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Biodegradable Textiles and Apparel as an Opportunity for Private Sector Environmental Impact

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ABSTRACT: The global fashion and sportswear industries produce 4-5 billion tons of carbon dioxide emissions annually, which contribute to about 10-12% of total global CO_2 emissions. Using biodegradable textiles instead of petroleum-based plastics can lower greenhouse gas emissions by roughly 25%. This review explores how companies producing biodegradable materials might gain from adopting standardized reclaim systems that improve end-of-life management and promote more sustainable retail practices. The analysis of online public country-level databases (WRAP and EUROSTATS), which address current waste management and sorting practices, supports this literature review. Peer-reviewed literature was gathered through Google Scholar. Statistical analyses methods were performed using JASP software. (Version 0.95.1). The WRAP database included data from 128 countries, out of which 43 countries met study inclusion criteria. The most common output technologies were reusable textiles (n=20), sorted textiles for open-loop recycling (n=18), and non-textiles (n=17). A significant positive correlation exists between total textile and plastic waste generation (Spearman $\rho = 0.591$, $p = .011$). Absolute government environmental expenditure (Pearson $r = 0.736$, $p = .002$; Spearman $\rho = 0.879$, $p < .001$) and waste management expenditure correlate with tonnes of waste recycled (Pearson $r = 0.546$, $p = .035$; Spearman $\rho = 0.757$, $p = .002$). National textile recycling rates were correlated with outputs for disassembled textiles in fibre-to-fibre recycling (Pearson $r = 0.484$, $p = .042$; Spearman $\rho = 0.495$, $p = .037$). High production costs and competition for agricultural land limit the adoption of biodegradable textiles. Future recommendations include advancing material properties for diverse conditions, reducing costs through biopolymer innovation, and integrating biodegradable textiles into circular economy frameworks to support sustainable development in the sportswear sector.

KEYWORDS: Chemistry, Biodegradable Textiles, Closed-Loop Textiles Systems, Environmental Impact, Recycling Infrastructure.

Introduction

The world fashion and sportswear markets account for 4–5 billion tons of CO_2 annually, or 10–12% of global annual CO_2 emissions, on top of being two of the largest consumers of water and producers of waste.[1] To counter this, several companies have begun focusing their attention on biodegradable materials as an alternative to traditional synthetics.[1] Bioplastics like PLA (polylactic acid) save two-thirds of the energy consumed in producing regular plastics and emit 70% fewer greenhouse gases when degrading in landfills.[2,3] PLA alone can reduce greenhouse gas emissions by 25% compared to regular plastics.[2,3] PLA is most used in compostable packaging bags, coatings for paper and food packaging, and controlled-release systems in pharmaceutical delivery.[4] In the apparel industry, PLA is being adopted for green fashion, 3D printing of accessories, and zero-waste clothing.[5]

Despite these advantages, biodegradable fibers have been challenging to adopt in the apparel market, as most clothing is made up of two or more synthetic polymers.[6] The production of environmentally friendly materials, like PLA, can be 50% pricier than traditional polyester.[7,8]

Closed-loop cycles offer promising ways to address this environmental strain. Rejected products can be gathered and reprocessed, mechanically, chemically, or biologically, into the same type of materials for the same purpose, enabling fiber-to-fiber recycling and waste reduction.[9] With biodegradable fabrics, it can also involve a return to the biological cycle, where they decompose to nutrient-rich biomass that can be used to create new resources.[10]

One of the primary roadblocks preventing the use of closed-loop cycles and the growth of the biodegradable sportswear industry is the absence of formal reclaim and disposal procedures. There is no standard method of collection or sorting of biodegradable material. Most post-consumer clothing is channeled through customary landfilling, burning, or downcycling to secondary forms.[11] Moreover, public participation in using disposal facilities is virtually nonexistent, largely due to confusing labeling and the absence of clear manufacturer instructions.[12] This leads to the loss of both environmental benefits and business profitability.

These waste pathways present challenges for biodegradable products, as they necessitate specific composting or biological treatment conditions that are rarely available on a large scale. Currently, about 75% of global textile waste ends up in landfills, while roughly 25% is recycled or repurposed, typically for lower-value products such as wiping clothes or insulation.[13]

In mixed landfills, biodegradable apparel anaerobically breaks down, releasing methane and leachate, which degrades

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their environmental benefits.[14] However, when segregated and pumped into well-operating aerobic composting facilities, anaerobic degradation can be prevented because oxygen-based systems inhibit the formation of methane.[15] Proper utilization of biodegradable fabrics thus depends on advanced sorting technologies such as near-infrared spectroscopy, image-based recognition, and RFID (Radio-Frequency Identification), which can segregate them from regular fabrics and place them into appropriate composting or recycling streams.[15]

Countries investing in companies engaged in biodegradable product manufacturing would benefit from the development and deployment of an established reclaim process and sorting facility.[10,16] Utilizing closed-loop systems, companies would be able to achieve maximum material recovery, minimize damage to the environment, save on the cost of production through reusing, and generate greater consumer confidence.[9] Building on previous work in bioplastics, textile recovery processes, and supply chain models, this work investigates whether companies producing biodegradable products can benefit from implementing standard reclaim processes to improve end-of-life management and accelerate environmentally protective retail practices.

