MAKE THE LABEL COUNT

DELIVERING EU ENVIRONMENTAL POLICY THROUGH FAIR COMPARISONS OF NATURAL AND SYNTHETIC FIBRE TEXTILES IN PEF

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Sustainability has become a priority objective for the European Union (EU). It is a key driver for policy development through the global leadership role the EU has taken in addressing climate change, decoupling economic growth from resource use, and the sustainable use of resources. The global supply of textiles has been recognized by the EU as a major source of emissions and resource use; the sector has become increasingly reliant on fossil feedstocks to supply synthetic fibres, and the textile industry has been roundly criticised for unsustainable and non-circular consumption patterns.

The Product Environmental Footprint (PEF) system – which assesses a product's environmental impact and provides consumers with information on that impact – has the potential to be paramount in directing the textile sector towards a sustainable system of production and consumption. However, the PEF system has not been designed to deliver the EU's strategies and, without amendment, its application to the textiles sector risks undermining the EU's laudable intent. The PEF system is designed to facilitate like-with-like comparisons, but assessment of textiles made from natural and synthetic fibres are not yet comparable because the impacts of forming natural fibres are fully accounted for, but omitted for fossil fuels. The single biggest sustainability issue for the textile industry is the growth in synthetic fibre production and the causally related rise in fast fashion. A PEF-derived comparison will not challenge the over-consumption of resources, and risks legitimising unsustainable consumption with an EU-backed green claim.

These limitations present a significant challenge to the delivery of both EU strategy and the PEF goal of providing fair comparisons of products based on their environmental credentials.

In combination, the characteristics of the textiles category, together with the limitations of PEF methodology, provide a strong argument for not comparing textiles made from renewable and non-renewable raw materials. However, achieving the EU Green Deal and circular economy objectives mandates a pragmatic approach; hence our analysis recommends methodological improvements to deliver EU environmental policy through fair comparisons of natural and synthetic fibre textiles in PEF. Addressing these limitations now will avoid the same problems arising when PEF is applied to other product categories that compare renewable and non-renewable raw materials, such as furniture and fuel.

Current concerns with the PEF methodology as it stands

There are critical environmental impacts that either aren't fully accounted for, or aren't included in the PEF methodology, that could significantly distort the credibility of the EU's environmental impact ratings of clothing and footwear products.

FULL IMPACT OF FOSSIL FUELS

PRODUCTION PRACTICES

MICROPLASTIC POLLUTION

RENEWABILITY & BIODEGRADABILITY

DURATION OF SERVICE LIFE

For consumers to understand the sustainability credentials of a product, they also need information on social impacts.

SOCIAL IMPACTS

Our analysis has identified the main challenges the PEF system poses to an equal comparison of products made from natural and synthetic fibres, and presents pragmatic recommendations to better align the methodology with the EU's Green Deal and circular economy objectives:

1

The PEF system must include impacts from microplastics to be consistent with EU expectations, strategies and communications, and to follow the precautionary principle. Omitting microplastics as an indicator effectively assigns zero impacts to this emission, which risks unintentionally guiding consumers towards plastic products and fibres, further increasing microplastic emissions. Similarly, omitting microplastics from the PEF single score and relegating the results to fields that are invisible to consumers (i.e., the 'Additional information' section of a PEF report) will not influence their purchasing choices. Microplastics can be added as an inventory-level indicator ahead of complete integration into the PEF system.

2

The PEF system must include a plastic waste indicator to be consistent with EU directives on plastic waste. This indicator would have broad applicability across product categories, including disposal of textiles made from synthetic fibres/plastics. There is a need to reduce the volume of plastic waste by reducing the demand for this material, and/or by diverting plastic away from landfill to preferred end of life processes, including fibre recycling. At present, the recycling of synthetic fibres is negligible, and end of life energy recovery is not sustainable because the incineration of plastic waste releases fossil CO_2.

3

The PEF system must include a circularity indicator to be consistent with the Circular Economy Action Plan (CEAP). Fossil materials are not renewable or circular and currently, none of the 16 PEF indicators directly measure circularity. Renewable and biodegradable raw materials (i.e., natural fibres) are inherently circular and more sustainable than those made from fossil feedstocks which resist biodegradation (i.e., synthetics). Including circularity as an indicator in PEF is the best means of equitably assessing the sustainability of raw materials originating from renewable and non-renewable sources.

Efforts to introduce EU-harmonised assessment criteria that enable leveraging the power of the EU Single Market to transition global supply chains towards more sustainable production and consumption are laudable. However, the PEF system, in its current form, is not yet ready to deliver key EU environmental policies including the Green Deal and CEAP, nor is the method adequate to provide fair comparisons between products made from natural and synthetic raw materials.

Until these methodological limitations of the PEF system have been addressed, fair comparisons of products made from renewable and non-renewable raw materials are not possible, and the use of PEF scores to inform product labelling or substantiate green claims may mislead well-intended consumers. Failure to address these limitations now risks entrenching a system that is counter-productive to EU environmental policy, and misses opportunities for the transition to a circular economy.

INTRODUCTION

Cause for concern

Sustainability has become a powerful theme for the European Union (EU) and a key driver for policy development through the global leadership role the EU has taken in addressing climate change, decoupling economic growth from resource use, and the sustainable use of resources. Key pieces of EU environmental policy acknowledge the single market presents on opportunity to apply EU standards relating to product sustainability and supply chain management at a global scale [1–2].

