodological. Current life cycle assessment models were built around linear, industrial production systems. They cannot account for biogenic carbon flows - the continuous cycling of carbon through living organisms that underpins wool's renewability, biodegradability and circularity. The result is a systematic overstatement of wool's carbon footprint and an equally systematic understatement of the geological carbon burden carried by polyester, acrylic and nylon.

New peer-reviewed research commissioned by IWTO, published in *Agricultural Systems* and certified to ISO 14067:2018 by TÜV SÜD, corrects this. By incorporating bidirectional biogenic carbon flows, the model demonstrates that wool's true emissions intensity is dramati-

cally lower than conventional LCAs suggest. IWTO is now developing biogenic modelling tools for wide use, alongside a harmonised global definition of regenerative wool farming - recognising that the best wool production systems do not merely avoid harm, but actively restore soil health and biodiversity. Supporting all of this is a growing infrastructure of traceability and certification tools that give brands, retailers and consumers the verified evidence they need to make genuinely well-informed sourcing decisions.

KEY TAKEAWAYS

Nature Got There First – Wool's biogenic, biodegradable and recyclable properties make it inherently suited to the circular economy. Its low laundering frequency delivers measurable reductions in use-phase energy and water consumption.

The Accounting Is Broken – Current LCA and PEF tools ignore biogenesis, causing wool's carbon footprint to be significantly overstated. New IWTO-commissioned research corrects this, showing a dramatically lower true emissions intensity.

Grass Is a Climate Tool – Grasslands and grazing herbivores are active participants in the global carbon cycle. Growing year-round photosynthesis through responsible grazing is one of the most scalable climate solutions available.

Farming That Gives Back – Regenerative grazing improves soil carbon, biodiversity and water resilience. IWTO is progressing global standards to underpin and accelerate adoption worldwide.

Trust Built Into Every Bale – IWTO provides a growing ecosystem of traceability tools and a new licensing framework for sustainability certification, giving the entire supply chain the transparency it needs.



Foreword

WOOL IS INCREASINGLY seen by conscious consumers as a more sustainable material choice for fashion and interiors. Renewable, recyclable and biodegradable, wool fits perfectly into the emerging circular economy.

Grown on a diet of sunlight, water and grass, wool delivers a supreme sustainability message. Its applications range from the personal to the industrial, and lanolin, its by-product, is a highly desirable ingredient for cosmetics. Hand-knitters swear by it. Designers adore it. In a world awash in synthetic fibres, wool is still the one they most try to emulate. Yet despite their efforts, the properties of wool remain unmatched.

Meanwhile, wool value chain stakeholders are being asked ever more searching questions about provenance, origin and sustainability. Caring for the planet and its inhabitants are now central elements of corporate social responsibility efforts.

IWTO is the recognised global authority for manufacturing standards in the wool textile industry. As such, we are well aware that we are working in an area where sustainable practices need to be transparent at all stages in the pipeline. It is in this light that I am delighted to be able to introduce the Green Book. As an initiative, the Green Book is the result of the incredible generosity of the Italian wool textile industry through Confindustria Moda. As a resource, it reflects the longstanding commitment of IWTO and its members to evidencing and communicating the environmental credentials of wool.

The Green Book is designed to assist brands, retailers and final consumers with the relevant know-how and understanding of wool sustainability standards, to support their wool purchasing decisions, and to help shape the thinking and choices of the consumers who are the lifeblood of all our businesses. It summarises wool's ecological basis and values, our supply chain integrity standards, and it draws from the latest research providing new insights into our carbon footprint and combats misleading narratives.

Complementing IWTO's existing Red Book (test specifications), White Book (regulations) and Blue Book (model agreements) platforms, the IWTO Green Book is a resource which should be required reading for anyone with an interest in our noble fibre, or the future of the planet itself. 🐏

Klaus Steger
President
International Wool Textile Organisation (IWTO)



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A Sustainable Fibre by Nature

Biogenic, carbon-storing, biodegradable, recyclable, efficient — wool checks off an impressive number of boxes for a low-impact fibre. This first section provides a quick guide to wool's multifaceted sustainability credentials.

Wool is a unique natural fibre produced by wool-bearing sheep that has played an integral role in the Earth's natural cycle for millennia. Composed of keratin, the same protein found in human hair, its primary biological role is to protect the animal's skin from environmental stress. This evolutionary function is expressed through a range of inherent properties, shaped by nature.

Each of these evolved functions, which have served sheep so well, have also contributed to the broader performance profile that makes it such a sought-after fibre for human applications. In this section, we explore how.

WOOL IS BIOGENIC

Biogenesis means 'development of life from pre-existing life' ¹. While this may sound like another way of saying "natural," or "renewable", biogenesis is in fact much more than this: it is the key to all life on this planet, whereby biological life cycles reflect nature's incredibly efficient re-use of materials. This has several implications for wool fibre:

The key global standard for product carbon footprinting, ISO 14067:2018, defines biogenic material as anything of biological origin, excluding material in geological formations or fossilized (Clause 3.1.7.1) ².

Biogenic carbon, meanwhile, is carbon from biomass (3.1.7.2) ², including organic material of biological origin (Note 1 - 3.1.7.1) ².

The biogenic carbon content is the biomass-derived carbon in a product. This content must, for example, be reported in cradle-to-gate studies due to its value chain relevance (6.4.9.3) ².

Clean wool is pure protein, a 100% biogenic biofibre formed in nature by nature, constructed entirely of creatively upcycled biological materials. Thus, wool falls squarely under the ISO 14067:2018 definition of biogenic material. Wool's biogenic nature is covered in more detail in Section 2.

WOOL IS CARBON STORING

Wool functions as a store of biogenic carbon, operating within the biological carbon cycle. In this natural loop, plants absorb CO₂ from the atmosphere through photosynthesis; this carbon is then transferred to sheep – including their wool – via grazing and feed. The same applies to cellulosic fibres like cotton, hemp, and regenerated options such as viscose, whereby carbon remains stored in plant matter and wood pulp.

When you purchase a garment made from these materials, you are acquiring carbon that was part of the active biological cycle. Upon disposal, this carbon returns to the soil or atmosphere through biodegradation, completing a closed loop cycle without adding net new carbon to the system.

BUT DON'T SYNTHETIC FIBRES ALSO STORE CARBON?

Yes. But in stark contrast, synthetic apparel fibres – such as polyester, acrylic, nylon, and elastane – rely on the geological carbon cycle. The carbon in these materials originates from fossil fuels (oil, coal, gas) that were locked underground for millions of years. Extracting this carbon through mining or drilling and converting it into fibre eventually releases ancient carbon back into the active atmosphere, creating a net increase in atmospheric CO₂. Unlike the biological carbon cycle, this process is linear and non-renewable.

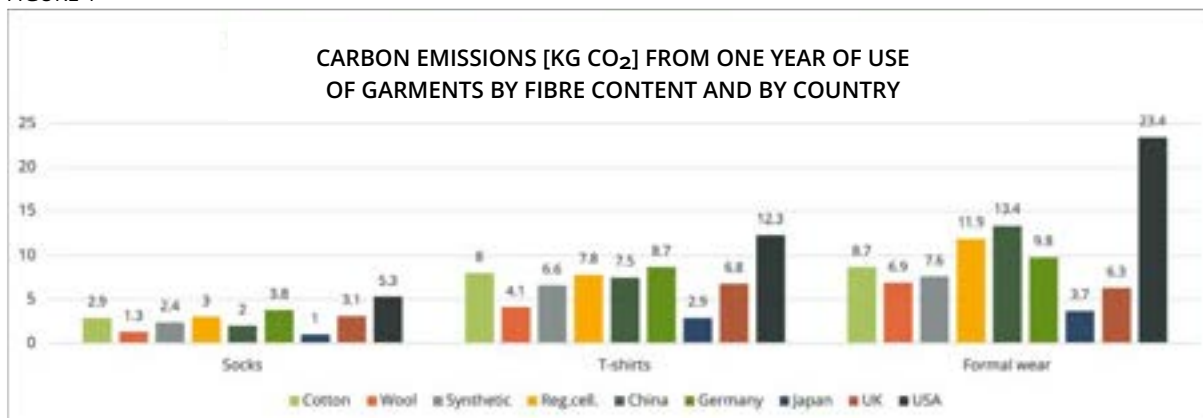
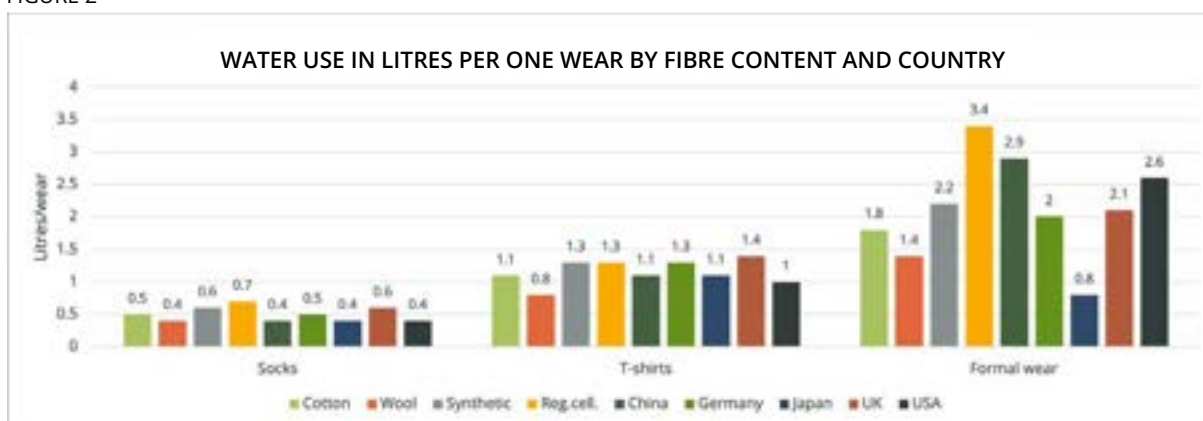
Furthermore, the production of these fibres involves complex chemical transformations: polyester is made from a fossil-fuel-derived compound also used in PET plastics; acrylic is created using chemicals derived from fossil fuels, dissolved in solvents; nylon is produced by transforming fossil-fuel-based chemicals into polymers; and elastane is formed by combining fossil-fuel-derived acids and other chemical compounds.

In short, as these fibres rely on fossil fuels for their raw materials, they are both non-renewable and non-biogenic, fundamentally disrupting the carbon balance. For a deep dive into the carbon cycle, read Section 3.

A man in a blue uniform is operating a large industrial machine. A large, cylindrical bale of red wool is suspended from the top of the machine. The man is using a tool to work on the bottom of the wool bale. The machine has a large, circular, metallic lid that is open. The background shows a green wall and some industrial equipment.

WOOL & CARBON

1. The carbon in wool is derived from carbon in biomass, sequestered from the current atmosphere
2. Pure biogenic carbon makes up 50% of the clean weight of wool ³⁻⁵, higher than cotton (44%) or wood pulp-derived regenerated cellulosic fibres such as viscose (24%) ⁶⁻⁷.
3. Converted into CO₂ equivalents (CO₂eq), 1 kg of clean wool equates to approximately 1.7 kilograms of CO₂eq stored in a durable, functional, readily recyclable, and ultimately biodegradable form ⁸.
4. A typical bale of fleece wool from any of the major supplier nations weighs around 178 kgs ⁹ and so represents around 300 kilograms of CO₂ equivalents.