Without established industrial composting systems, most biodegradable sportswear is disposed of with conventional textiles, where it enters landfills or incineration streams. Under these conditions, biopolymers such as PLA may release methane, a greenhouse gas up to 30 times more potent than CO_2, if degradation occurs anaerobically.[14] Furthermore, mixed fibers and inadequate sorting infrastructure cause biodegradable apparel to behave like synthetics, reducing their environmental benefit.[6] Current circular practices remain limited: approximately 75% of global textile waste is landfilled, about 25% reused or downcycled, and less than 1% closed-loop recycled into new clothing.[13] Experts emphasize that building coordinated collection and fiber-to-fiber recycling systems is essential for realizing the full potential of biodegradable textiles.[10,11]

Sorting Technology

Image sorting technology analyzes objects' inherent visual features, such as shape, texture, and color, and it has achieved high precision in waste sorting. The process has four stages: recognition, tagging, detection, and segmentation. By automatically extracting thousands of tiny visual features from pictures, machines can pick up small differences that are beyond human capabilities.[17] When paired with Support Vector Machine (SVM) and Convolutional Neural Network (CNN) algorithms, classification accuracy can reach up to 94.8% for SVM and 83% for CNN.[18] These models can sort metals, paper, glass, plastics, waste, cardboard, and fabric in real time on high-speed conveyor belts. Continuous training with annotated new images enhances their ability to increase performance over time, which makes them very adaptable to diverse waste compositions.[19] For textile sorting specifically, hyperspectral/NIR data in combination with ML algorithms correctly identify fiber types, conveying the potential to sort large-scale automated fabric.[20] Another deep learning model, trained on more than 28 recyclable classes, obtained 83.11% accuracy and 0.63 mean average precision (mAP) on detection tasks.[19] Using near-infrared (NIR) multi-spectral sensors and machine learning, Convolutional Neural Networks (CNNs) have achieved a mean classification accuracy of 72.5% in plastics, with a peak accuracy of 83.5% for PS plastic and 66% for PET.[21] These results illustrate that image-based recognition is capable of sorting massive waste streams efficiently and accurately.

Radio-Frequency Identification (RFID) is another technology that can be integrated with image recognition to further increase sorting efficiency. This technology uses radio waves to automatically identify and track objects through tags embedded with electronic data. RFID improves recycling efficiency since it identifies material composition, reduces sorting time, and avoids contamination from non-recyclables.[22] In closed-loop systems, RFID reduces CO_2 emissions and water consumption by 99%, chemical use by 88%, and energy demand by 53% compared to original material production.[22] It can help extend garment life through digital care labeling, further lowering another 5–10% of carbon, water, and waste footprints.[22]

Beyond its environmental advantages, RFID addresses issues such as forced labor and counterfeiting, supports secondary resale channels, creates employment for 35–50 workers per plant, and has the potential to save over $175 million each year by eliminating landfill diversion.[22]

NIR spectroscopy offers another capability to waste management systems. It is a non-destructive method that measures how near-infrared radiation interacts with molecular bonds to identify materials such as polyester, cotton, wool, cashmere, nylon, and blends with accuracy.[15] It is highly accurate for identifying complex fiber blends when combined with statistical programs such as Principal Component Analysis (PCA) and Partial Least Squares (PLS).[20] NIR spectrometers are compact, modular, affordable, and environmentally friendly, making them suitable for large-scale recycling facilities. When combined with visual spectroscopy (VIS) or attenuated total reflectance (ATR), they can even detect multilayered or pigmented materials that otherwise would go undetected.[15]

These technologies are even more effective when supported by policy and collaboration across industry. The United Kingdom's Waste & Resources Action Programme (WRAP) delivers an example through the Textiles 2030 program, which aims for a 50% decrease in carbon emissions and a 30% decrease in the water footprint of clothes by 2030 compared to 2019 levels.[28] The program promotes circular design, extended product life, and higher fiber-to-fiber recycling. Over 110 organizations, representing 62% of UK clothing sales, have already joined the effort.

Members have documented a 12% per-tonne carbon footprint decrease and 4% water footprint decrease since 2019, conserving 1.1 million tonnes of CO_2 and 385 million cubic meters of water in 2022 alone.[28]

Methodology

This study investigates some of the current relationships between government expenditure, public waste trends, and innovative textile waste recovery programs in Europe. Using data

collected from WRAP and EUROSTATS public databases, regression and correlation analyses were conducted using JASP (2024, Version 0.95.1) [Computer software].

Data was extracted from online databases and organized in an Excel sheet. The WRAP database was used to analyze the companies that were engaged in the processing of textiles in various life stages and levels of material damage. Companies engaged in the WRAP initiative were filtered based on the feedstock they processed. Only companies receiving post-industrial textiles, pre-consumer textiles, reusable post-consumer textiles, non-reusable post-consumer textiles, workwear, hospitality, or duvets/pillows were included. Information on output composition, output technology, current processing capacity, and geographical location was extracted to an Excel file, and descriptive statistics were used to classify the concentration of each of these variables in their respective countries. Eurostat's data from 2022 provided the size of each country, population, total waste, waste sent to disposal operations, environmental expenditure (euros and %GDP), total landfill facilities, household waste, recycled waste, plastic waste, and textile waste.