This is important because EU policy also recognises the drivers of climate change and biodiversity loss are global, and cannot be achieved by the EU acting alone [1]. This global reach is particularly relevant in the context of products such as textiles and garments because they are produced by long, complex and dynamic supply chains, often originating and terminating in regions far-removed from the EU.

The PEF (Product Environmental Footprint) scheme is an initiative of the European Commission (EC), designed to provide a common means of assessing and communicating the sustainability and environmental credentials of products (and organisations) within the single market [3–5]. The PEF scheme is based on a set of 16 indicators that cover environmental impacts, resource use and toxicity (both human and ecological) [5]. To derive a single PEF score, these impacts are normalised, weighted, then summed. There were three key motivations for PEF as a single methodology: (1) to reduce costs for businesses by reducing compliance burden from multiple systems, (2) to increase the free movement of 'green' products within the EU, and (3) bolster consumer confidence in green labels [3]. When PEF was first proposed, environmental issues were a significant issue but the focus for PEF was on facilitating the single market via green labelling. Subsequent EU environmental policies such as the Green Deal and Circular Economy Action Plan have focused on achieving sustainability and pollution reduction, which is a far more complex undertaking [1–2–6–8]. Of particular relevance to addressing the problem of fast fashion are those policies that seek to maintain products (as well as their materials) in circulation for longer within the economy. These policies include the Circular Economy Action Plan (CEAP), the EU Strategy for Sustainable and Circular Textiles and the New Consumer Agenda and ideas such as new sharing and repair services and strong markets for second-hand products [2–9–10]. However, PEF is designed for comparative purposes, not to challenge the choice of whether a purchase decision should be made. Sustainable consumption requires that our production-consumption systems use less resources – this is addressed most effectively by consuming less [11]. Accordingly, research has shown that even large contrasts in the environmental footprint of garments are minor relative to the reduction in impacts achieved by using less resources [12–13]. Consequently, a PEF-informed label may lead to a consumer decision that may be ineffective at addressing the reduced product utilisation and concomitant over-production that makes conventional textile business models unsustainable. Importantly, consumers tend to make decisions that maximise their self-benefit, which leads to a causal relationship between satisfaction with green labels and buying more [14]. This may lead to a PEF-backed 'green' label that legitimises over-consumption, whereas the most sustainable outcome would be a reduction in demand. This leads to doubt that the PEF system can deliver environmental outcomes in the direction, let alone the magnitude, required for a transition to a circular economy. **There is a risk that the PEF system will be out-dated at the completion of the transition phase, and that subsequent legislation will achieve sub-optimal or even undesirable changes in the production and consumption of goods.**

The PEF system has been the subject of much concern. For example, rather than progressing the EU goal of harmonising existing methods and curbing the proliferation of environmental standards, the PEF system presents new methods, some of which are in direct conflict with international standards in LCA [15]. There are concerns that many features of the PEF system reduce comparability, including the failure to clearly define important attributes such as functional unit and product category [16]. Similarly, there are concerns that methodological choices have created a PEF system that favours reproducibility rather than comparability [17], that important impacts relating to toxicity and biodiversity/ecosystem function are underrepresented [18], and that in the case of textiles, the PEF system is incapable of addressing the twin problems of over-production and over-consumption [19]. **The PEF system, and LCA more broadly, are based on framework elements that were never designed to equitably compare the environmental impacts of life cycles that commence with raw materials from extractive and non-extractive industries, such as synthetic fibres made from fossil fuels and natural fibres obtained from farming systems.** This intractable problem, and the three key issues that must be addressed to foster an equitable comparison of synthetic and natural fibres in the PEF system, are introduced below.

The system boundary problem increases the imperative for action

PEF category rules (PEFCRs) have been or are being developed for a limited selection of products, all of which are either principally extracted from the Earth's crust (e.g., information technology equipment, renewable batteries and water supply pipes) or composed of material obtained from biological systems (e.g., animal feed, dairy, beer), many of which are farmed. However, extractive and non-extractive industries have a fundamentally different system boundary (Figure 1). The system boundary in LCA studies typically begins with a unit process in which raw material acquisition brings natural resources such as water, CO2, land and minerals into the realm of human activity, but it may also involve the acquisition of materials within this realm (i.e., salvage such as urban mining and recycling).

This boundary is practical – it identifies those processes over which the entity commissioning an LCA has operational or financial control or responsibility. However, initiating a system boundary with raw material acquisition omits the environmental processes that created these initial inputs [20]. For example, the assessment of natural fibres (e.g., wool, cotton, silk, cashmere) includes all impacts for monomer production (i.e. the plant and animal processes involved, and the agricultural system required to support these) [21–22]. By contrast, a conventional LCA of fossil feedstock-derived fibres (e.g., polyester, nylon, acrylic) will not include the impacts of monomer production; that is, the formation of fossil fuels is omitted [23]. This leads to higher impacts for natural fibres because the raw material acquisition phase (i.e., farming) is a common hotspot for environmental impacts (Figure 2). Other product categories where renewable and non-renewable raw materials are compared include interior furniture (which may be made from wood, metal, plastic, glass, leather, etc) and fuels (which may be from fossil and biogenic sources). For example, the full life cycle water and freshwater eutrophication impacts of diesel derived from first-generation hydrogenated vegetable oil are much greater than those of diesel derived from fossil feedstocks due entirely to raw material extraction and manufacturing processes [24].