FIGURE 1 ²⁷FIGURE 2 ²⁷

WOOL IS BIODEGRADABLE

Ready biodegradability is the essential life-partner for biogenesis. Through biodegradation, micro-organisms in soil or water break down and consume matter, and in turn these micro-organisms are consumed. This is how biogenic matter flows from one life form to the next, and life is sustained.

THE SCIENCE BEHIND WOOL BIODEGRADATION

As a keratin fibre, clean dry wool fibres do not readily degrade. This is on account of its unique chemical make-up including a water-repellent outer membrane layer ¹⁰. However, if exposed to moisture for prolonged periods, such as in soil, compost, or marine environments, the fibre is food for micro-organisms and fungi ¹⁰⁻¹¹.

In healthy soil or composting conditions, wool products are almost completely degraded after six months, being readily attacked by a range of bacteria and fungi that occur in large numbers in these environments ¹².

In marine environments, research by AgResearch shows wool biodegradation rate is slower, but still relatively rapid ¹³.

FROM WASTE TO NUTRIENT

Research also shows that wool functions as an effective soil conditioner and fertiliser, slowly releasing sulphur, nitrogen, phosphorous and potassium as it biodegrades ¹⁴. Tests have shown that ground-up wool carpet can act as a fertiliser, increasing grass biomass growth by 24 - 82% ¹⁵.

BIODEGRADATION & MICROFIBRE POLLUTION

Products can be made to resist biodegradation through physical or chemical treatments, which in turn makes it difficult for living organisms to recycle the material. Products that resist biodegradation tend to accumulate in the environment.

One of the greatest problems for the planet, and for future generations, is the lack of biodegradability of many synthetic materials, including the most common synthetic textile fibres.

Wool's natural biodegradability ensures that wool does not contribute to the persistent microfibre plastic pollution that currently contaminates all parts of the globe, the food chain and our bodies. You can find more on biodegradation in Section 2.

WOOL IS RECYCLABLE

While textile-to-textile recycling remains in its infancy with all other common fibres, a commercially profitable wool recycling industry has existed for more than 200 years. Post-consumer wool is in high demand by recyclers to produce new clothing (closed-loop recycling) as well as for bedding, insulation and industrial products (open-loop recycling).

WHAT DOES THE DATA SAY?

Research by Textile Materials and Technology at Leeds University has shown that wool products have the potential for multiple 'lives' (see fact box on opposite page), and a total 'active life' of 20-30 years ¹⁶⁻¹⁸.

The same research shows that wool already is one of the most re-used of all fibres, accounting for up to 5% by weight of total clothing donated by consumers for recycling and re-use. This is substantially higher than wool's share of the virgin fibre supply, which is about 0.9%¹⁹.

DRIVING THE CIRCULAR ECONOMY

Due to increased awareness of both waste and pollution, the fashion and textile industry is experiencing a shift in its supply chain practices from a 'linear' production model to a 'circular' one.

A robust policy and legislative framework supporting circularity within the textile industry has been established through the EU's European Green Deal²⁰ and Circular Economy Action Plan²¹. This strategy is designed to facilitate the EU's transition to an economy where fashion and textile products are intentionally created for greater durability, reusability, and recyclability.

Additionally, under the EU's Waste Framework Directive²² and associated Extended Producer Responsibility (EPR) legislation²², brands are required to assume responsibility for the full life cycle of their products, encompassing production, post-retail activities, take-back, recycling, and final disposal.

WOOL IS ENERGY AND WATER EFFICIENT

Wool textiles are naturally odour resistant due to wool's unique properties. A New Zealand study with 13 trained olfactory assessors, for example, found that wool fabrics retained 66% less body odour intensity than polyester and 28% less than cotton. How does wool do it? The sulphur-rich chemistry of the wool matrix proteins is able to capture and hold odour-causing molecules generated by sweat until they are washed, minimising unwelcome smells and allowing wool garments to stay fresh for longer^{23 24}.

Wool garments can even be refreshed simply by hanging them up. This translates into significant use phase impact-reductions, as less odour requires less laundering. In a study of global apparel consumer data²⁵, researchers analysed the number of times clothes are worn before they are washed. Wool was found to be worn more times prior to washing than other fibres, saving energy, water, as well as time. Wool is also washed at lower temperatures - 30.3°C on average compared to cotton at 41.1°C on average²⁶, translating to less energy use per washing cycle.

LOWEST USE-PHASE IMPACTS

Another recent study²⁷ showed that laundering frequency is the most influential factor for differences in the environmental impacts per wear between garment types. Woollen garments had the lowest water and energy use per wear, as well as calculated greenhouse gas emissions, mainly due to the reduced laundering frequency (see Figure 2). 🐑

BIODEGRADATION TESTING STANDARDS

- **Textile and Leather:** Assessing natural and synthetic fibre decomposition (ISO 21701 63, ISO 20136).
- **Anaerobic Biodegradation:** Testing in landfill conditions, anaerobic digestors, and aqueous mediums (ASTM D5511 65, ISO 15985 66, ISO 14853).
- **Marine Environment:** Analysis of non-floating plastic materials in seawater and sediment (ISO 16221, ISO 19679, ASTM D6691, ISO 5148, ISO 22403, ISO 22404, ISO 18830, OECD 306).

THE FOUR WORKING LIVES OF WOOL

1st life – First use: Wool garments are on average kept in use for longer periods of time than those made from other fibre types (and are also suitable for repair).

2nd life - Reuse: Wool is the most reused fibre on the planet of the major apparel fibres, with wool garments often preferentially donated for extended life.

3rd life - Recycling: Wool is the most recycled fashion fibre on the planet relative to its global volume.

4th life - Downcycling: Wool products are pulled apart and fabricated into non-woven products for insulation, padding, interiors etc.

What then? Re-life: At the end of its working lives, wool fibres can decompose in soil, slowly releasing valuable nutrients and carbon back into the earth.

Time to Lift Eco-Accounting Standards

Despite wool's impressive sustainability credentials, environmental footprint tools often favour synthetics over wool. This section unpacks the misunderstanding.

Since the 1970s, consumer attitudes towards sustainability have evolved significantly. Among other things, this has been driven by increased awareness of and direct exposure to environmental issues such as climate change and pollution, coupled with a growing desire for social responsibility and ethical consumption. While much is arguably financially context-dependent, consumers increasingly seek alignment of their purchasing decisions with their ethical values, which can in turn translate into prioritizing brands and products that demonstrate a credible commitment to sustainability. These sensitivities are reflected in the political and regulatory realms, and especially in corporate social responsibility (CSR) frameworks.

THE REAL VALUE OF NATURAL FIBRES

All natural fibres, including wool, are part of ongoing debates about sustainability. At its core, it comes down to the ethics of the production and consumption of textiles. But also the ethics of the environmental accounting systems being used to influence consumer behaviour – such as the myriad of product environmental footprint (PEF) tools.

The reality is that wool – and indeed all natural fibres – are being misrepresented. They are often portrayed as environmentally damaging by PEF systems that have been fed with selective data, assumptions based on incomplete science, and a persistent confirmation bias.

For this reason, it is important for all stakeholders to understand the underlying facts of PEF standards, the risks associated with current PEF and labelling systems, and who stands to benefit from poor standards and misinformation. Equally important, stakeholders must know what can be done about it.

A key purpose of the IWTO Green Book is therefore not only to expose this undesirable situation, but also

to point out actions wool stakeholders can take today. Because ultimately, widespread awareness and understanding are the keys to informed discussion, debate, and positive change.

PEF TOOLS NEED TO BE “BIOLITERATE”

In today's media landscape, there is growing cynicism about what is read, seen or heard. And perhaps it is not strange as narratives often conflict with what many believe to be the underlying reality. This threat of misleading narratives also applies to the global textile industry, where product environmental footprint tools such as the EU-PEF²⁸, the Higg Index²⁹, and ADEME's Ecobalyse³⁰ tool generate comparative environmental damage scores designed to inform decision-making by consumers, brands, and retailers.

In these tools, wool and other natural fibres are currently penalized, while synthetic fibres are rated as best for the environment. Take the figure to the right, which shows how Ecobalyse v7.0.0, PEFCR v3.1, and the Higg MSI rate the environmental damage propensity of common apparel fibres in the form of a 150g knit T-shirt with generic ingredients processed in China³¹. Note the similarities and differences between these tools: the synthetic fibres underpinning fast fashion rate consistently low for environmental damage. Meanwhile, wool rates as consistently damaging to the environment.

Why would these tools represent the fibres underpinning fast fashion and the microplastic pollution crisis as the most eco-friendly option? The answer lies in how they deal with land use and in what is missing from these models: a recognition of the difference between biotic and abiotic products. In other words, they lack an appreciation of the twin processes which underpin all biological systems and agricultural land use, **biogenesis** and **biodegradation**.

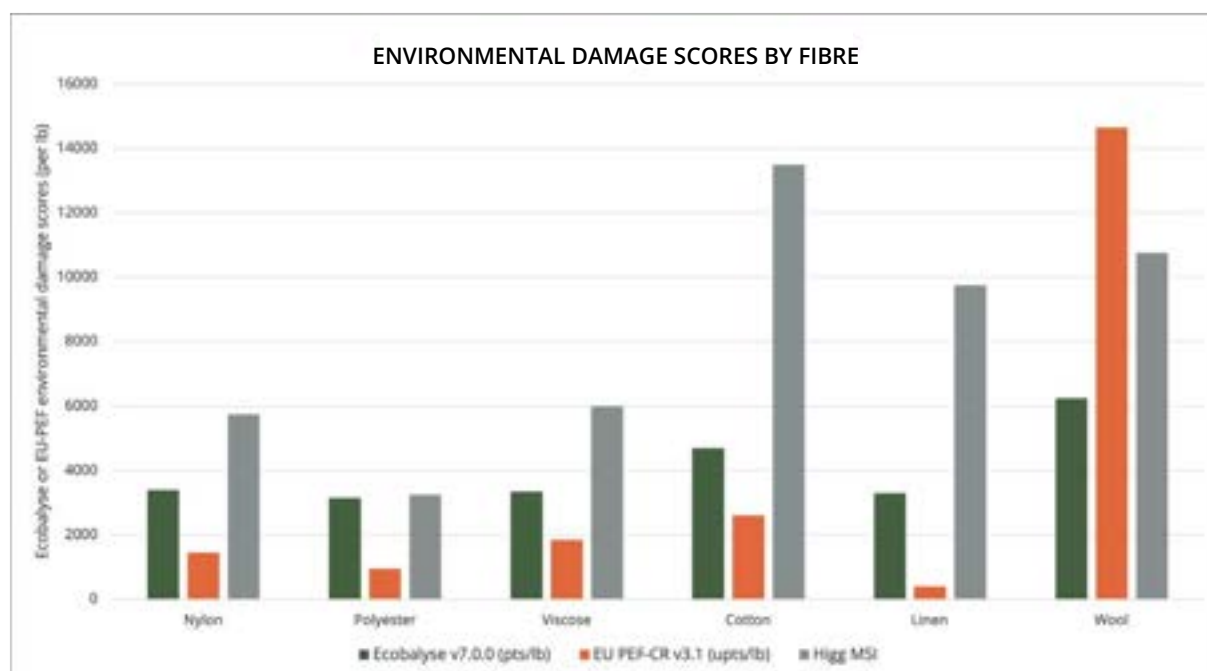


FIGURE 3: 1. Ecobalyse data for 150 gm t-shirt processed in China sourced from Ecobalyse beta. Fiber impacts expressed in points per lb. 2. EU PEF-CR data for 150 gm t-shirt processed in China sourced from Glimpact. Fiber impacts expressed in micropoints per lb. 3. Higg MSI data sourced from Kymo using data supplied by LENZING.