Results

The WRAP database housed reports from 128 European companies engaged in textile sorting and recycling. Filtering by feedstock type allowed 43 companies to be analyzed. None of the companies included currently host websites documenting statistical information regarding their current processing engagements; however, a few listed their current processing capacity. This data was excluded due to the inconsistency of reporting.

The WRAP database included 22 countries, with the UK (n=17), Italy (n=8), and the Netherlands (n=8) having the highest number of WRAP textile waste processing facilities (see Figure 1). The most frequently reported WRAP facility output technology was reusable textiles (n=20), followed by sorted textiles for open-loop recycling (n=18), and non-textiles (n=17) (see Figure 2). Of the countries engaged in advanced output technology, Denmark-based facilities engaged in the highest diversity of technological operations, with an average of 77% (SD: 27%) of the companies engaging in each type of output technology. Italy, Turkey, and Finland reported the lowest density of technological adoption with 35% (SD: 10%, n=8), 5% (SD: 16%, n=2), and 0% (SD: 0%, n=1). Ireland was excluded from the analysis due to a lack of companies engaging in textile waste processing.

Table 1: This figure demonstrates the number of WRAP-associated facilities present in each reporting European country.

		Count
WRAP Facilities	Austria	2
WRAP Facilities	Belgium	6
WRAP Facilities	Bulgaria	1
WRAP Facilities	Croatia	1
WRAP Facilities	Denmark	3
WRAP Facilities	Finland	1
WRAP Facilities	France	5
WRAP Facilities	Germany	5
WRAP Facilities	Greece	2
WRAP Facilities	Hungary	1
WRAP Facilities	Ireland	NaN
WRAP Facilities	Italy	8
WRAP Facilities	Lithuania	1
WRAP Facilities	Netherlands	8
WRAP Facilities	Norway	2
WRAP Facilities	Poland	1
WRAP Facilities	Portugal	2
WRAP Facilities	Spain	5
WRAP Facilities	Sweden	4
WRAP Facilities	Switzerland	3
WRAP Facilities	Turkey	2
WRAP Facilities	UK	17

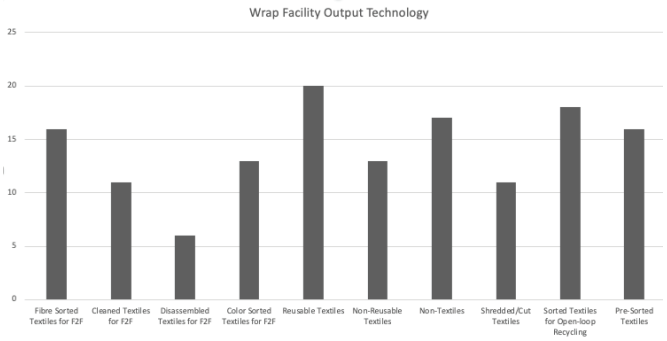

Figure 1: This figure demonstrates the number of companies advertising advanced recycling output technology.

Table 2: This figure shows the availability of output technology in each country's total WRAP facility population.

	Fibre Sorted Textiles for F2F	Cleaned Textiles for F2F	Disassembled Textiles for F2F	Color Sorted Textiles for F2F	Reusable Textiles	Non-Reusable Textiles	Non-Textiles	Shredded/Cut Textiles	Sorted Textiles for Open-loop Recycling	Pre-Sorted Textiles
Austria	50%	50%	50%	100%	50%	50%	100%	50%	100%	100%
Belgium	50%	17%	17%	50%	67%	50%	83%	33%	83%	50%
Bulgaria	0%	100%	0%	0%	100%	100%	0%	100%	100%	100%
Croatia	100%	100%	0%	100%	100%	0%	100%	0%	100%	100%
Denmark	67%	33%	33%	67%	100%	100%	100%	67%	100%	100%
Finland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
France	80%	60%	60%	100%	40%	20%	40%	80%	80%	60%
Germany	80%	20%	20%	60%	40%	40%	60%	40%	80%	60%
Greece	0%	50%	0%	50%	50%	50%	50%	50%	100%	100%
Hungary	0%	0%	0%	100%	0%	0%	100%	0%	100%	100%
Ireland	0%	100%	0%	0%	100%	100%	0%	100%	100%	100%
Italy	50%	25%	25%	50%	38%	38%	38%	25%	38%	25%
Lithuania	100%	100%	100%	100%	0%	0%	0%	100%	0%	0%
Netherlands	63%	38%	38%	50%	50%	50%	63%	38%	75%	50%
Norway	100%	100%	100%	50%	50%	50%	50%	50%	50%	50%
Poland	0%	0%	0%	100%	0%	0%	100%	0%	100%	100%
Portugal	50%	0%	0%	100%	0%	0%	50%	50%	100%	50%
Spain	80%	60%	40%	100%	40%	20%	40%	60%	100%	80%
Sweden	75%	75%	75%	75%	50%	50%	75%	50%	75%	75%
Switzerland	100%	67%	33%	100%	100%	67%	100%	33%	100%	33%
Turkey	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%
UK	35%	29%	24%	29%	47%	24%	47%	41%	47%	47%

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Table 3: This table summarizes country-level EUROSTAT data gathered from the 21 included countries. Environmental expenditure represents the proportion of a country's GDP that is spent on environmental protection, pollution abatement, protection of biodiversity and landscape, research and development, etc. Waste Management Environmentalism Expenditure represents the proportion of a country's GDP allocated toward environmentalism efforts in the waste management sector specifically.