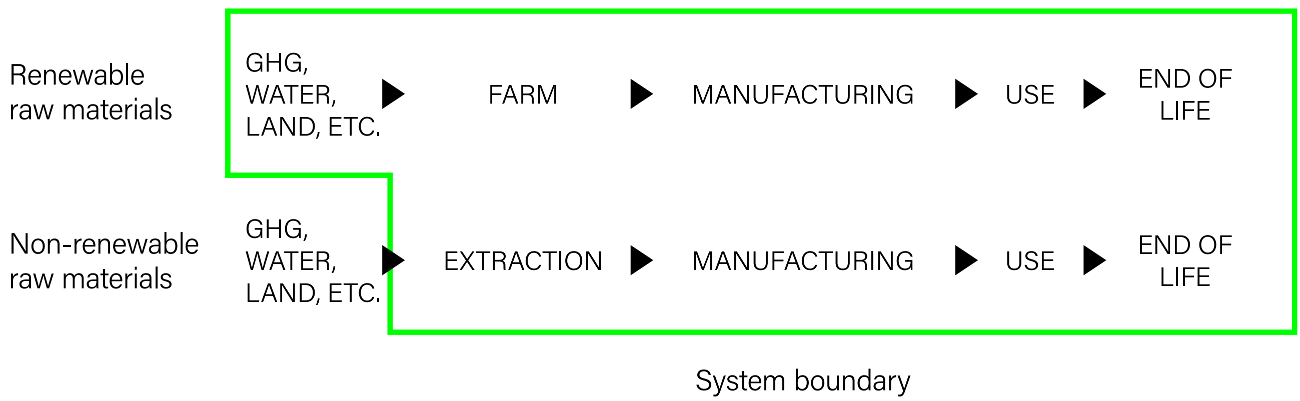


Figure 1. *The contrast in system boundary between a life cycle commencing with renewable and non-renewable raw materials. The life cycle of non-renewable materials, such as fossil fuels extracted from the Earth's crust, excludes the Earth-system processes (such as ancient photosynthesis and geological processes) that lead to their formation. The life cycle of renewable raw materials, such as natural fibres produced on-farm, includes the processes involved in fibre formation, such as greenhouse gas emissions, water use and land occupation.*

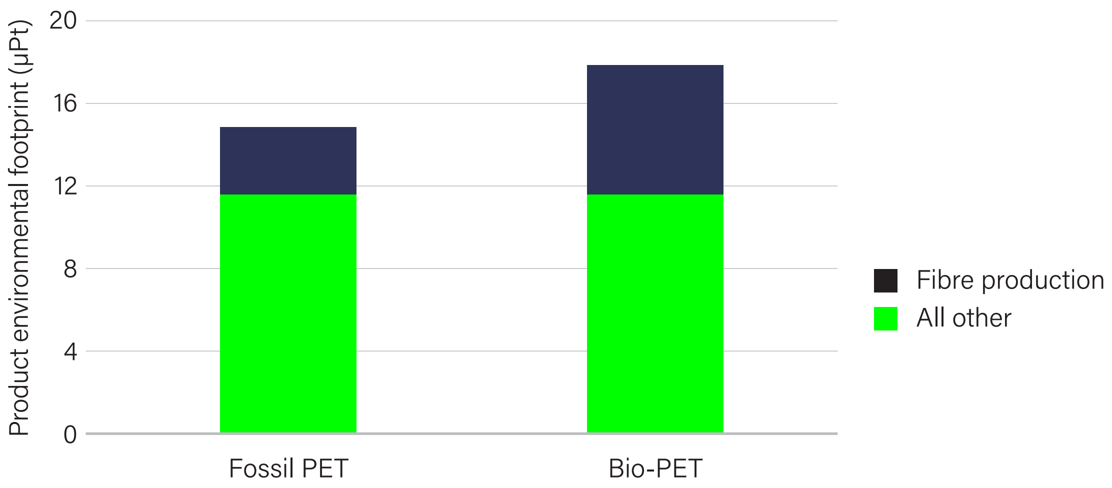


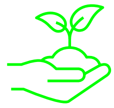
Figure 2. *Effect of fibre type on a PEF single score. This example shows a sweater made from polyester (PET) either derived from fossil fuels or from biological feedstocks (maize) – the life cycles have contrasting fibre production stages, but all other stages are equal. Impacts for the bio-PET sweater are 20% greater, due largely to water scarcity impacts associated with the farm stage, and to a lesser extent farm stage climate change and land occupation impacts.*

The challenge posed by inequitable system boundaries are not unique to comparisons of renewable and non-renewable raw materials. For example, wild caught fishery LCA studies conventionally include vessel use and the maintenance of fishing operations but exclude the processes that lead to the formation of fish biomass [25]. The system boundary issue means a PEF study isn't capable of equitably comparing raw materials from extractive and non-extractive industries. This is problematic in the context of EU environmental policies because key tenets of the Green Deal include decoupling economic growth from resource use, and the sustainable use of resources [1]. This issue is also problematic in the context of the single market for green products, because equitable comparisons of environmental credentials was one of the key problems to be addressed [4]. The seemingly intractable challenge posed by the system boundary of conventional LCA studies increases the importance of a pragmatic approach that considers other ways in which raw materials derived from renewable and non-renewable sources can be handled equitably in the PEF scheme. This white paper identifies solutions to three of the largest challenges the PEF system poses to an equitable comparison of natural and synthetic fibres, and places these in the context of EU environmental policy objectives.