BIOTIC LIFE CYCLE: BIOGENESIS & BIODEGRADATION

The adjective 'biotic' means 'involving, caused by, or relating to living things in the environment'³². A biotic product is a product drawn from or reflecting living things. The noun 'biogenesis', meanwhile, literally means 'to create life from life'¹. This process is intimately entwined with the process of biodegradation, where life essentially feeds a life. In biotic life cycles, nothing is wasted.

Similarly, carbon originally captured from the atmosphere in the form of biomass is called 'biogenic carbon', which then flows from life form to life form to create the elemental skeleton of all life on Earth.

All natural fibres – including wool, cotton, and hemp – are products of such biogenic systems. Here, atmospheric carbon dioxide is creatively upcycled to produce new carbon forms. The biotic life cycle of wool is summarised in the figure on the following page, and consists of the pasture production, use, reuse, and soil & water phases.

ABIOTIC LIFE CYCLE: FOSSIL FUELS & POLLUTION

The adjective 'abiotic' means 'relating to things in the environment that are not living'³³. Unlike biogenic carbon, abiotic carbon is released into the contemporary biosphere through non-living sources. Similarly, the noun abiogenesis means the creation of life from non-living materials³⁴. An abiotic product is therefore one that is synthesised or drawn from non-living materials, including the highly concentrated fossil carbon sources we know as oil, coal, and natural gas. These

same sources also have the notable distinction as being the greatest drivers of the world's climate crisis. Not to mention the non-biodegradability of synthetic plastics, which is the cause behind the micro and nanoplastic pollution now polluting our environment.

These fossil carbon-based fibres include polyester, acrylic, and polypropylene. The abiotic life cycle for these is summarised below, consisting of the emission, use, reuse, and soil & water phases.

LCA NEEDS A BIOLOGY LESSON

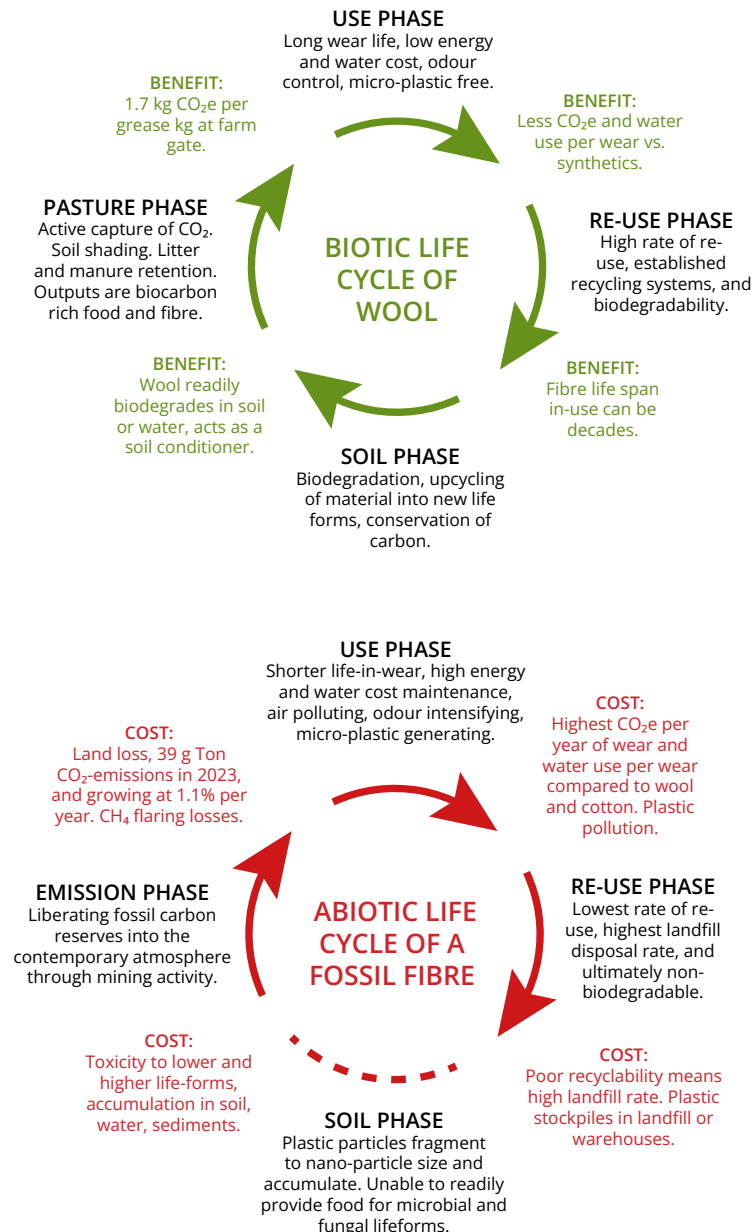
Ignorance of biogenesis and biodegradability are the major weakness of our current carbon accounting standards, fibre ratings tools, and most textile life cycle analyses. They are also methodological choices made by individuals who should know better, especially where readily available product carbon footprinting standards exist that explicitly recognise and differentiate fossil and biogenic carbon (e.g. ISO 14067:2018³). It is an accounting choice to decide that carbon sinks are only worth counting when effectively permanent.

It is this 'convenient yet misleading' decision that discounts biogenesis and the biodegradation cycle underpinning the renewability, biodegradability, and circularity properties of biogenic fibres such as wool.

WOOL'S EXAGGERATED NET CARBON EMISSIONS

Figure 5 summarises the GHG emissions intensity of greasy wool at farm gate, from 14 published studies, covering 102 case studies and 6 countries⁸. Note the incredible range in emissions intensity across these 14

FIGURE 4



studies, a reflection of the importance of the context and the assumptions the researchers used. Note also that the mode of the distribution of results is 20.1–25.0 kg CO₂eq per kg of greasy wool. Using this metric, a typical adult Merino breeding ewe would produce around twice her own body weight in wool-related GHG emissions each year, and over 300 kg of meat-related emissions at 6–7 kg CO₂eq per kg live-weight.

These values are a consequence of a partial accounting method and demonstrate the need for accurate and bio-literate information. More balanced and scientifically sound environmental assessment methods that properly account for renewable biological systems are urgently needed. Fashion companies making sourcing decisions based on misleading assessments may inadvertently choose less sustainable options, undermining their own sustainability goals.

CONVENTIONAL VS. BIOGENIC LCA

From the moment the production system is thus defined, conventional LCA modelling betrays its production-line mindset. The system boundary definition from the widely cited wool LCA³⁵ has been applied to ISO 14044:2006 as the LCA standard (see Appendix 1). Evident here are the:

- hypothetical system units or compartments, so that the sheep flock is considered a separate 'system' from the feed production 'system'.
- one-way input/output flows, without return flows (e.g., recycling).

The absence of circularity or return flows is not a demand of the ISO 14044 standard: it is a choice made



THE COUNTING PROBLEM

Most life cycle assessments (LCAs), including those behind the Higg Index and ADEME's Ecobalyse, include the emissions from monomer production and recycling when assessing bio-based fibres. However, they do not include monomer production when assessing petrochemical fibres. This creates an inconsistency - one that significantly affects the reported greenhouse gas (GHG) emissions intensity of wool.

LAND USE IMPACTS IN LCA AND PEF

Land use impact is one of the most important impact categories to consider for LCA of agricultural products. In the Product Environmental Footprint (PEF) method, land use is assessed using the LANCA model³⁶⁻³⁷. LANCA is a 'bio-based product environmental damage calculator', weighted mostly to soil loss arising from agricultural land use and to a lesser extent on biotic production loss relative to a presumed natural state. LANCA is known to have major limitations when applied across synthetic and agricultural fibre production systems³⁸, which means the PEF representations of land use impacts of different textile fibres must be treated with great caution.

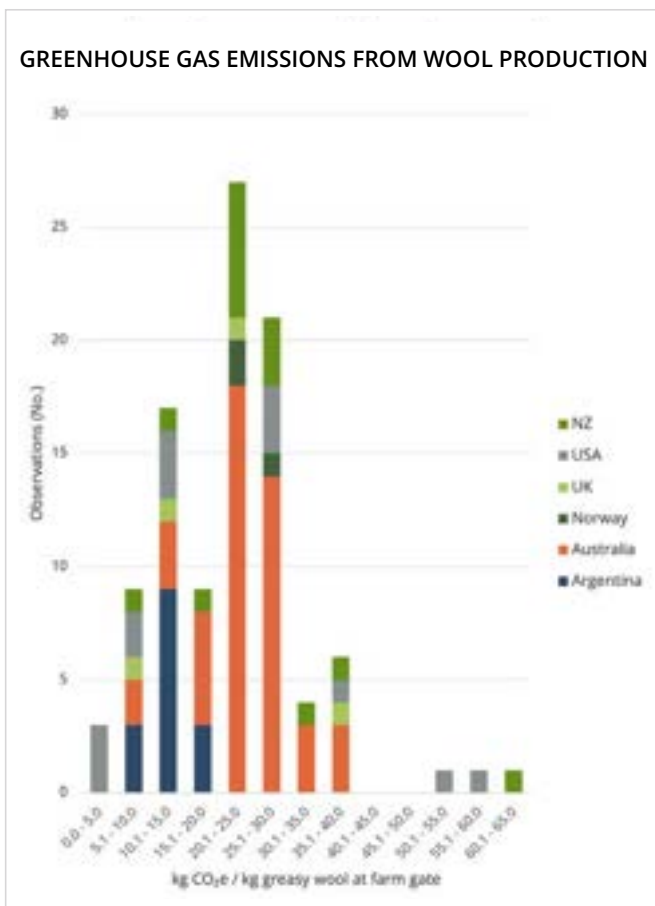


FIGURE 5

by the LCA practitioner. Unfortunately, the current status quo sees the majority of practitioners neglecting the impact of return flows or recycling. This simplifying assumption excludes biogenic carbon flows from being mapped in the assessment.

CALCULATING WOOL'S ACTUAL CARBON FOOTPRINT

In 2018, ISO released ISO 14067, Greenhouse gases: Carbon footprint of products, requirements and guidelines for quantification². ISO recommends this as the generic standard for product carbon footprints.

This standard explicitly recognises the fundamental importance of accounting for biogenesis in carbon footprints, recommending the inclusion of biogenic GHG removals, removals from direct change in land use and management change, and it permits reporting of the biogenic carbon content of products if reported separately (see Appendix 2).