Descriptive Statistics

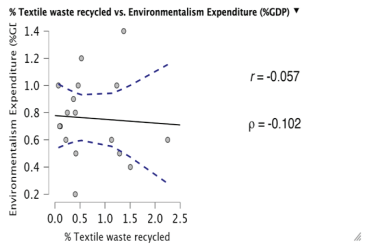
	Median	Mean	Std. Deviation	Minimum	Maximum
Population	$1.05\times10^{+7}$	$2.62\times10^{+7}$	$2.86\times10^{+7}$	$2.89\times10^{+6}$	$8.55\times10^{+7}$
Total Waste (tonnes)	$6.93\times10^{+7}$	$9.30\times10^{+7}$	$9.50\times10^{+7}$	$3.34\times10^{+6}$	$3.47\times10^{+8}$
Recycled Waste (tonnes)	2,353.00	4,201.87	5,997.00	344.60	23,788.40
Textile Waste (tonnes)	26,441.50	123,037.60	231,998.87	3,363.00	815,956.00
Recycled Textile Waste (tonnes)	20,482.50	82,279.00	137,501.75	1,247.00	513,007.00
Recycling Facilities	752.00	1,623.76	2,158.74	125.00	7,923.00
Environmentalism Expenditure (%GDP)	0.70	0.74	0.29	0.20	1.40
Waste Management Environmentalism Expenditure (%GDP)	0.20	0.29	0.24	0.00	0.80

The mean population of countries included in this study was 2.62x10^7 (SD: 2.86 x 10^7). The mean total waste per country was 9.30x10^7 tonnes (SD: 9.5x10^7). The mean recycled waste per country was 4201.87 tonnes (SD: 5997.0). The textile waste (in tonnes) mean was 123,037.60, and the median was 26,441.5 with a standard deviation of 137,501.75. The mean number of recycling facilities per country was 1623.76 (SD: 2158.74). The mean percentage of GDP allocated towards national environmentalism efforts was 74% (SD: 29%). The mean percentage of GDP allocated towards environmentalist efforts in the waste management sector was 29% (SD: 0.24).

Correlation Table

			Pearson r	Pearson p	Spearman rho	Spearman p
% Textile waste recycled	–	Environmentalism Expenditure (%GDP)	−0.057	.827	−0.102	.696

Scatter plots

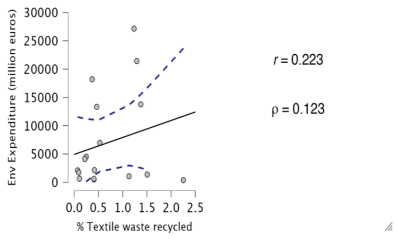


(A)

Correlation Table

			Pearson r	Pearson p	Spearman rho	Spearman p
% Textile waste recycled	–	Env Expenditure (million euros)	0.223	.390	0.123	.639

Scatter plots



(B)

Figure 2a: This figure shows a non-significant weakly negative correlation between the percentage of total textile waste that is recycled and the percentage of each country's GDP spent on environmentalism (environmental protection, pollution abatement, protection of biodiversity and landscape, research and development, etc.).

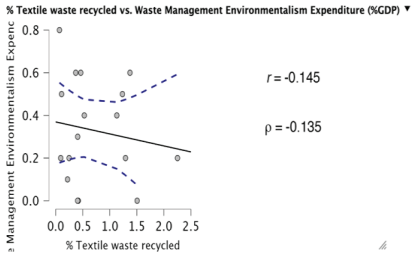
Figure 2b: This figure shows the correlation between the percentage of total textile waste recycled and the total amount spent by each country's government on environmental initiatives in millions of euros. There was a non-significant, weakly positive association (r: 0.223, p: 0.390).

Pearson correlation revealed no association between the percentage of GDP spent on environmentalism and the percentage of textile waste that is recycled annually (Figure 2a, r: -0.057, p: 0.827). It also failed to show any significant association between textile waste and absolute spending value (Figure 2b, *r: 0.223*, *p: 0.390*). A similar lack of association was observed when analyzing the percentage of textile waste recycled in comparison to government expenditure specifically allocated toward waste management initiatives (Figure 3a, Figure 3b). The reported number of recycling facilities and recycling facilities per capita demonstrated no significant association with the percentage of textile waste recycled in each country (Figure 4a and Figure 4b)

Correlation Table

			Pearson r	Pearson p	Spearman rho	Spearman p
% Textile waste recycled	–	Waste Management Environmentalism Expenditure (%GDP)	−0.145	.579	−0.135	.605

Scatter plots

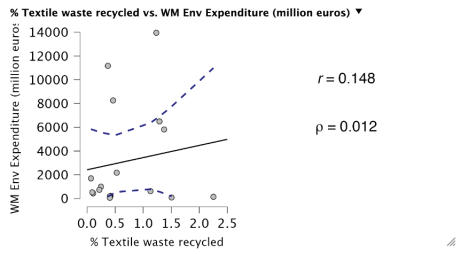


(A)

Correlation Table

			Pearson r	Pearson p	Spearman rho	Spearman p
% Textile waste recycled	–	WM Env Expenditure (million euros)	0.148	.572	0.012	.966

Scatter plots



(B)

Figure 3a: This figure shows the correlation between the percentage of total textile waste recycled and the percentage of GDP allocated to waste management and environmentalism efforts. There was a non-significant, weakly negative association (r: -0.145, p: 0.579).