These challenges fall under the following topics:


Microplastic pollution


Plastic waste


Circularity

For each of the above key areas, our approach is to (1) identify key issues with the application of the PEF system to renewable and biodegradable raw materials such as natural fibres, (2) identify their relevance to the goals of EU environmental policies, and (3) propose constructive changes that could be made to improve the PEF system. The importance of these issues to informing and advancing EU environmental policy should be reflected by (1) their inclusion as PEF indicators, and (2) the weighting they receive when impacts are summed to derive a single PEF score. **This white paper shows that amendments to the PEF system can improve alignment with EU environmental policies and the task of equitably comparing the environmental credentials of products made from renewable and non-renewable materials.**

ISSUE ANALYSIS

The PEF system must include microplastic emissions as an indicator

THE ISSUE

Despite covering a diverse set of indicators, the PEF scheme does not include an indicator that reflects the impact of microplastic emissions. **Microplastic emissions are a concern because (1) they are readily transported through the ecosphere, including through food chains, (2) they are resistant to biodegradation, (3) pose an obstructive or toxicological (including via the desorption of contaminants) hazard to organisms, and (4) are practically impossible to remove from the environment after release [26].** Plastic emissions can be either macroplastics (> 5 mm long), microplastics (1 µm to 5 mm long) or nanoplastics (< 1 µm, which makes them more difficult to detect and less well studied). Microplastics can be either primary (directly associated with processes within the technosphere, such as washing and using synthetic garments) or secondary (generated via the degradation of plastics in the environment) [27]. Microplastic losses to the environment are a function of the rate at which the emissions are transferred to initial compartments (i.e. oceans, freshwater, soils, the terrestrial environment, air), the subsequent transfer to the ultimate receiving compartment, and the rate at which microplastic emissions degrade [27–28]. In the case of garments, known sources of microplastics are manufacturing (including pre-washing) and product use (i.e., wear and laundering) [27]. There is a paucity of studies on microplastic emissions across the full life cycle of garments, particularly the end of life stage.

RELEVANCE TO EU ENVIRONMENTAL POLICIES

The CEAP states that it will propose mandatory measures to address the presence of microplastics in the environment by, amongst other things, developing labels, standards, certification and regulations on the unintentional release of microplastics, including measures to capture macroplastics across product life cycles, and developing methods for measuring unintentionally released microplastics, especially from tyres and textiles, and delivering harmonised data on microplastics concentrations in seawater [2, p. 12]. The CEAP also emphasises the need to enhance circularity in a toxic-free environment, including the development of methodologies that "minimise the presence of substances that pose problems to health or the environment in recycled materials and articles made thereof" (p. 17). The Strategy for Plastics in a Circular Economy [29] and EU Strategy for Textiles Roadmap [30], both specifically refer to the need to address the release of microplastics. The recently released EU Strategy for Sustainable and Circular Textiles [9] clearly identified the shedding of microplastics as an environmental issue that compounds impacts relating to the linearity of textile life cycles. The Commission plans to address microplastic pollution via a range of initiatives targeted at stages throughout product life cycles, from product design through to manufacturing, wear, care and the treatment of textile waste [9]. It is therefore noteworthy that, following an earlier report [31], the European Chemicals Agency (ECHA) has delivered its final opinion on regulating microplastics intentionally-added to products such as cosmetics, detergents, fertilisers and paint [32]. The EC is now overdue to prepare a proposal to amend the list of restricted substances to include intentionally-added microplastics [33]. Recently, a series of test methods for fibre release, appropriate for all fibre types and fabric structures, was delivered to the

European Committee for Standardisation, which are expected to become ISO standards [34]. The Nordic Swan Ecolabel requires that textiles with ≥90% synthetic fibres be subject to a standard test conducted by *The Microfibre Consortium*, or a future equivalent EN/ISO standard test [35] – this shows immaturity of testing methods is no impediment to providing information on microplastic emissions to consumers. Microplastic emissions are therefore an active area of environmental policy development and implementation in the EU, which increases the importance of considering their impacts in the PEF scheme.

RESOLUTION

A strong argument can be made for the inclusion of microplastic emissions as an indicator in the PEF system. **Omitting microplastics as an indicator effectively assigns zero impacts to this form of emissions, which risks unintentionally guiding consumers towards plastic products and fibres.** In the case of the textile industry, a 'do nothing' rationale is difficult to justify. The increase in garment consumption has been almost entirely driven by the consumption of synthetic fibres [36]. These additional impacts are related to discretionary consumption, and therefore warrant close scrutiny using indicators that target known environmental impacts, such as microplastic particle emissions, just as the European Chemicals Agency has decided in relation to intentionally-added microplastics [26].

In the first instance, an 'inventory-level' indicator is proposed (i.e., a simple summation of modelled emissions across the life cycle, to which no characterisation factor accounting for attributes such as toxicity and particle breakdown, is applied). For example, one of the most important PEF indicators, 'resource use – fossil fuels' is largely a compilation of inventory data. There is therefore a precedent for using inventory-level impact assessment methods in LCA and the PEF system. The PEF system also includes largely untested impact categories (such as the LANCA method for assessing the impact of land occupation), and the scoring of impact categories on their 'robustness' [5]. The willingness of the PEF system to accept methods varying in maturity puts it in an ideal position to pioneer the development and application microplastic emissions as the subject of an LCA indicator.