This post-dated the key papers used to populate LCA inventory databases. Prior to IWTO's work, there have been no peer-reviewed publications demonstrating the application of ISO 14067:2018 to the wool and sheep meat sectors in the six years since its release.

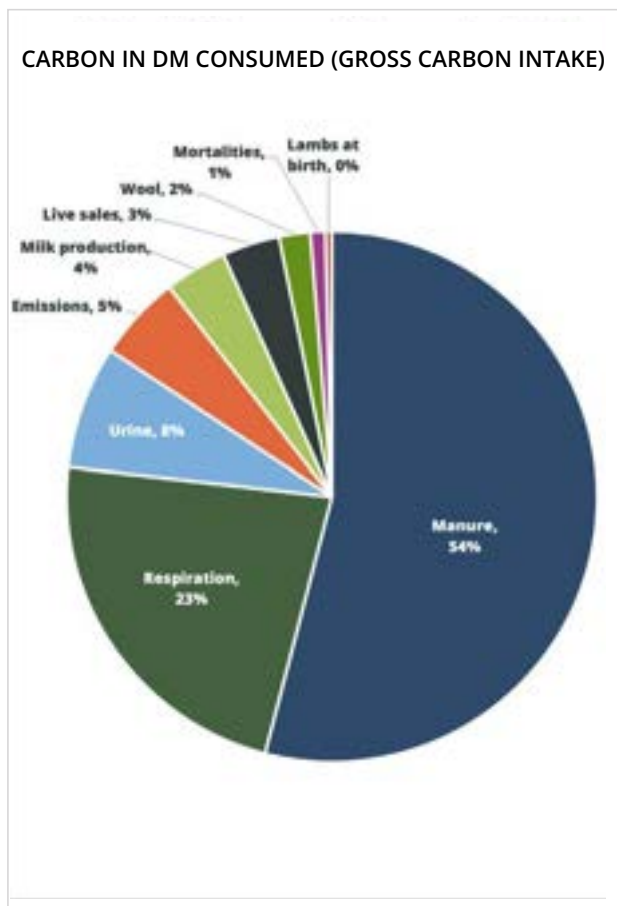


FIGURE 6

NEW IWTO COLLABORATION MAPS CARBON FLOWS

Then in 2024, IWTO and Cape Wools SA commenced a collaborative effort to conduct the first comprehensive biogenic LCA for wool sheep enterprises. The first peer-reviewed scientific publications arising from this effort are now published in Elsevier's Agricultural Systems journal⁸, having received an ISO 14067:2018 conformity assessment from TÜV SÜD in October 2025.

Current status quo sees LCA practitioners neglecting the impact of return flows or recycling.

The newly developed model included bidirectional flows and reflects the substantially increased complexity of biogenic systems required for alignment with the recommendations and requirements of ISO 14067:2018. The model was validated using the same six case study clusters reported in the reference LCA study³⁵ (see Appendix 2).

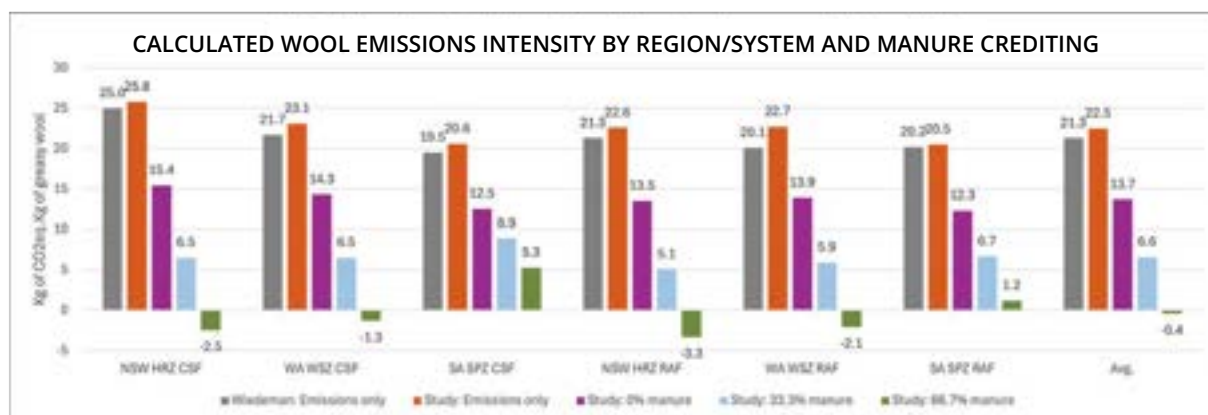


FIGURE 7

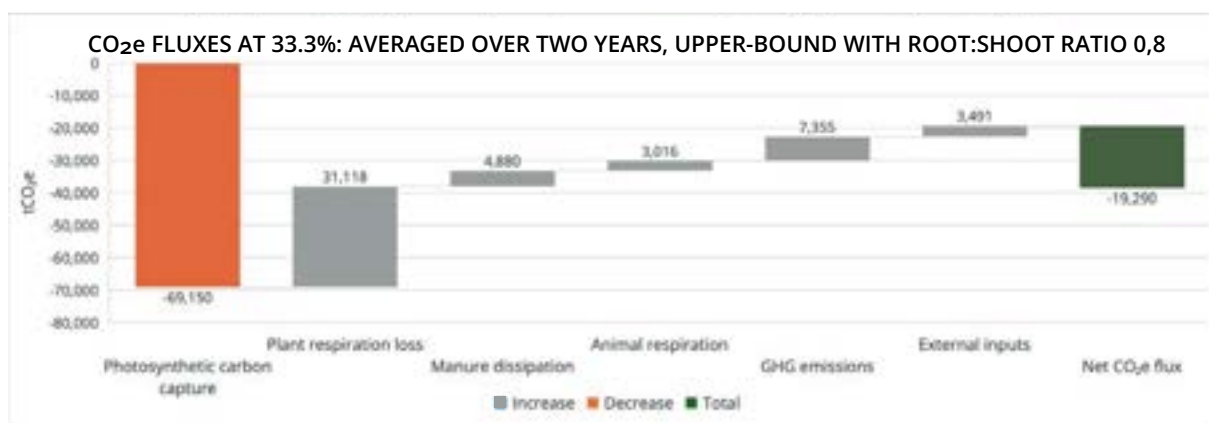


FIGURE 8

GAME-CHANGING RESULTS

The results show that on average 54% of the carbon ingested by sheep is returned as manure, 7.5% in the urine, and a further 22.7% in the outbreath of sheep (respiration) – a total of 84.2% of the ingested carbon. By comparison, only 5.2% of the carbon is contained in emissions (see Figure 6).

The comparative analysis demonstrates that the new model closely matches published results when biogenesis is not considered. As biogenic processes are gradually added to the analysis, however, the apparent emissions intensity of wool decreases substantially.

When two-thirds of manure is retained as a flow into the soil, emissions intensity is reduced by close to 100%.

The study showed that by virtue of being biogenic carbon-rich, each kilo of greasy wool at farm gate was estimated to contain 1.7 kgs of biogenic CO₂e, or around 300 kgs per average farm bale. This included the 50% carbon in the clean wool as well as the carbon present in the wool wax, suint compounds, and vegetable matter.

BIOGENESIS CHANGES THE CARBON STORY

The principal conclusion of the research is that LCAs that ignore system biogenesis will substantially over-

state the true carbon emissions intensity for wool. The follow-on research is addressing the whole farm context, including the ungrazed above-ground biomass, supported by additional case studies.

Take for example Figure 8 above, which is drawn from a case study completed on a 3,550 Ha superfine Merino enterprise in southern Australia³⁹. The graph shows the estimated gross photosynthate capture, losses to plant and animal respiration, to manure and urine, as GHG emissions, including from external inputs. The net CO₂ balance, to the far right in green, indicates overall sequestration.

In parallel, the biogenic accounting approach has already been successfully applied to the South African beef and dairy sectors, in publications by Blignaut and co-workers. These publications, and others now underway, are part of the coming change to the dominant LCA accounting paradigm.

This development contributes to growing recognition that the current accounting approaches need change, and recognition of the critical importance of photosynthesis in mitigating the worst of the fossil carbon emissions crisis, while both clothing and feeding the planet. 🐏

Wool's Role in the Planetary Ecosystem

The carbon cycle underpins life on Earth – and wool is part of it. From photosynthesis to soil systems, find out how natural fibres sustain ecosystems and store carbon.

Carbon is the foundation of life on our planet. Our economies, our residences, and our transportation systems all rely on carbon. And just as it is food for life, carbon is concentrated where most life is, on the surface of the planet.

By weight, carbon makes up:

- 0.0116% of the atmosphere ^{40 41}
- 0.0029% of the oceans ⁴²
- 41–50% of plant dry matter
- 60% of soil organic matter ⁴³
- 18.5% of the human body ⁴⁴

Photosynthesis is the primary mechanism responsible for concentrating carbon on the surface. That's why to understand wool and carbon, we need to first understand photosynthesis.

PHOTOSYNTHESIS IS KEY TO LIFE

Photosynthesis is the process by which organisms convert light energy into carbon-based chemical energy, like glucose, while releasing oxygen as a by-product. Photosynthetic organisms harvest inbound light from the visible light part of the spectrum. This converts between 1–2% ⁴⁵ (120 billion terawatts) of the inbound energy into productive chemical energy (biomass), or about 7–10 times the total energy consumed by humans each year ⁴⁶.

Photosynthesis has quite literally shaped life on Earth by enabling organisms to harness this solar energy directly, creating an abundant source of chemical energy for life. It also produced the oxygen that made Earth habitable for complex lifeforms. Indeed, photosynthetic life is at the core of the ability of the planet to sustain life.

However, it has also set the stage for a new threat to

life. Roughly 350–300 million years ago, photosynthesis generated vast coal, gas, and oil reserves that later fuelled the growth of human industry and carbon emissions. Meanwhile, when sunlight reaches the earth's surface, some energy is absorbed and converted to heat. This is radiated back as infrared radiation that carbon emissions trap, creating the greenhouse effect driving global warming.

PARIS AGREEMENT TARGETS NOT BEING MET

Most of the economic growth that has occurred over the past 100 years has been driven by innovation spurred by the advent of cheap fossil energy. In fact, economists have shown an almost perfect correlation between global energy consumption and global GDP existed between 1900 and 1973, which while slowing, is still rising ⁴⁶. It is the ongoing massive release of fossil carbon by industry that continues to unbalance the global carbon cycle.

Since 2006, University of Exeter's Professor Pierre Friedlingstein has led a global consortium of scientists to establish a common and mutually agreed understanding of the Earth carbon cycle, through the Global Carbon Project ⁴⁷. This consortium tracks the trends in global carbon emissions and sinks and is a key measure of progress towards the goals of the Paris Agreement.

It makes for sobering reading. Their data (see Figure 10) shows that fossil carbon emissions are the primary culprit driving atmospheric CO₂ levels, overloading the capacity of natural oceanic and land-based photosynthetic sinks to draw down and upcycle this carbon.