Figure 3b: This figure shows the correlation between the percentage of total textile waste recycled and the absolute sum of GDP allocated to waste management and environmentalism efforts. There was a non-significant, weakly positive association (r: 0.148, p: 0.572).

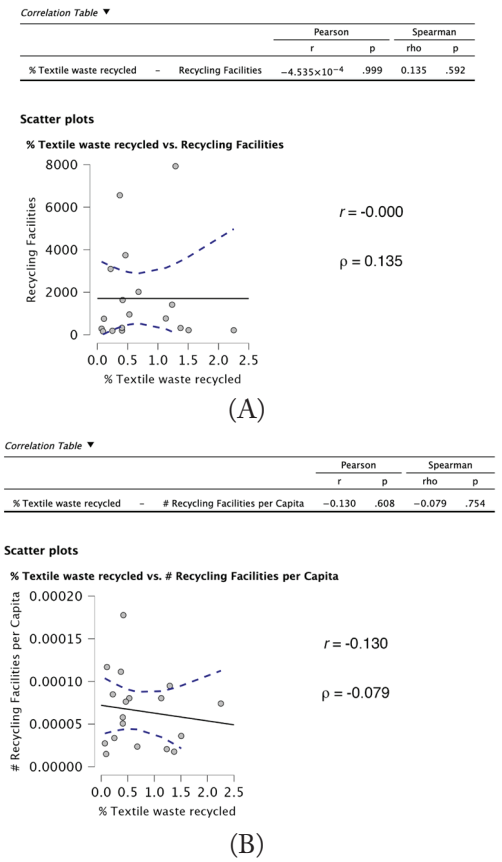


Figure 4a: This figure shows the correlation between the percentage of total textile waste recycled and the number of recycling facilities. The level of association was negligible (r: -4.535x10^-4, p: 0.999).

Figure 4b: This figure shows the correlation between the percentage of total textile waste recycled and the number of recycling facilities per capita. There was a non-significant, weakly negative association (r:-0.130, p: 0.608).

Table 4: Correlation analyses between textile and plastic waste streams yielded mixed findings. National textile and plastic recycling rates were not significantly related (Pearson r = –0.336, p = .203), indicating limited association in recycling performance across material categories. However, a significant positive association was observed between total textile and plastic waste generation (Spearman ρ = 0.591, p = .011), validating the assumption that countries producing greater volumes of textile waste also tend to produce more plastic waste. This suggests that although waste generation patterns are linked across materials, the recycling systems and infrastructure may differ between textiles and plastics.

Variables Compared	Pearson r	p-value	Spearman ρ	p-value
% Textile Waste Recycled – % Plastic Waste Recycled	–0.336	.203	–0.194	.470
Textile Waste (tonnes) – Plastic Waste (tonnes)	0.197	.434	**0.591**	**.011**

Table 5: Correlations between expenditure measures and recycled waste volumes showed that total spending levels were strongly linked with outcomes, whereas relative (%GDP) spending showed no relationship. Specifically, total environmental expenditure in millions demonstrated a robust positive correlation with recycled waste (Pearson r = 0.736, p = .002; Spearman ρ = 0.879, p < .001). Waste-management-specific expenditure also correlated significantly with recycled waste (Pearson r = 0.546, p = .035; Spearman ρ = 0.757, p = .002). In contrast, expenditure as a percentage of GDP showed no significant associations (all p > .40). These results indicate that the amount of financial investment plays a greater role than proportional budget share in predicting recycling performance.

Correlation Between Recycled Waste (tonnes) and Expenditure Variables

Expenditure Variable	Pearson r	p-value	Spearman ρ	p-value
Waste Management Environmental Expenditure (%GDP)	0.048	.865	0.227	.416
Environmentalism Expenditure (%GDP)	–0.051	.857	0.207	.459
Environmental Expenditure (million €)	**0.736**	**.002**	**0.879**	**< .001**
WM Environmental Expenditure (million €)	**0.546**	**.035**	**0.757**	**.002**

Table 6: Correlation analyses were conducted to examine the association between national textile recycling rates and company-level output types. A significant positive correlation was observed between % textile waste recycled and the proportion of companies producing disassembled textiles for fibre-to-fibre recycling (Pearson r = 0.484, p = .042; Spearman ρ = 0.495, p = .037). This suggests that countries with higher textile recycling rates are more likely to have companies engaged in advanced fibre-to-fibre disassembly practices.