Quantis' Plastic Leak Project (PLP) was a key development in inventory analysis for garments with respect to microplastic emissions [27]. The PLP begins with the mass of synthetic fibre by polymer type, an estimate of lifetime microplastic loss during washing, and ends with a country-specific estimate of release to the environment based on the efficiency of wastewater treatment. Gaps that can be filled using the latest research include microplastic release during manufacturing [e.g., 37], release to air during garment use [e.g., 38], and release upon landfill [e.g., 39]. It is acknowledged that the subsequent development of a characterisation model to determine mid-point impacts should be a research priority.

ISSUE ANALYSIS

The PEF system should include plastic waste as an indicator

THE ISSUE

Waste generation is an important issue in the context of textiles. Estimates suggest European consumers annually dispose of 2.8 – 7.2 kg clothing per person, and a total of over 11 million tonnes across the whole life cycle of clothing consumed [40]. These high rates of disposal have been facilitated by the development of fast fashion, in which Western consumers have been presented with an abundance of inexpensive clothing items capturing the latest fashion trends, manufactured cheaply across global supply chains [41]. **Historical trends in fibre production show that the increased demand has been met almost entirely by growth in demand for synthetic fibres [36, Figure 3], and the recycling rate is negligible [5]. Plastic polymers can take many forms, including solid blocks, flexible sheets, as well as fibres. Consequently, the increase in consumption has therefore been accompanied by an increase in the mass of plastic waste originating from the textile supply chain.** Until recently, textile waste was *not* subject to an export prohibition under the shipment of waste regulation [42], so there was a risk that low-quality, non-biodegradable, difficult-to-recycle synthetic garments disposed of by EU consumers become an end-of-life problem in other jurisdictions. The export of waste to non-OECD (Organisation for Economic Cooperation and Development) countries now requires such countries to demonstrate an ability to manage waste in an environmentally sound manner [43]. Textiles are also absent from the directive on single use plastic products [44] and therefore not subject to its deterrents, such as extended producer responsibility schemes and the enforcement of infringement penalties. The absence of a measure of plastic waste generation as a clear output of PEF study therefore has the potential to contribute to an inequitable comparison of natural and synthetic fibres, and decreases the utility of a PEF study more broadly.

Quantifying plastic waste becomes more necessary if microplastic emissions form the basis of an indicator (see above). This is because a consequence of a microplastic indicator may be an increase in the mass of macroplastic emissions within a product life cycle. For example, microplastic fibre release during laundering could be avoided if garments were used once and never laundered, or if the number of wear/wash cycles was kept to a minimum. Such behaviours would contribute to greater environmental impacts via under-utilisation of clothing (see below) and a

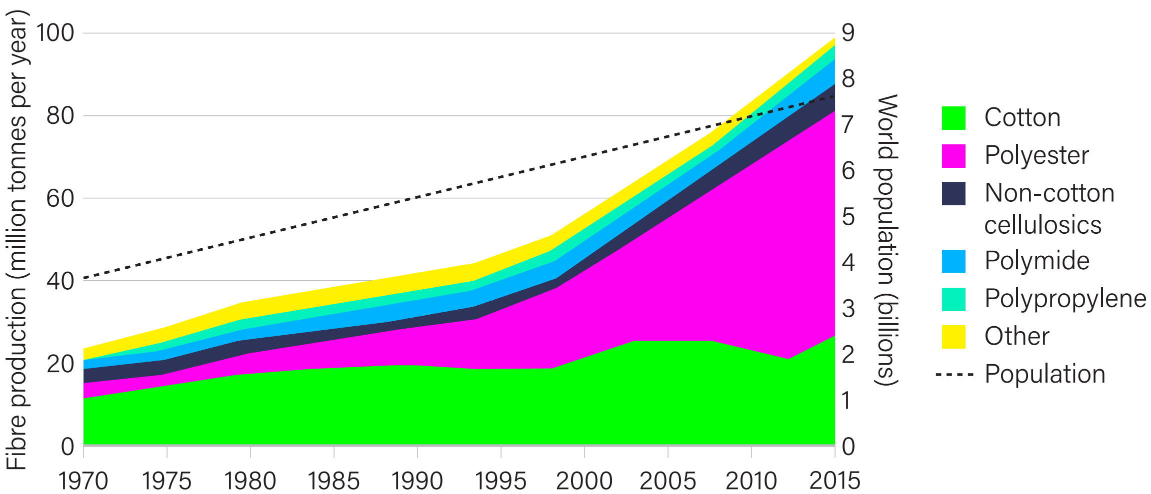


Figure 3. *World fibre production, 1970 – 2018 [36].*

premature shift of plastics from the use phase to the end of life phase. Taken to the nth degree, this would promote the single use of plastic products, such as garments made from polyester fibres. This burden shifting across life cycle phases could be avoided by a comprehensive PEF indicator set that includes plastic waste.