DE-OXYGENATION ALSO ON THE RISE

Alongside CO₂, atmospheric oxygen (O₂) is the other crucial fuel on earth: aerobic lifeforms depend on it to release energy from carbon-based foods. However, the

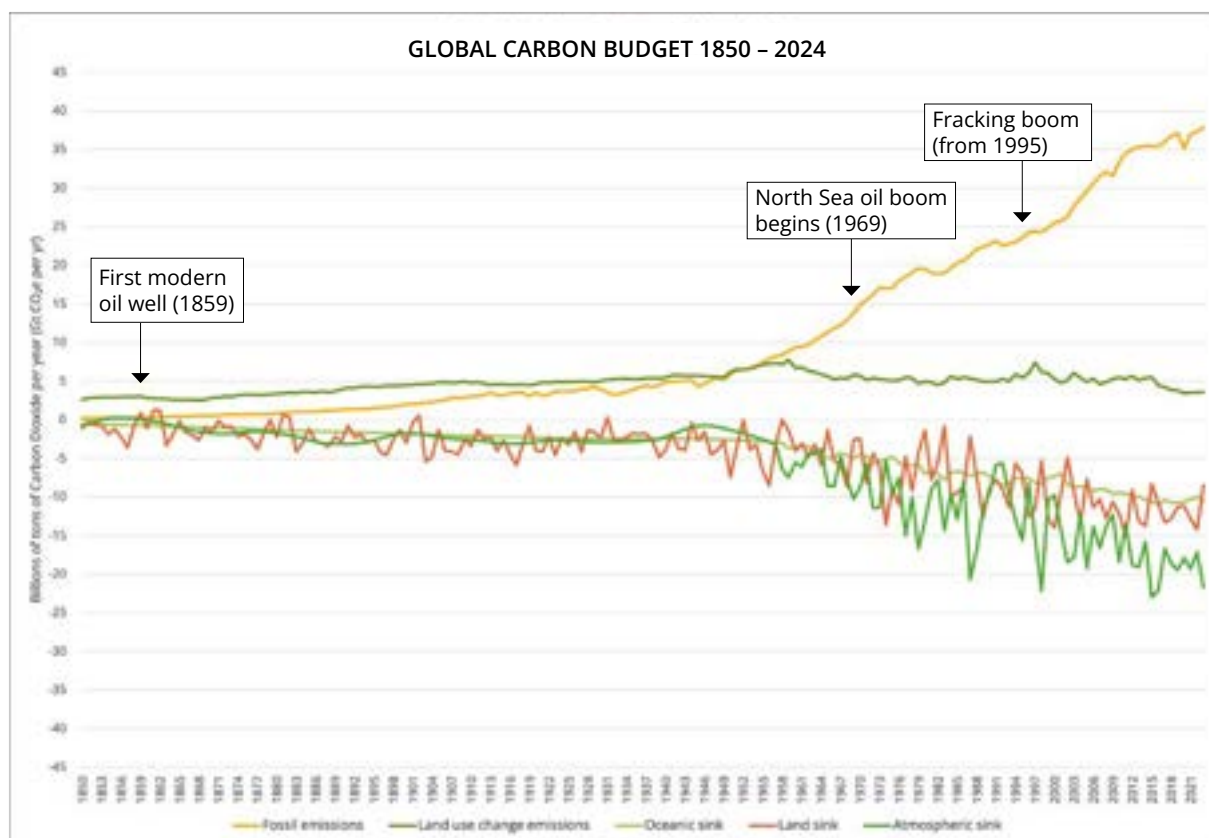


FIGURE 9

continued rapid growth of fossil fuel emissions is also decreasing oxygen (O_2), as fossil energy combustion consumes O_2 .

The global study of Huang et al. (2018) ⁴⁸ showed that fossil combustion is largely responsible for a growing atmospheric O_2 deficit, which reached 38.2 billion tons per year in 2015, and may continue to accelerate.

WE NEED YEAR-ROUND PHOTOSYNTHESIS

We now know that decarbonisation is not happening fast enough, despite decades of international effort, inter-governmental frameworks, national accounts, mitigation, and offsetting, and the establishment of a major global carbon accounting and reporting industry.

We also know that the same fossil sources that are driving atmospheric CO_2 levels upwards are simultaneously causing decline in atmospheric O_2 levels through combustion of fossil energy sources. This serious issue is rarely discussed, ignored by climate scientists as O_2 is not a greenhouse gas.

GRAZING: A TIME-TESTED SOLUTION FOR GLOBAL CARBON DRAW-DOWN

One of the most practical, viable, and scalable solutions to our planetary climate problem is to grow year-round photosynthesis. However, to achieve this while feeding the planet and raising living standards, employment, and economic growth, the key is to stimulate food-producing biomass that drives GDP.

This is a more pragmatic approach than to focus on intensive reforestation or 'rewilding' as has been proposed, as it is compatible with sustained economic growth, employment (especially regionally), and generating gross domestic product. It is a win-win.

SO, WHERE TO BEGIN?

The first place to focus attention is on the world's grassland and savanna ecosystems, which cover 40% of the terrestrial land surface ⁴⁹ and are often already grazed by wild or domesticated herbivores ⁵⁰⁻⁵¹. The global distribution of grasslands, shrublands, and savanna can be seen in Figure 11 ⁵² on the next page.

One of the most practical solutions to our planetary climate problem is to grow year-round photosynthesis.

Grasslands allocate a large proportion of their biomass below ground, resulting in large root-to-shoot ratios ⁵³. This pattern of biomass allocation, coupled with slow decomposition and weathering rates, can tend toward significant accumulations of soil organic matter and often highly fertile soils ⁵³.

Massive efforts are underway to prevent further desertification in Africa and China, and the initial results