Association between % Textile Waste Recycled and Company Output Types

Output Type	Pearson r	p-value	Spearman ρ	p-value
Fibre Sorted Textiles for F2F	0.419	0.084	0.438	0.069
Cleaned Textiles for F2F	0.097	0.701	0.045	0.859
Disassembled Textiles for F2F	**0.484**	**0.042**	**0.495**	**0.037**
Color Sorted Textiles for F2F	0.239	0.339	0.196	0.436
Reusable Textiles	–0.105	0.680	–0.015	0.953
Non-Reusable Textiles	–0.037	0.885	0.044	0.862
Non-Textiles	–0.037	0.884	0.104	0.681
Shredded/Cut Textiles	0.311	0.209	0.137	0.587
Sorted Textiles for Open-loop Recycling	–0.283	0.255	–0.334	0.176
Pre-Sorted Textiles	–0.267	0.283	–0.204	0.418

Additionally, fibre sorting for fibre-to-fibre recycling demonstrated a positive, though marginally non-significant, correlation with textile recycling rates (Pearson r = 0.419, p = .084; Spearman ρ = 0.438, p = .069). Other output categories, such as cleaned textiles, reusable textiles, and shredded/cut textiles, were not significantly associated with national recycling rates (all p > .20).

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Table 7: In contrast, analyses using recycling facilities per capita as the independent variable revealed no significant correlations with any company-level output categories (all p > .35; Table 5). Neither Pearson nor Spearman coefficients indicated meaningful associations, suggesting that the sheer density of facilities is not a strong predictor of advanced output adoption.

Correlation Between Recycling Facilities per Capita and Company Output Types

Output Type	Pearson r	p-value	Spearman ρ	p-value
Output Type	Pearson r	p-value	Spearman ρ	p-value
Fibre Sorted Textiles for F2F	–0.047	.841	–0.077	.739
Cleaned Textiles for F2F	–0.014	.952	–0.063	.785
Disassembled Textiles for F2F	0.013	.955	–0.001	.995
Color Sorted Textiles for F2F	0.176	.444	0.138	.550
Reusable Textiles	0.011	.962	–0.043	.853
Non-Reusable Textiles	0.007	.977	–0.093	.688
Non-Textiles	0.208	.366	0.180	.435
Shredded/Cut Textiles	–0.026	.910	–0.174	.451
Sorted Textiles for Open-loop Recycling	0.118	.609	0.115	.620
Pre-Sorted Textiles	0.185	.421	0.205	.373

Together, these findings indicate that system outcomes (national recycling rates) are more closely aligned with advanced company behaviors than infrastructure availability (facilities per capita). This underscores that investment in facilities alone may be insufficient without parallel improvements in reclaim processes and market alignment toward fibre-to-fibre recycling.

Discussion

The statistical analyses in this study are based primarily on simple correlations, which reveal associations but do not establish causality. Future work incorporating controlled experiments or multivariate analyses could help clarify the direction and strength of these effects. Since GDP expenditures and textile recycling were not correlated, it suggests that allocating a higher percentage of GDP to environmental efforts may not be enough to reduce the impact of textile waste in the current European infrastructure.[23] There is a slight positive trend suggesting that countries with larger raw budgets may recycle a bit more, but the lack of significance shows that budgets alone may not be the key. Wealthier countries may spend more, but if recycling systems or consumer behaviors don't change, results won't follow.[24]

The future focus should combine financial investment with public education and a strong textile-recycling infrastructure.[25]

When considering the concentration of recycling facilities and textile recycling efficiency, these analyses imply that building more facilities doesn't guarantee better recycling rates. Facilities may be underutilized, inaccessible, or not designed for textiles.[26] Optimization of existing systems and equipping them with textile-specific technology and supply chains may have a greater impact.[10]

The finding that disassembled fibre-to-fibre outputs are positively correlated with national textile recycling rates highlights the critical role of advanced processing capacity in driving system-level performance.[11,26] Disassembly is a higher-order stage of fibre-to-fibre recycling, requiring both technical expertise and investment in infrastructure, and its association with greater recycling outcomes suggests that countries capable of supporting these processes also have stronger overall waste-management ecosystems. This aligns with the principle that end-of-life textile recovery is most effective when supported by specialized infrastructure rather than broad expenditure alone.[9]

The marginal association with fibre sorting reinforces this pattern: preliminary sorting is necessary but insufficient, while true system gains are realized when companies engage in deeper processing that closes the loop back into high-quality fibres.[10,11] In contrast, the lack of association for categories such as reusable textiles or shredded textiles reflects the limits of downcycling and low-value pathways, which, while beneficial in the short term, do not fundamentally alter circularity metrics.[25]

These results suggest that policy frameworks should prioritize scaling advanced fibre-to-fibre capabilities, not just collection or basic sorting, if recycling targets are to be meaningfully increased. For biodegradable textiles specifically, this has two implications. First, without integration into disassembly and fibre-to-fibre loops, biodegradable products risk being relegated to landfill or compost streams where their environmental potential is lost.[14] Second, investment in reclaim systems that combine sorting with advanced disassembly ensures that biodegradable textiles can serve as a true complement to circular recycling systems, rather than a fallback disposal option.[9,10]

The WRAP and Eurostat databases are used in this study that provide valuable insight into textile waste management trends; however, several limitations should be noted. The WRAP database primarily includes European facilities and companies that voluntarily participate in sustainability initiatives, which may not represent all countries or smaller private operations. This suggests that the dataset could overrepresent technologically advanced or well-funded regions and underrepresent low-income or non-EU countries, which limits the generalizability of the findings. The database was developed through the United Kingdom Waste and Resources Action Programme to promote circular economy practices, and company participation is self-reported rather than independently verified.