RELEVANCE TO EU ENVIRONMENTAL POLICIES

Reducing waste and ensuring there is a well-functioning internal market for secondary raw materials are essential components of the interrelated CEAP initiatives [2–6]. The EU has many policies targeted at reducing the use and promoting the recycling of plastics. These include the directive on single-use plastics which promotes alternatives to common single-use plastics [44]; the Plastic Bags Directive, which addresses the unsustainable consumption of single use, lightweight plastic bags [45]; the Packaging Directive, which requires that EU countries to set producer responsibility schemes and recycling targets for all packaging [46]; and rules on certain shipments of plastic waste to, from and within the EU and non-EU countries, particularly in relation to hazardous or hard-to-recycle plastic waste [42]. Forthcoming EU initiatives include leading a global intergovernmental committee to address the mismanagement of plastic waste and the release of plastic into the environment [47], providing consumers with bio-based, biodegradable and compostable plastics [48], and public consultation on evidence relating to the release of microplastics from synthetic textiles, from tyres and from plastic pellets [49]. By January 2025, all EU Member States must have separate collection processes for textile waste, in addition to meeting targets for re-use and recycling of municipal waste [50]. These initiatives are taking place across the product life cycles, from raw material acquisition (i.e., alternatives to fossil feedstocks), through to manufacturing (i.e., pellets and packaging), the use (i.e., single use) and end of life (i.e., recycling, shipment of recyclables) phases. **The life cycle approach to measuring plastic waste that would be achieved via PEF may be particularly effective at instigating the systematic practice change that is required to turn the diverse EU policy targets into achievements [51].**

RESOLUTION

The PEF system should include plastic waste as an indicator. This idea is not controversial – solid waste production is the least preferred option in the EU waste hierarchy [52]. Although our starting point is plastic waste originating from the life cycle of synthetic garments, a plastic waste indicator would have broad applicability across product categories. A reduction in the volume of plastic waste may be brought about by a decrease in raw material consumption, and/or by the diversion of material from landfill to preferred end of life processes, such as recycling. End of life energy recovery is not a preferred process because the incineration of plastic waste releases fossil CO2. A plastic waste indicator may be effective for aligning the diverse interests of the people and organisation upon who the composition and volume of plastic waste depends. For example, a study on compostable bioplastics showed that those companies with clear landfill minimisation goals sent their waste to compost facilities, whereas those with less clearly defined sustainability goals corresponded with the disposal of waste in landfill [53]. For all recyclables, particularly those recovered by mechanical rather than chemical processes, identifying contamination may require a whole of life cycle approach [54] that could be fostered by comprehensive inventory data based on plastic quantity and composition. This is important for material recovery industries the CEAP seeks to support because their financial viability may depend on sufficient flows of high quality recyclables, as well as the appropriate collection infrastructure and a market for recyclates [55]. **Textiles are an ideal target for a plastic waste indicator because incentives are needed to align their recycling rate with circular economy objectives.** At present, the rate of apparel recycling is negligible [5], and the predominant source of recyclate for synthetic textiles is plastic bottles [56]. **Recycling plastic from bottles into fibres is identified as problematic by the EU for three reasons – the practice misleads consumers, down-cycles food-grade plastic, and increases the risk of microplastic fibre release** [9]. In the absence of interventions, recycling synthetics in the textile industry will remain synonymous with down-cycling, and simply delay rather than prevent the creation of plastic waste.

The primary challenge in advocating for a plastic waste indicator is similar to that of microplastics – conceptually, the indicator is inventory-level, not mid-point, as without the necessary characterisation model, the pathway to impact isn't clear. However, like the need to include microplastic emissions, ignoring plastic waste is akin to assigning the issue zero impact, which would conflict with the aims of the EU to afford the environment a high level of protection, rectify environmental damage at its source, and ensure that polluters be held accountable for their impacts [57].

ISSUE ANALYSIS

The PEF system should be based upon sustainability principles

THE ISSUE

As mentioned above, a diverse range of raw materials are used as feedstocks for fibre production, ranging from natural fibres (e.g., wool, angora, silk, cotton, flax, hemp), synthetics from non-renewable sources (e.g., polyester, nylon, acrylic), semi-synthetics (e.g., rayon, lyocell), and fibres recycled via open- and closed loops (e.g., from pre- or post-consumer wool), through to those that share the attributes of multiple categories (e.g., polyester made from bio-based feedstocks). Fibre choice is important in terms of sustainability. To be 'sustainable', a product life cycle should (1) avoid the accumulation of extracted substances from the lithosphere (Earth's crust and upper mantle), (2) avoid substances produced in the technosphere (the human system of materials, industries and products) accumulating in the ecosphere (environments capable of supporting life), (3) avoid anthropogenic activities that impair the function of the ecosphere, and (4) be accompanied by the efficient allocation of resources within and between societies [58]. **Thus, renewable, biodegradable fibres (i.e., natural fibres), and fibres made from recycled materials, are more sustainable than those made from fossil feedstocks (i.e., synthetics) or those resistant to biodegradation (e.g., bio-polyester).** From an LCA perspective a life cycle must deliver a specific function [in response to questions of "what, how much, how well and how long?" in the PEF system – 5], whereas sustainability is concerned with preserving the capacity of the ecosphere (including societies) to tolerate, adapt and change in response to environmental change. Techniques such as normalisation could enable LCA studies [such as PEF; –16] to be sensitive to the carrying-capacity of Earth systems [59]. However, normalisation in the PEF system is based on emissions to air, water and soil, and resources extracted, at the global scale for the year 2010 [60] – that is, it reflects the share of resource use and emissions, but not the extent to which these impacts threaten the sustainability of Earth systems. PEF includes 'resource use – fossils', but this indicator is ineffective at sending a signal to the market regarding the sustainability of raw materials (Figure 4). The **result is that a PEF study permits processes that would be considered an anathema under a sustainability paradigm, such as choosing a fibre**