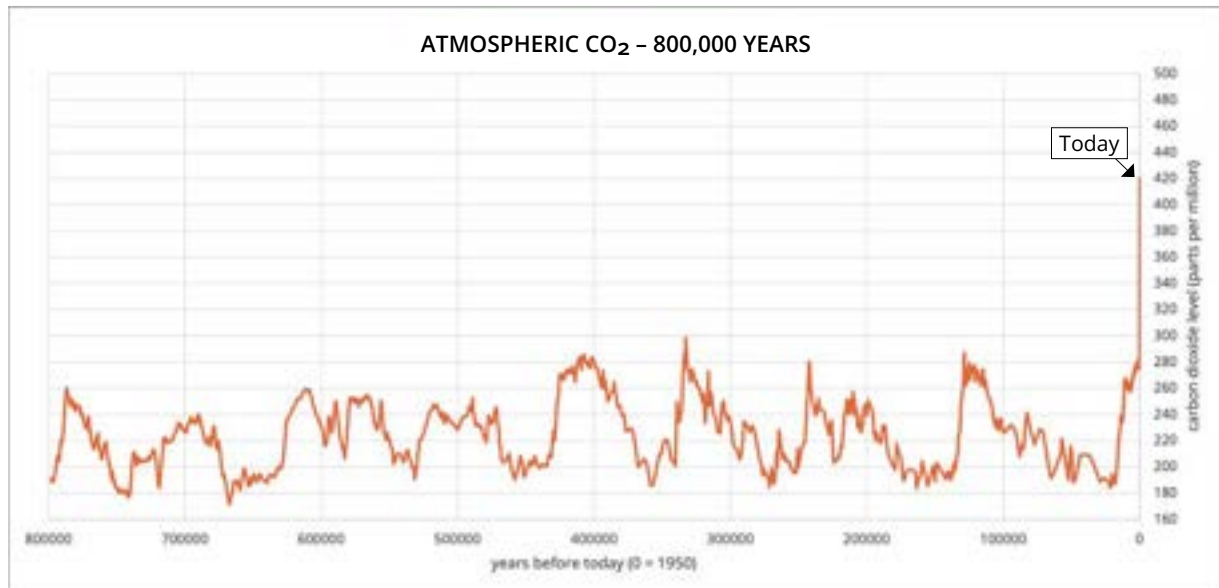


FIGURE 10

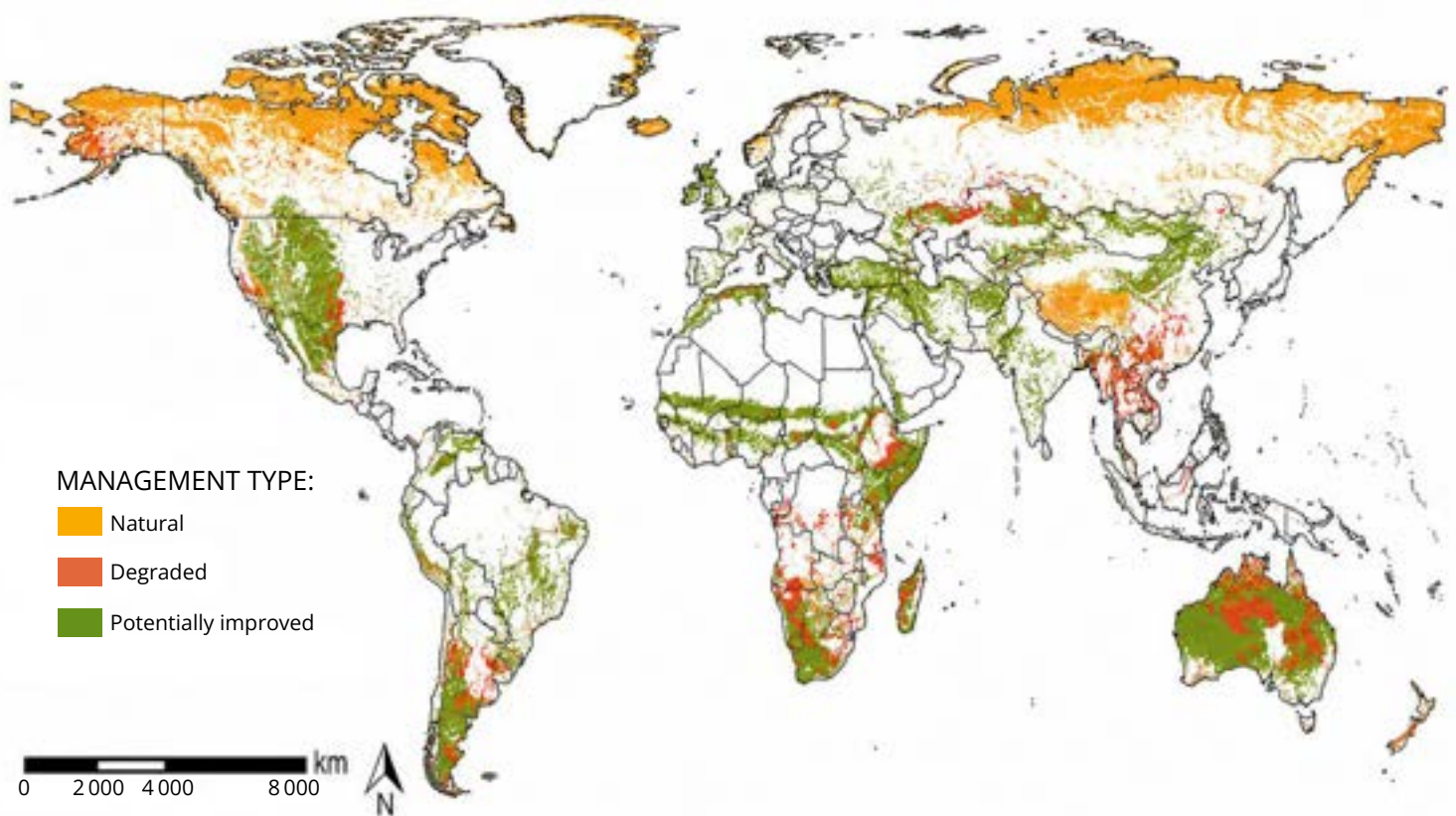
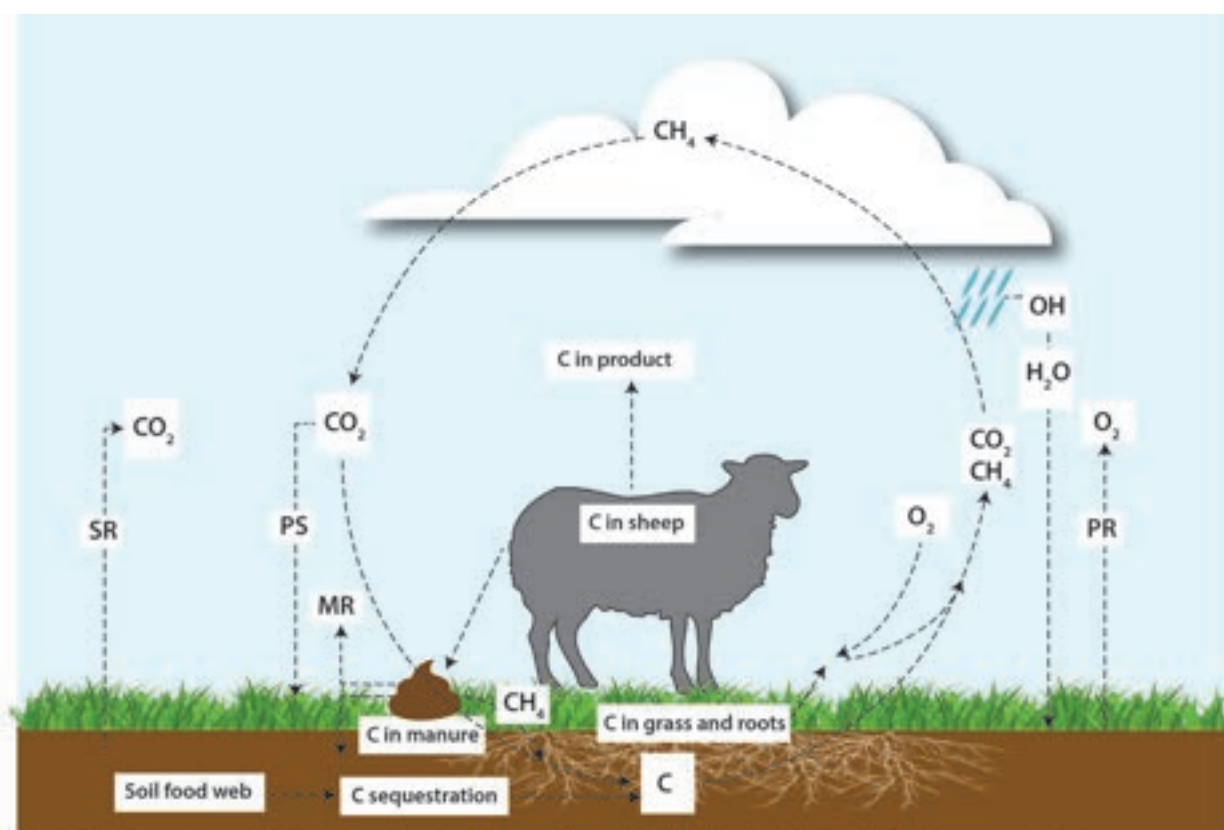


FIGURE 11



SR = Soil respiration; PR = Plant respiration; PS = Photosynthesis; OH = Hydroxyl oxidation; MR = Manure respiration

FIGURE 12: Sheep's role in nutrient cycling and climate regulation.

offer the potential to dramatically improve the productivity of arid zone areas, relying only on the simplest of technologies to hold precious water in the soil to permit plants to re-establish. The Great Green Wall of Africa⁵⁴ or the equivalent in China⁵⁵ are prime examples. These efforts impact potentially millions of hectares of land, not only creating food and livelihoods, but also drawing down carbon from the atmosphere, cooling and humidifying the microclimate, and productively using solar radiation that would otherwise be reflected as thermal radiation⁵⁶.

THE CRITICAL ROLE OF SHEEP & OTHER HERBIVORES

Plants have co-evolved with species that depend on them for food, and in turn, support the plant to flourish. This is termed 'symbiosis'. Specialised micro-organisms evolved to metabolise plant matter. These are mostly soil-living bacteria, but also include microfauna such as earthworms, millipedes, springtails, and slugs.

However, some mammals evolved specialised 'fermentation vat' fore- and hind-guts, which contain large populations of plant matter-digesting micro-organisms. These mammals are termed 'herbivores' and include sheep, cattle, and goats, these animals obtain the nutrients they need from their symbiotic relationship with the micro-organisms.

Herbivores play a crucial role in planetary health by shaping nutrient cycling, plant communities, and even climate regulation. As primary consumers, they transfer

energy from plants to the broader food web, while their grazing habits influence plant diversity, biomass, and distribution. Their interactions with vegetation also enhance soil health, supporting the fertility of Earth's grassland ecosystems.

ECOSYSTEM ENGINEERS

Recent research⁵⁷ notes that herbivores have several other important secondary effects: they also help prevent wildfires, reduce solar heat absorption by the Earth's surface, and contribute significantly to soil stability. Far from being disruptive, they actively support ecosystem resilience. Additionally, herbivores exhale more carbon dioxide than they inhale, providing a vital resource for photosynthesis and sustaining the balance of natural cycles (see Figure 12). 🐏



Wool's Role in Regenerative Systems

Wool can do more than just avoid negative impacts. Through regenerative practices, wool production can promote positive soil health, biodiversity, and carbon balance.

The last section (Section 3) established that sheep and their wool are part of the planet's natural carbon cycle. It also outlined the basis for global warming resulting primarily from the burning of fossil fuels.

And as the global community has become more concerned with the increase in atmospheric CO₂ resulting from human activities, the wool sector has been actively assessing its own climate impacts and exploring ways in which it can contribute to reducing the quantity of carbon escaping into the atmosphere.

We have also established (Section 1) that sheep and wool are represented in the carbon cycle as biogenic carbon. This carbon cycle involves not just carbon from the atmosphere, but also in the soil – and it is to the soil we will now turn.

KEEPING THE SOIL ALIVE

Dry soil is essentially hibernating, whereby microbes do not survive extreme drying. Add water to soil, however, and it and all the plants depending on it come alive. There are more soil microbes in a teaspoon of soil than there are humans on the planet. These microbes are essential to promoting and sustaining soil health. They provide plants with not just vital nutrients, but also a natural competition between microbe species, thereby lowering the occurrence of pests.

Responsible grazing practices, where plants are grazed for a controlled period of time and then allowed enough time to regrow, promotes soil health. Grazing sheep trim down the plants, maintaining them in a healthy, productive state. Some of the plant material will also be trampled and form ground litter, which together with urine and faeces produced by the sheep will be incorporated into the soil. This, in turn, will serve as food for soil microbes and earthworms.

The rest will form a protective layer on top of the soil, which prevents soil erosion and also provides insulation from extreme temperature fluctuations. The litter and sheep waste that is incorporated into the soil increases the soil's organic carbon content, which in turn promotes better soil structure by making it spongier and allowing for soil to retain more water.

Soil that is able to absorb water quickly reduces water run-off during heavy rains, preventing soil erosion, while soil that is able to retain water effectively will maintain its soil moisture for longer after a rainfall event. This increases the soil's resilience to extreme weather events such as flooding and droughts.

WHAT IS 'REGENERATIVE AGRICULTURE'?

A global transformation is underway in agriculture. While modern extractive farming techniques have greatly increased food production to meet the demands of a growing global population, there is now recognition that they have also led to soil deterioration, a decrease in biodiversity, and have contributed to climate change. This is where regenerative agriculture comes into play.

Regenerative agriculture is an evolution of conventional agriculture, reducing the use of water and other inputs and preventing land degradation and deforestation. It protects and improves soil, biodiversity, climate resilience and water resources while making farming more productive and profitable. Moreover, it ensures high-quality food and fibre production.

Growing pains exist, however. And as it is farm context-dependent, one size definitely does not fit all. Clear, standardised definitions remain elusive despite advancements in commercial and scientific realms. Similarly, the ecological outcome verification sector remains fragmented, and verification costs remain high.

To address this issue and facilitate understanding

IWTO DEFINITION OF REGENERATIVE WOOL

Regenerative wool farming utilises nature-positive approaches that promote measurable improvements in both soil and ecosystem health, while also improving animal welfare and supporting the economic stability of farming communities.

The goal is to create a resilient and efficient wool production system that yields considerable benefits for the environment, animal welfare, and local communities.



WOOL & THE CARBON CYCLE



FIGURE 13

6 KEY PRINCIPLES OF REGENERATIVE GRAZING SYSTEMS

FIGURE 14

PRINCIPLES	WHY?
Maintain high levels of ground cover, at all times	• minimise rainfall run off, soil loss to wind or water, and evaporative losses from bare soils
Maintain good levels of surface litter	• improve surface soil structure and support micro-fauna populations (e.g., worms)
Maintain sufficient year-round green leaf area	• maximise year-round photosynthetic capacity and efficiency • promote root growth & plant resilience by avoiding continuous over-defoliation
A diverse mix of plant functional groups	• ensure rainfall can be utilised year-round • maximise soil microbial biomass
Provide tree and/or shrub cover for shade and shelter	• minimise evaporative water loss from soils, excessive evapotranspiration from plants, and heat and wind stress on animals
Minimise soil disturbance, & physical, chemical & biological soil constraints	• ensure the soil is not limiting to plant production, soil microbial communities are diverse and flourishing, and maximise plant-available water holding capacity



PHOTO: DANIEL SANDVIK/UNSPLASH

and adoption of regenerative wool production, IWTO is progressing a global harmonised definition as well as biogenic modelling tools for wide use.

REGENERATIVE AGRICULTURE & CLIMATE CHANGE

Estimates are that poor agricultural land practices have contributed significantly to the loss of carbon from the soil over 12,000 years, perhaps as much as 116 billion tons of carbon from the top two metres of soil, or 8% of total global carbon soil stocks.

Yet soils are one of the Earth's most important carbon sinks, holding more carbon than all the world's vegetation plus our atmosphere combined. When practices that maximise carbon inputs to soils, such as planting cover crops, are combined with practices that minimise carbon losses, like reduced-tillage, soils can sequester significant amounts of carbon each year.

Regenerative agriculture therefore has the potential to transform agriculture from a source of greenhouse gases towards net carbon drawdown.

REGENERATIVE AGRICULTURE & BIODIVERSITY

With a holistic focus on soil health, regenerative farming practices aim to nurture biodiversity, both below and above ground.