The inclusion criteria for this analysis required companies to process post-industrial textiles, pre-consumer textiles, or reusable and non-reusable post-consumer textiles. However, inconsistencies in reporting quality led to the exclusion of the incomplete records. Although Eurostat provides comprehensive data, it relies on national self-reporting and varying definitions of recycled waste, which can introduce inconsistency between countries.

Several descriptive statistics in Table 3 show substantial variability, including a mean population of 2.62×10^7 with a standard deviation of 2.86×10^7. This reflects the major differences in country size and waste management capacity. The variability does not indicate miscalculation but instead the diverse nature of the sample, which may introduce errors in

correlation analyses and reduce the accuracy of cross-country comparisons. Future research should normalize results by population size or GDP and use weighted regression or multilevel models to reduce variability and improve interpretive accuracy.

Conclusion

The difference becomes clear by looking at the global trends. It is estimated that 75% of the world's textile waste ends up in landfills, 25% is reused or recycled (frequently in downgraded forms), and less than 1% is regenerated into new apparel.

The European Union generates 16 million metric tons of fashion waste every year, with only 26% being recycled or reused and 70% being sent to landfilling or burning. China, which produces 65% of garments and 31% of man-made fibers, disposes of about 45% of its annual production. In 2017, this represented nearly 26 million metric tons of textile waste sent to landfills, while only 3.5 million metric tons were recycled or reused. The United States generates nearly 17 million metric tons a year, 85% of which is sent to the landfill, which is equivalent to 5% of municipal solid waste and 29.3 kilograms of clothing landfilled per capita a year. Canada adds around 500,000 tons to the landfill per year, with individuals disposing of 30 to 55 pounds of clothes to the landfill per year. In Vancouver, textiles are equal to 5% of municipal landfill waste.

These statistics suggest that even with advanced technology and well-organized programs, current systems cannot control the volume of waste generated. Although around 95% of all the textiles thrown away can be recycled in theory, infrastructure constraints and user habits mean that the majority are sent to landfills. Synthetic fibers can take decades to decompose, releasing microplastics, which leads to long-term contamination. Biodegradable materials, therefore, become an essential supplement to recycling. When reuse and recycling are not feasible, biodegradable textiles can decompose naturally, reducing their environmental footprint and forming an essential part of the solution to reverse the increasing waste caused by fast fashion.

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Bibliography

1. Abrishami, Shayan, Armineh Shirali, Nicole Sharples, Gulsah Ekin Kartal, Lisa Macintyre, and Omid Doustdar. "Textile Recycling and Recovery: An Eco-Friendly Perspective on Textile and Garment Industries Challenges." *Textile Research Journal* 94, nos. 23–24 (2024): 2815–34. https://doi.org/10.1177/00405175241247806
2. Vink, Eric T. H., Kristina R. Rabago, Dale A. Glassner, and Patrick R. Gruber. "Applications of Life Cycle Assessment to NatureWorks™ Polylactide (PLA) Production." *Polymer Degradation and Stability* 95, no. 3 (2010): 374–80. https://doi.org/10.1016/j.polymdegradstab.2009.11.009
3. Jamshidian, M., E. A. Tehrany, M. Imran, M. Jacquot, and S. Desobry. "Poly-Lactic Acid: Production, Applications, Nanocomposites, and Release Studies." *Comprehensive Reviews in Food Science and Food Safety* 9, no. 5 (2010): 552–71. https://doi.org/10.1111/j.1541-4337.2010.00126.x
4. Groot, Wim, and Tom Borén. "Biobased Plastics as Renewable Raw Materials: Their Potential and Limitations." *Green Chemistry* 12, no. 9 (2010): 1687–93. https://doi.org/10.1039/c004986a
5. Hamad, Khalil, Mohammad Kaseem, and Faisal Deri. "Processing and Recycling of Biopolymers: PLA and PHA." *Journal of Polymers and the Environment* 22 (2014): 427–38. https://doi.org/10.1007/s10924-014-0711-8
6. Mehta, Sunidhi. "Biodegradable Textile Polymers: A Review of Current Scenario and Future Opportunities." *Environmental Technology Reviews* 12, no. 1 (2023): 441–57. https://doi.org/10.1080/21622515.2023.2227391
7. Sabbah, Mohammed, and Raffaele Porta. "Plastic Pollution and the Challenge of Bioplastics." *J. Appl. Biotechnol. Bioeng* 2, no. 3 (2017): 00033.
8. Shen, Luning, Ernst Worrell, and Martin K. Patel. "Environmental Impact Assessment of Man-Made Cellulose Fibres." *Resources, Conservation and Recycling* 55, no. 2 (2010): 260–74. https://doi.org/10.1016/j.resconrec.2010.10.001
9. Ellen MacArthur Foundation. *A New Textiles Economy: Redesigning Fashion's Future*. Cowes, UK: Ellen MacArthur Foundation, 2017. https://ellenmacarthurfoundation.org
10. Ribul, Maria, Lara McLaren, Kate Goldsworthy, and Richard S. Blackburn. "Circular Design for Fashion: Transforming Linear Systems into Sustainable Ones." *Sustainable Production and Consumption* 27 (2021): 1350–62. https://doi.org/10.1016/j.spc.2021.02.010
11. Payne, Alice. "Open- and Closed-Loop Recycling of Textile and Apparel Products." *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*, December 31, 2015, 103–23. https://doi.org/10.1016/B978-0-08-100169-1.00006-X
12. Niero, Monica, and Michael Z. Hauschild. "Closing the Loop for Packaging: Finding a Framework to Operationalize Circular Economy Strategies." *Procedia CIRP* 61 (2017): 685–90. https://doi.org/10.1016/j.procir.2016.11.152
13. Juanga-Labayen, Jeanger P., Ildefonso V. Labayen, and Qiuyan Yuan. "A Review on Textile Recycling Practices and Challenges." *Textiles* 2, no. 1 (2022): 174–88. https://doi.org/10.3390/textiles2010010
14. Atiwesh, Ghada, Abanoub Mikhael, Christopher C. Parrish, Joseph Banoub, and Tuyet-Anh T. Le. "Environmental Impact of Bioplastic Use: A Review." *Heliyon* 7, no. 9 (2021): e07918. https://doi.org/10.1016/j.heliyon.2021.e07918
15. Taneepanichskul, Nutcha, Danielle Purkiss, and Mark Miodownik. "A Review of Sorting and Separating Technologies Suitable for Compostable and Biodegradable Plastic Packaging." *Frontiers in Sustainability* 3 (2022). https://doi.org/10.3389/frsus.2022.901885
16. European Environment Agency. *Textiles and the Environment: The Role of Design in Europe's Circular Economy*. Luxembourg: Publications Office of the European Union, 2022. https://www.eea.europa.eu
17. Fotovvatikhah, Farnaz, Ismail Ahmedy, Rafidah Md Noor, and Muhammad Umair Munir. "A Systematic Review of AI-Based Techniques for Automated Waste Classification." *Sensors* 25, no. 10 (2025). https://doi.org/10.3390/s25103181
18. Faghih, Ehsan, Zahra Saki, and Marguerite Moore. "A Systematic Literature Review—AI-Enabled Textile Waste Sorting." *Sustainability* 17, no. 10 (2025). https://doi.org/10.3390/su17104264
19. Sayem, Faizul Rakib, Md. Sakib Bin Islam, Mansura Naznine, *et al*. "Enhancing Waste Sorting and Recycling Efficiency: Robust Deep Learning-Based Approach for Classification and Detec-