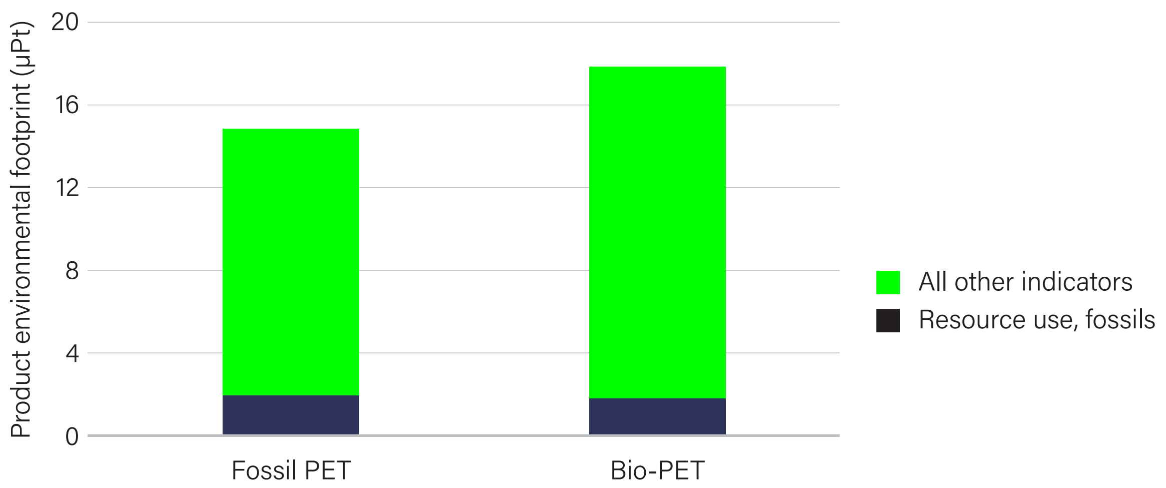


Figure 4. *The contribution of 'resource use – fossils' to a PEF single score. This example shows a sweater made from polyester (PET) either derived from fossil fuels or from biological feedstocks (maize) – all other aspects of the product life cycle are equal. 'Resource use – fossils' contributes 2.0 and 1.9 µPt to the respective single scores, despite the contrast in the renewability of the raw materials.*

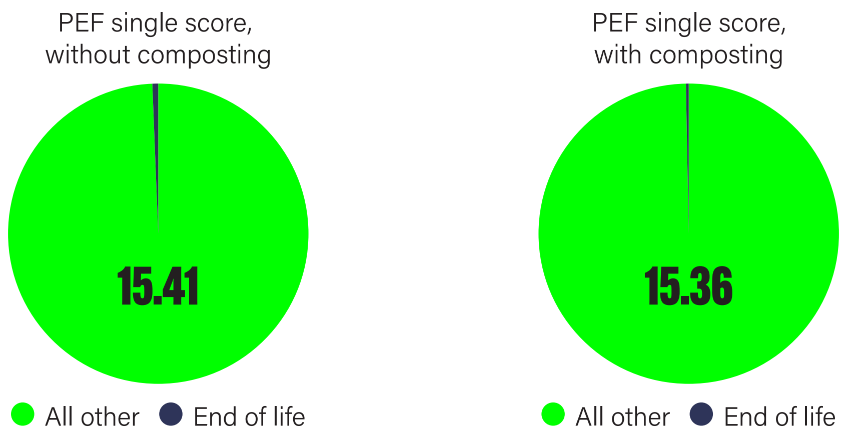


Figure 5. *The contribution of compositing to a PEF single score. This example shows a sweater made from wool either derived disposed of via conventional pathways (incineration and landfill) or composted – all other aspects of the product life cycle are equal. The insensitivity to composting provides no incentive to divert biodegradable waste away from processes that are less desirable according to the waste hierarchy.*

made from a non-renewable feedstock, using the resulting product, then disposing of it in landfill. A PEF score is also insensitive to composting as an end of life process, which has the effect of failing to provide an incentive for recycling materials through biological cycles rather incineration or sending them to landfill Figure 5). As a result, the correlation between the impacts determined in a PEF study and the sustainability of a product life cycle is likely to be sub-optimal.

RELEVANCE TO EU ENVIRONMENTAL POLICIES

Due to their important role in supporting sustainability, renewable material inputs play an important role in key EU environmental policies. The CEAP [6] identified the ability of bio-based materials to provide alternatives to non-renewable products (and energy) in a circular economy due to their renewability and potential biodegradability (p. 17). Reducing dependence on non-renewable resources was one of the key societal challenges of the Bioeceonomy Strategy [61, p. 4].

RESOLUTION

To meet the need for a quantitative metric capable of assessing the sustainability of an economy progressing towards circularity, a number of circularity indicators have been developed. Some of these operate at the macroscale (e.g., the Eurostat circular economy monitoring framework) while others operate at the microscale familiar to LCA. The circular footprint formula (CFF) of the PEF system is useful for modelling the recycled content and end of life processes of a product life cycle, but recent research shows the CFF does not produce an impact assessment materially different from that obtained using conventional methods [12].

None of the 16 PEF indicators directly measure circularity, despite the availability of indicators operating at the product scale, such as the Material Circularity Indicator (MCI), developed by the Ellen MacArthur Foundation [62]. The MCI is driven by three product characteristics: feedstock attributes, product utility (which is a function of the length and intensity of product use), and the destination and attributes of spent materials. Based on these processes, the MCI assigns a score to a product life cycle between 0 and 1, where higher scores reflect minimisation of linear flows and maximisation of restorative flows for component materials [62]. More specifically, the MCI recognises (1) material inputs to a product life cycle that are from a renewable and verified sustainable source, reused, or recycled, (2) products that last longer or deliver more functional units per lifespan, and (3) reuse, recycling, compost (of non-toxic biological accessible materials) and energy recovery (of circular inputs only) as circular end of life pathways. The MCI material input criteria are consistent with criteria set for identifying circular fibres, which emphasise recycled and renewable content from regenerative sources, and prioritise non-edible renewable feedstocks as alternatives to synthetic raw materials [63].

