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Workstream on Private Sector Financing and Investment

Modelling Approach for Estimating Financial Needs for the Cotton Textile Value Chain Transition

From Hazardous Chemicals to Safer Alternatives

A preliminary approach for review and refinement

November 2026

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Positioning statement

This document outlines a preliminary modelling approach for estimating financial needs for the cotton textile value chain transition. This pilot approach draws on the available qualitative analysis prepared by Chronos Sustainability which has been supplemented by additional insights and considerations contributed by members of the GFC Private Sector Financing and Investment Workstream under the GFC Implementation Programme and combined with research carried out at a point in time, notably between March and October 2026. Methodologies, assumptions, data sets and market practices will continue to evolve, and this natural evolution, together with the intention to review and refine the pilot modelling approach, should be considered by users. Source references are contained and accredited within, as are relevant limitations.

Acronyms

Acronym	Full term
APEO	Alkylphenol Ethoxylate
BAU	Business-As-Usual
BAT-AEL	Best Available Techniques — Associated Emission Levels (EU)
BCI	Better Cotton Initiative
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CoC	Chemical of Concern
DFI	Development Finance Institution
DPP	Digital Product Passport
EPR	Extended Producer Responsibility
ESPR	Ecodesign for Sustainable Products Regulation (EU)
FAO	Food and Agriculture Organization of the United Nations
FFS	Farmer Field School
GFC	Global Framework on Chemicals
GOTS	Global Organic Textile Standard
HHP	Highly Hazardous Pesticide

Acronym	Full term
ICAC	International Cotton Advisory Committee
ILO	International Labour Organization
IPM	Integrated Pest Management
MRL	Maximum Residue Limit
MRSL	Manufacturing Restricted Substances List
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational Expenditure
PES	Payments for Ecosystem Services
PFAS	Per- and Polyfluoroalkyl Substances
PPE	Personal Protective Equipment
PPP	Public-Private Partnership
PRO	Producer Responsibility Organisation
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (EU)
RSL	Restricted Substances List
SAICM	Strategic Approach to International Chemicals Management
T2T	Textile-to-Textile (fibre-to-fibre recycling)
UNIDO	United Nations Industrial Development Organization
USDA	United States Department of Agriculture
WACC	Weighted Average Cost of Capital
WFD	Waste Framework Directive (EU)
WHO	World Health Organization
WTO	World Trade Organization
ZDHC	Zero Discharge of Hazardous Chemicals

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Note: The present note has not been formally edited or designed.

Executive Summary

Disclaimer: This modelling approach is a first iteration of a draft modelling approach for review and refinement purposes.

Purpose of this document

This document proposes a possible modelling approach to estimate the financial needs for transitioning the global cotton textile value chain away from hazardous chemicals toward safer alternatives over a 10-year period (2025–2035). It seeks to assign costs to priority actions identified in the Phase 1 and Phase 2 reports '*Chemical use in textile value chains: Cotton clothing*' (UNEP, 2025; GFC, 2026a) and explore the possible source of finance for each action. The primary aim of this analysis is to propose a structure and a modelling approach that can be reviewed and refined to estimate financial needs in the cotton clothing value chain and then could be adapted to estimate financial needs for other priority value chains under the Global Framework on Chemicals (GFC) Implementation Programme.

What this modelling approach is, and what it is not

What the modelling approach does. The modelling approach applies a top-down investment gap methodology that embeds bottom-up unit process calculations. It takes global sector-level data — total cotton production area, global textile chemicals market size, installed machinery base, post-consumer cotton waste volumes — and feeds these through a set of sub-calculations for specific transition activities (IPM adoption, chemical substitution, equipment retrofit, traceability, recycling infrastructure, extended producer responsibility). Each sub-calculation multiplies a quantity (area, volume, units, market size) by a unit cost or cost differential, then aggregates over the 10-year horizon with explicit Low / Central / High parameter ranges. A sector growth rate (central 1.7% CAGR) is applied through annuity formulas so that volumes grow realistically over the horizon. All calculation parameters in this report are in their relevant sections and compiled in the Annex.

What the modelling approach is not. The modelling approach is not intended to be complete at this stage. Several important limitations should be understood by any reader or reviewer:

- The modelling approach is global and does not provide any regional or national disaggregation.