DOI: 10.36838/IJHSR87.154

tion." *Neural Computing and Applications* 37, no. 6 (2025): 4567–83. https://doi.org/10.1007/s00521-024-10855-2
20. Du, Wenqian, Jiahui Zheng, Wenxia Li, Zhengdong Liu, Huaping Wang, and Xi Han. "Efficient Recognition and Automatic Sorting Technology of Waste Textiles Based on Online Near Infrared Spectroscopy and Convolutional Neural Network." *Resources, Conservation and Recycling* 180 (May 2022): 106157. https://doi.org/10.1016/j.resconrec.2022.106157
21. Martinez-Hernandez, Uriel, Gregory West, and Tareq Assaf. "Low-Cost Recognition of Plastic Waste Using Deep Learning and a Multi-Spectral Near-Infrared Sensor." *Sensors* 24, no. 9 (2024). https://doi.org/10.3390/s24092821
22. Denuwara, Navodya, Juha Maijala, and Marko Hakovirta. "Sustainability Benefits of RFID Technology in the Apparel Industry." *Sustainability* 11, no. 22 (2019). https://doi.org/10.3390/su11226477
23. Eurostat. *Environmental Protection Expenditure Accounts – 2023 Edition*. Luxembourg: European Commission, 2023. https://ec.europa.eu/eurostat
24. Ranta, Valtteri, Jarkko Aarikka-Stenroos, Outi Ritala, and Sami Mäkinen. "Exploring Institutional Drivers and Barriers for the Circular Economy: A Cross-Regional Comparison of China, the US, and Europe." *Resources, Conservation and Recycling* 135 (2018): 70–82. https://doi.org/10.1016/j.resconrec.2017.08.017
25. European Environment Agency (EEA). *Textiles and the Environment: The Role of Design in Europe's Circular Economy.* Luxembourg: Publications Office of the European Union, 2022. https://www.eea.europa.eu/publications/textiles-and-the-environment
26. Sandin, Gustav, and Greg M. Peters. "Environmental Impact of Textile Recycling and Reuse: A Review." *Journal of Cleaner Production* 184 (2018): 353–65. https://doi.org/10.1016/j.jclepro.2018.02.266
27. Nizamuddin, Sabzoi, Abdul Jabbar Baloch, Chengrong Chen, Muhammad Arif, and Nabisab Mujawar Mubarak. "Bio-Based Plastics, Biodegradable Plastics, and Compostable Plastics: Biodegradation Mechanism, Biodegradability Standards and Environmental Stratagem." *International Biodeterioration & Biodegradation* 195 (November 2024): 105887. https://doi.org/10.1016/j.ibiod.2024.105887
28. WRAP (Waste and Resources Action Programme). *Textiles 2030 Annual Progress Report 2024*. Banbury, UK: WRAP, 2024. https://wrap.org.uk/textiles-2030
29. Zhao, X., *et al*. (2025). *Ecological risks of biodegradable plastics.* Science, 387(6670), adw9060. https://doi.org/10.1126/science.adw9060

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