Like many circularity indicators, the MCI is focused on the material aspects of circularity, but it is more comprehensive than most because it quantifies other aspects of circularity, such as product reuse/refurbishment and embodied energy [64]. However, there is an implicit assumption in the MCI that the processes it rewards will not result in impacts that outweigh the benefits of circularity. For example, recycling maybe be an energy intensive process, or a low-yielding sustainable supply of renewable raw materials may induce land use change. These possibilities are routinely considered in LCA, meaning that potential oversights such as these are accounted for in PEF. Conversely, **the principal advantage of a circularity indicator like the MCI is the ability to capture and emphasise product or material attributes that are essential to a sustainable product life cycle, yet poorly represented by an LCA-based approach such as PEF** (Figure 6). Integrating circularity indicators into PEF can go some way towards addressing the inability of LCA to equitably compare extractive and non-extractive industries given their contrasting system boundaries (see above) – if a circularity indicator was a 17th PEF indicator, it would represent 6% of a normalised PEF score but would require a weighting of at least 3× to compensate for contrasts such as that shown in Figure 2. The MCI provides for more equitable comparisons because it can recognise the potential sustainability of a non-extractive industry such as farming (e.g., production of animal or plant fibres), and simultaneously recognise that raw materials obtained from an extractive process (e.g., mining or drilling for fossil feedstocks) are inconsistent with sustainability principles. Thus, despite relying on similar inventory data, circularity indicators and the PEF system may deliver contrasting yet complementary data on the sustainability of product life cycles, thereby jointly provide direct support for key EU environmental policy objectives.

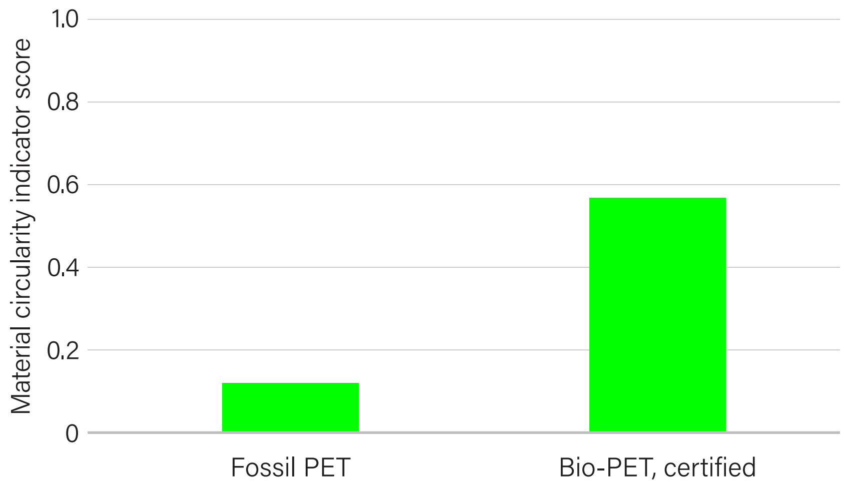


Figure 6. *Material circularity indicator scores for sweaters made of polyester (PET) either derived from fossil fuels or from biological feedstocks (maize, certified sustainably produced) – all other aspects of the product life cycle are equal. Higher scores reflect materials, products and processes that are consistent with circularity objectives of sustainable sourcing, maximising use and re-use, and recycling materials via technological and biological processes. The score for the fossil PET sweater is lower because the feedstock consists of virgin raw materials. The score for a sweater made from either fibre type is kept low by negligible rates of post-consumer recycling.*

CONCLUSIONS

PEF is a commendable initiative that presents an opportunity for the power of the EU single market to transition global supply chains towards more sustainable production and consumption. However, the system is not ready to deliver against key EU environmental policies such as the Green Deal and CEAP, not ready to address the threat to sustainability posed by the mass of synthetic fibres made from fossil feedstocks, not ready to deliver consumers meaningful information, and not capable of providing equitable comparisons between products made from renewable and non-renewable fibre inputs. Reasons for these inequitable comparisons are diverse, but include the historic focus of LCA on the processes an entity conducts (which ignores the natural processes that form extracted resources) that leads to: inequitable system boundaries when products obtained from extractive and non-extractive processes are compared; the omission of microplastic emissions and plastic waste generation as important indicators; and the absence of measures (such as a circularity indicator) that would enable a PEF impact assessment to directly relate to sustainability principles and support the transition to a circular economy. Despite their diversity, technically feasible solutions could be identified for each limitation:

i. Include inventory-level indicators quantifying microplastic emissions as a PEF indicator,

ii. Include an inventory-level indicator quantifying plastic waste as a PEF indicator, and

iii. Include a product-based circularity indicator such as the MCI as a PEF indicator.

These solutions will be most effective when they are accompanied by PEF single score weighting factors that reflect their importance to informing and advancing EU environmental policy. **By adopting the recommendations, there is potential for the PEF system to (1) provide more meaningful guidance to EU consumer purchasing decisions and to (2) assist in delivery of the sustainability objectives of EU environmental policy through fair comparisons of natural and synthetic fibre textiles in PEF.**

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