Around 25% of the world's biodiversity is found underground, for example. A broad range of organisms like bacteria, fungi, worms and ants form a complex underground web. Reduced tillage leaves these organisms undisturbed. Covering the ground helps the soil retain moisture, and diverse crop rotation techniques nourish microbes in the soil with a more diverse diet.

Above ground, biodiversity is encouraged by a variety of planting techniques including biodiversity strips at the margins of fields or trees and shrubs around the boundaries of farmland. These create habitats for pollinators and other beneficial wildlife.

WHO IS FUELLING THE DEMAND FOR REGENERATIVE AGRICULTURE?

There is a rising interest in regenerative agriculture throughout the food and fibre value chains. For example, Nestle, one of the world's largest food and drinks company, is committed to source 50% of key ingredients through regenerative agricultural methods by 2030.

This trend addresses the escalating food insecurity and the heightened risks posed by climate change, along with the acknowledgment that agriculture plays a crucial role in tackling some of the world's most significant challenges.

WHAT PART DOES IWTO PLAY?

IWTO members are on the frontline of developments in regenerative wool production. IWTO maintains the global wool industry standards and regulations for wool testing and trading, and provides the global forum for standard development and textile community engagement. IWTO's Sustainable Practices Working Group has developed a working definition to underpin efforts to harmonise global wool trading standards in this key area.

Moreover, IWTO is also developing a novel biogenic carbon model which shows great promise in helping growers around the world understand their farm carbon cycle. 🐑

Responsible Wool Sourcing & Traceability

From farm to fibre, traceability and responsible sourcing are reshaping how the wool industry builds trust and transparency.

Responsible sourcing is a procurement strategy that prioritises ethical, social, and environmental factors across the supply chain. This approach transcends mere compliance with legal standards; it seeks to reduce adverse effects and foster positive transformations for both individuals and the environment. Here, 'responsibility' encompasses fair labour practices, sustainable environmental stewardship, and traceability and transparency in the sourcing process.

WHAT IS TRACEABILITY?

Traceability is the ability to establish a robust chain of custody from farm to finished product. Functionally, it is essentially a leak-proof pipeline for materials attribute and provenance data.

Traceability is critical for ensuring compliance with food safety and product labelling laws, as well as to underpin product ethical and sustainability claims such as Scope 3 GHG emissions reporting. It is also essential to help ensure effective biosecurity.

For these reasons, ensuring traceability of farm products along the supply chain is increasingly important for all agricultural industries, and the global wool industry has developed a comprehensive set of national and private systems for tracing wool back to where it was grown and harvested.

While these systems meet many of our present needs, efforts to enhance and future-proof them are also underway.

WOOL TRACEABILITY SYSTEMS

Many of IWTO's members have developed traceability systems. Each system varies in scope, but all serve to help provide supply chain transparency.

IWTO's Wool Traceability Systems report provides a comprehensive and annually updated list of transparency offerings from among the IWTO membership. Free

to download and with 30 traceability schemes or service providers currently listed, finding a solution that meets your needs is simple. You can find the link to access this resource in the References section ⁵⁸.

Another important development in traceability relates to eID technology. After decades of R&D, individual bale electronic ID technology is now a commercial reality in Australia and other countries, catalysing other digital traceability developments, such as the Australian Wool Traceability Hub (AWTH), a digital platform designed to enhance traceability across the wool supply chain within and from Australia.

SUSTAINABILITY CERTIFICATION SCHEMES

IWTO is the global authority for standards in the wool textile industry. Reflecting the rising importance of sustainability to consumers, brands and retailers, there has been a proliferation of wool sustainability standards and schemes available to the industry. These schemes vary in scope, ownership model, and in some cases are highly regional.

IWTO members from all stages of the wool supply chain have reported different issues arising from this overlap of standards. These include auditing fatigue among wool growers along with an increase in production costs. For processors and manufacturers to be certified for multiple standards means undergoing several audits per year. Parallel audits cost time and money, and perhaps more importantly the duplication of standards also leads to inventory issues, making the supply chain less efficient.

Ultimately, the multiplicity of parallel wool sustainability standards and schemes can also lead to confusion for brands, retailers as well as consumers.

IWTO EFFORTS TO HARMONISE CERTIFICATION SCHEMES

Due to the issue of audit fatigue, IWTO established a



Sustainable Standards Task Team (SSTT) in 2020 with a view to harmonising the then growing number of schemes that were being established to define and certify what each scheme separately believed constituted sustainable practices on a wool growing farm. The SSTT included representatives of the seven most substantial global wool sustainability standards.

The first stage in the work of the SSTT was to establish a comparison of the criteria adopted by the various schemes. Initially, a de-identified table was produced that allowed industry to understand the range of criteria assessed by the schemes.

In 2023, a formal comparator was published, identifying each scheme, thereby allowing contracting parties to compare the requirements of the standards of seven sustainability schemes.

FROM HARMONISATION TO IWTO RECOGNITION

Encouraged by commercial interests within IWTO, the SSTT has now gone further to develop a system whereby IWTO can license the various sustainability schemes in the market that meet industry-agreed requirements.

Details of the IWTO Licensing Scheme will soon be available on the IWTO website. Similarly, a Licensing Scheme Handbook has been prepared, the IWTO Agree-

ments and Arbitration framework (The IWTO Blue Book) has been updated.

The purpose of the IWTO License Scheme is to give enhanced credibility to wool sustainability claims, and to permit both a simple basis for equivalence (all must meet the IWTO standard) and the issuing of IWTO Sustainability Certificates. The three core components are:

1. Essential sustainability criteria: IWTO has adopted a set of essential criteria necessary to assess the sustainability of on-farm management practices, and to license those Sustainability Schemes that meet or exceed those essential criteria to issue IWTO Sustainability Certificates.

2. Scheme eligibility criteria: In order to be licensed, a Sustainability Scheme must have some form of membership with IWTO, either through a national committee of a member country or as an associate member in its own right.

3. Unique license numbers: Schemes that have been licensed by IWTO to issue IWTO Sustainability Certificates will be listed on the IWTO website and assigned an IWTO License Number, which must be reported on any IWTO Sustainability Certificates they issue. 🐏

A Brief History of Wool

Long before modern industry, sheep were already part of the human story. A partnership that continues to evolve today.

While there are more than 1,000 different breeds of sheep worldwide, the genetic evidence suggests all modern breeds evolved from a single ancestral type (the Asiatic Moufflon), first domesticated around 10,000 years before the present in the historic region of Mesopotamia – an area that includes modern Iran and Iraq, Kuwait, Turkey and Syria.

This era was the cradle of civilisation as we know it – inspiring six of the most important developments in the history of humankind: cursive script (writing), the wheel, mathematics, modern astronomy, cultivation of the first domesticated cereal crops, and domestication of the sheep.

That was the start of our long association – sheep were probably the second animal domesticated by humans after canines, and the oldest existing wool textile evidence dates to 7,000 BCE.

Since then, domesticated sheep have accompanied humankind – from the alpine deserts of Tibet to Iceland and Greenland, through the Americas, to the south of Africa and into Asia. A huge diversity of sheep types has evolved, reflecting incredible adaptability and resulting in a wide range of types of fleeces. Today, wool grows in a vast array of colours, thicknesses, textures and lengths.

Nowadays the most common types are the fine-woolled Merino and Rambouillet, UK's long-woolled Leicester type and hosiery downswool types such as the Dorset, and the dual-purpose Corriedale type, carrying wool suited to carpets and lamb production. 🐏

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GLOSSARY OF TERMS

Atmospheric carbon – in the atmosphere, carbon is present in gas form, either as carbon dioxide (CO₂), carbon monoxide (CO) and methane (CH₄). Collectively, these total only 0.0116% of the atmosphere by weight.

Biogenic carbon – Biogenic products are materials produced by or derived from living organisms, including from plants, animals, fungi and microorganisms. Wool is a biogenic material - formed in nature by nature, by upcycling biomaterials.

Fossil carbon – carbon contained in fossil fuels such as coal, gas, oil, and peat - which when released to the atmosphere results in an increase in atmospheric CO₂.

Greenhouse gases (GHG) – gases present in the atmosphere which absorb and then re-emit thermal radiation in the infrared range. GHG's play a critical role in regulating the temperature of the atmosphere, acting as a dynamic thermal insulation layer which prevents excessive heat loss to the solar system. This keeps the surface within a range capable of supporting life. The primary gases which cause the greenhouse effect are water vapour, carbon dioxide, methane, nitrous oxide and ozone – all naturally occurring, but human activities are increasing their concentration.

Microplastics and Nanoplastics – because the vast majority of the 10 billion tons of plastic polymer fibre and resin mankind has produced since the 1950's does not biodegrade, so plastic pollution in the environment simply fragments over time into increasingly small pieces. Microplastics are fragments less than 5mm long. Nanoplastics are the extremely small-scale form, typically ranging from 1 to 1,000 nanometres in size (0.001 to 1.0 microns).

Microfibres and Nanofibres – When a fibre breaks down into fragments of less than 5 mm in length, it is termed a microfibre. A subset of microfibres is now the Nanofibre – microfibres with diameters in the nanometre range, typically less than 100 nm.

Recycling, Upcycling, Downcycling – Recycling is the process of converting waste materials into new materials and objects. Upcycling and Downcycling are derivative terms which confer a value-adding or detracting meaning depending on whether the transformed materials are of higher value or function in the case of upcycling (which is also termed “creative reuse”), or to lower value or function in the case of downcycling. In the case of the atmospheric carbon cycle, atmospheric carbon dioxide is upcycled by photosynthesis to produce biomass – creatively reused by life-forms.

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 - EU PEF-CR DATA FOR 150G T-SHIRT PROCESSED IN CHINA, SOURCED FROM GLIMPACT ([HTTPS://TOOL.GLIMPACT.COM/JOIN?CONFIG=558265F4-E751-4DA1-A9DE-912FCFB2099A](https://TOOL.GLIMPACT.COM/JOIN?CONFIG=558265F4-E751-4DA1-A9DE-912FCFB2099A)). FIBRE IMPACTS EXPRESSED IN MICROPOINTS PER LB.
 - HIGG MSI DATA SOURCED FROM KYMO USING DATA SUPPLIED BY LENZING ([HTTPS://WWW.KYMO.DE/EN/BLOG/HOW-SUSTAINABLE-ARE-TEXTILES-A-COMPARISON-USING-THE-HIGG-MATERIAL-INDEX](https://WWW.KYMO.DE/EN/BLOG/HOW-SUSTAINABLE-ARE-TEXTILES-A-COMPARISON-USING-THE-HIGG-MATERIAL-INDEX)).
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FIGURE 3: DATA SOURCES AND METHODS FOR CHART:

A. ECOBALYSE DATA FOR 150 GM T-SHIRT PROCESSED IN CHINA SOURCED FROM ECOBALYSE BETA ([HTTPS://ECOBALYSE.BETA.GOUV.FR/#/TEXTILE/SIMULATOR](https://ecobalyse.beta.gouv.fr/#/textile/simulator)).

B. EU PEF-CR DATA FOR 150 GM T-SHIRT PROCESSED IN CHINA SOURCED FROM GLIMPACT, IM-PACTS EXPRESSED IN MI-CROPOINTS.

C. HIGG MSI DATA SOURCED FROM KYMO USING DATA SUPPLIED BY LENZING ([HTTPS://WWW.KYMO.DE/EN/BLOG/HOW-SUSTAINABLE-ARE-TEXTILES-A-COMPARISON-USING-THE-HIGG-MATERIAL-INDEX](https://www.kymo.de/en/blog/how-sustainable-are-textiles-a-comparison-using-the-higg-material-index))

FIGURE 9: NASA. DATA: LUTHI, D., ET AL.. 2008; ETHERIDGE, D.M., ET AL. 2010; VOSTOK ICE CORE DATA/J.R. PETIT ET AL.; NOAA MAUNA LOA CO₂ RECORD. SOME DESCRIPTION ADAPTED FROM THE SCRIPPS CO₂ PROGRAM WEBSITE, "KEELING CURVE LESSONS.")

FIGURE 10: PIERRE FRIEDLINGSTEIN ET AL. (2025), GLOBAL CARBON BUDGET 2024, EARTH SYSTEM SCIENCE DATA, ESSD, 17, 965–1039. [HTTPS://GLOBALCARBONBUDGET.ORG/](https://globalcarbonbudget.org/)

FIGURE 11: PETERMANN, J. S., & BUZHDYGAN, O. Y. (2021). GRASSLAND BIODIVERSITY. CURRENT BIOLOGY, 31(19), R1195–R1201.

FIGURE 14: GARDINER, B., AND REID, N. (2011), 'SUSTAINABLE LIVESTOCK PRODUCTION', CHAPTER 19, IN: INTERNATIONAL SHEEP AND WOOL HANDBOOK, ED. D.J. COTTLE, NOTTINGHAM UNIVERSITY PRESS, ISBN 978-1-904761-86-0

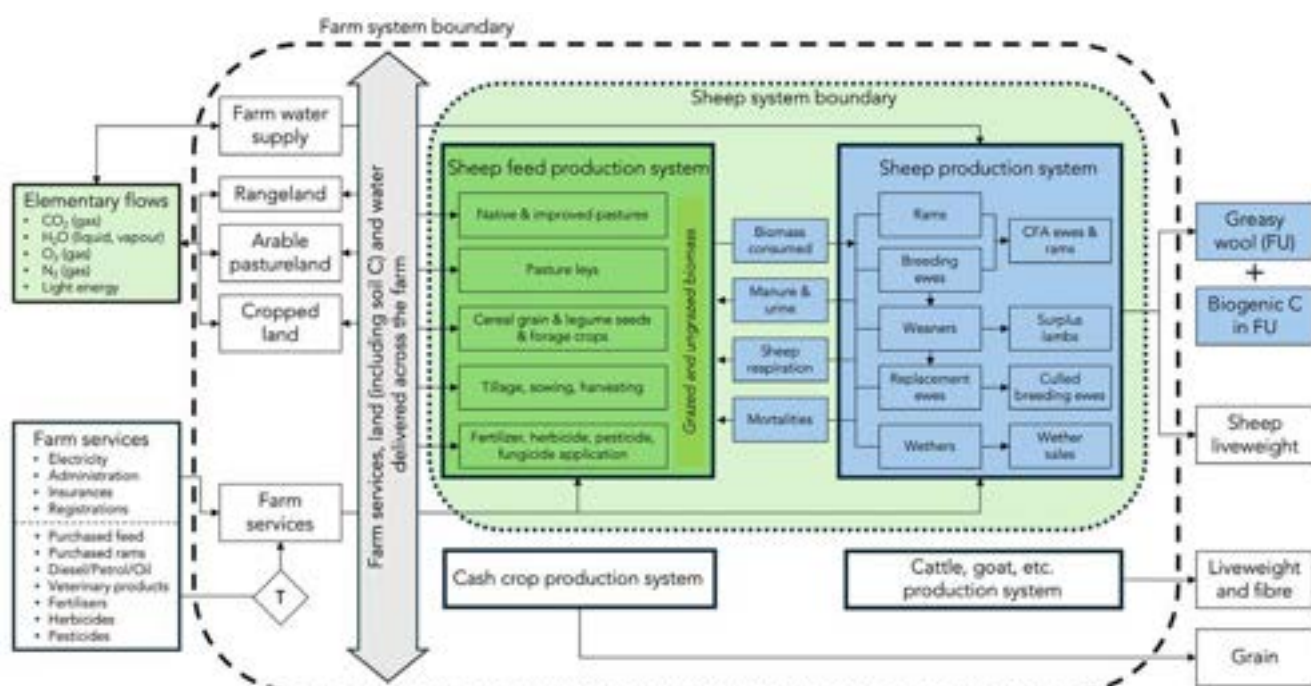
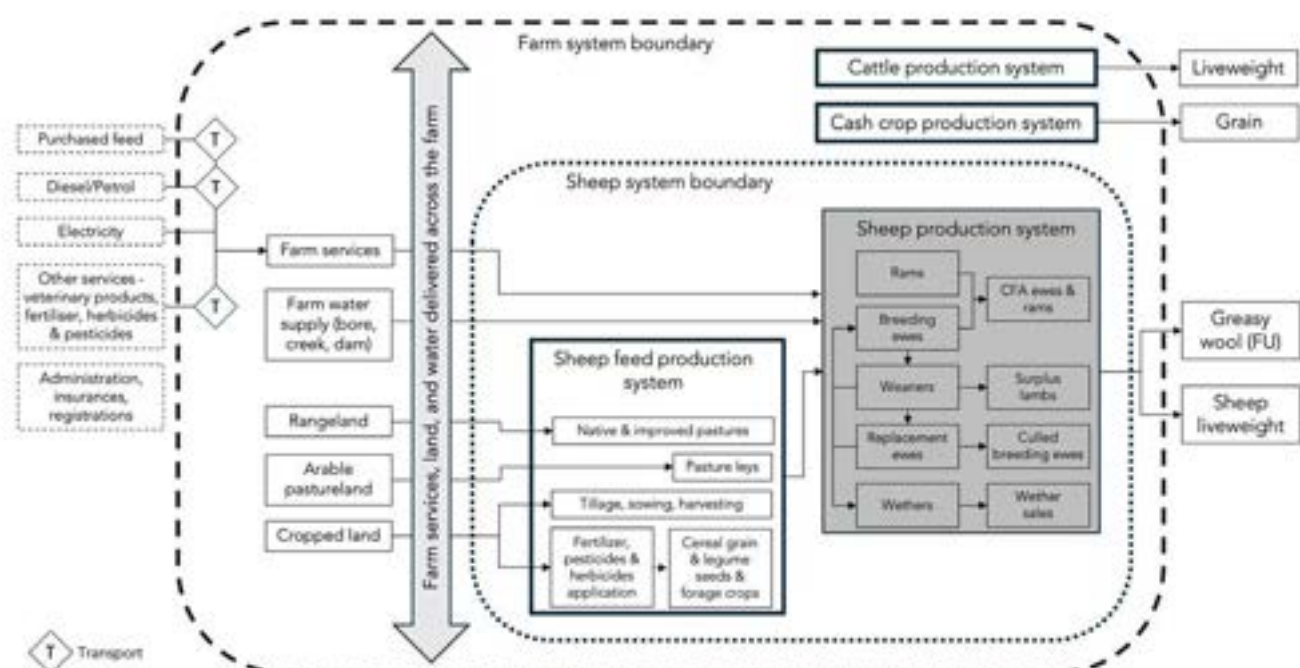


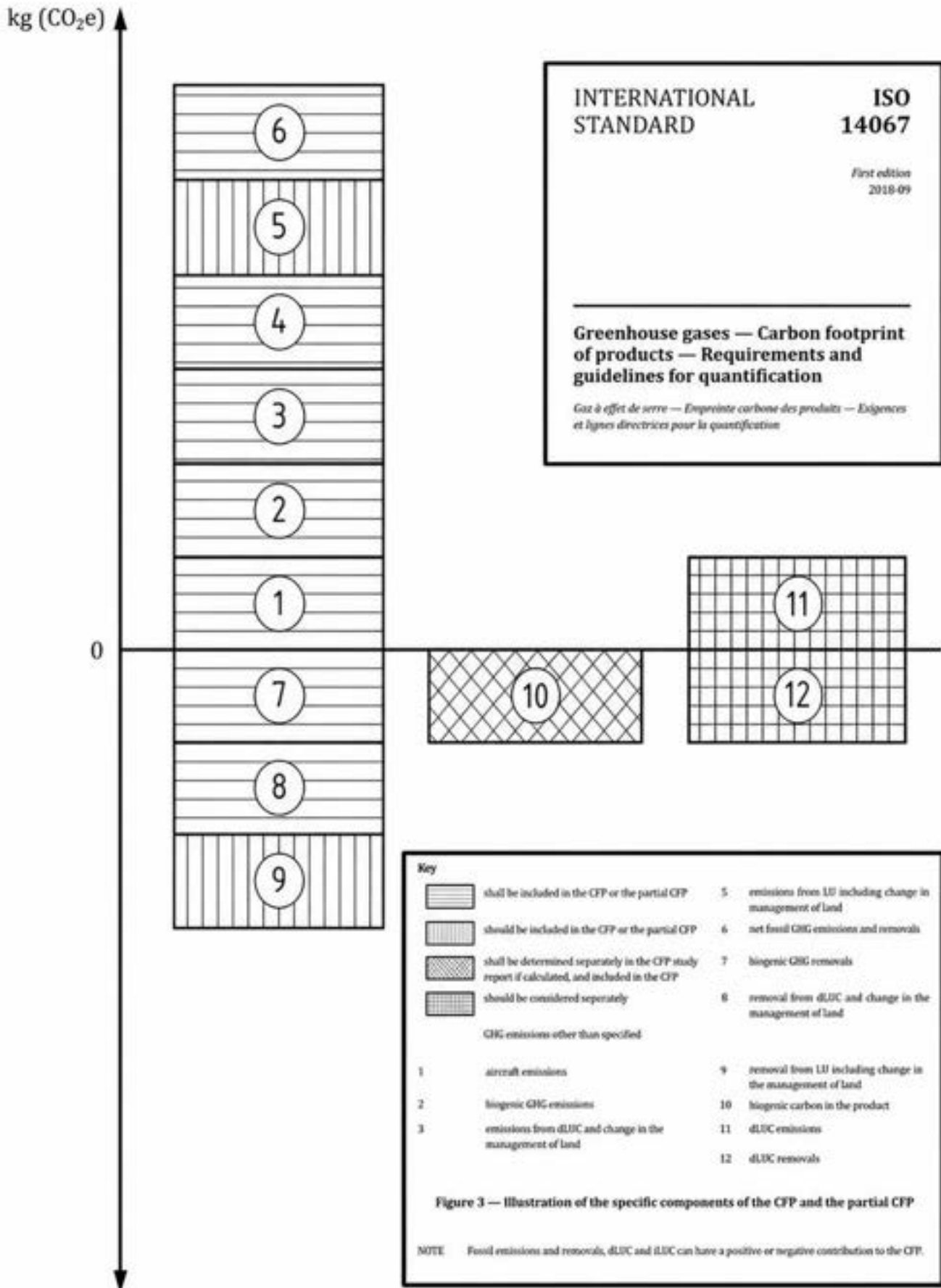
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