- Critical parameter values need reviewing.
- The proposed transition activities themselves require expert review.
- Not all chemicals currently used in the value chain are chemicals of concern, therefore the share targeted for substitution needs careful consideration.
- The cost of capital is not included.
- The modelling approach distinguishes between additional and redirected costs and assigns a public share and private share, which require validation. It does not represent specific financial instruments.
- The modelling approach incorporates a sector growth rate (1.7% CAGR, central).
- The modelling approach introduces recycling at the end-of-life stage. It does not model substitution for alternative textile fibres (synthetic, regenerated cellulosic, other naturals).
- System-level transaction costs are introduced through a dedicated value chain governance component.
- Disclosure and reporting costs are not priced.
- Placeholder estimates have been introduced for wastewater treatment (public share) and worker health and PPE (public share).
- Dynamic policy effects, technology breakthroughs and market shocks are not considered.
- Savings and co-benefits are not credited at this stage.
- Cost curves for “green premiums” are linear but could be modified to reflect front-loading of costs or non-linear trends.

Priority Actions and Stakeholders

The modelling approach seeks to represent the set of priority actions that were identified in the Phase 2 report ‘*Chemical use in textile value chains: Cotton clothing*’ (GFC, 2026a) as well as overarching priority actions linked to the GFC Strategic Objectives: (1) identify and eliminate issues of concern (Strategic Objective C), (2) time-bound substitution plan (Strategic Objective D), (3) traceability (Strategic Objective B), (4) international standards (Strategic Objective A), (5) active transition via R&D and finance (Strategic Objectives D and E), and (6) capacity building (Strategic Objective E).

Table 1. Representation of overarching priority actions linked to the GFC Strategic Objectives in the modelling approach

GFC priority action	How the modelling approach addresses it	Coverage	Gaps and caveats
1. Identify and eliminate issues of concern (linked to Strategic Objective C and Target A7)	IPM input cost differential of $150/ha over conventional $80/ha, applied to 80% of apparel cotton area (29.4 Mha*80%=18.8Mha) after recycled-fibre displacement (18.5 Mha). Contributes to achieving Target A7. 20% green premium (central, low 10%, high 30%) on the assumed share (central 50%, low 30%, high 70%) of cotton textile chemicals spend ($4.1B/yr) associated with chemicals of concern. Contributes to Target D6.	Elimina-tion priced	Both lines are redirected costs (premium on BAU spend). The 80% area and CoC share are modelling assumptions not derived from hazard data. The cost of identification and prioritisation of issues of concern is not separately priced; it sits inside policy establishment (action 4).
2. Time-bound substitution plan (linked to Strategic Objective D)	Structural representation with a 10-year horizon (2025–2035), annual premium decline rates (3% biopesticides; 2% chemicals and equipment) and 1.7% sector growth set the time path. Plan development is absorbed in policy establishment (1% of annual-average transition spend, $0.10B).	Structural only	Costs are spread evenly and not phased, with no S-curves, front-loaded CAPEX or regional sequencing yet implemented.
3. Traceability (linked to Strategic Objective B)	Value chain governance estimated at $80/MT (range $50–110) on 21.1 Mt/yr of apparel-destined cotton, covering digital tracking, forensic DNA marking, MRL residue testing and Digital Product Passports; 3%/yr cost decline.	Priced	Single per-tonne cost; not distributed by stage or actor. Pesticide-level disclosure (SDS, use logs, batch tracking) by agrochemical producers is not separately priced. End-of-life DPP layer requires confirmation.
4. Internatio-nal standards (linked to Strategic Objective A)	Institutional overheads considered include policy establishment ($0.10B one-off, 1% of annual-average transition spend); standards body establishment ($0.04B one-off, 1% of agrochemical spend); recurring institutional overhead (1.5%/yr); import controls (0.25% setup + 0.5%/yr of $53B cotton trade value). RSL/MRSL consolidation is absorbed here.	Partial (heuristic)	All lines sized by top-down percentage heuristics. Standards body is sized on the agrochemical base only; textile chemistry and circular-design standards are not separately sized.
5. Active transition via R&D	R&D uplift is represented across increasing biocontrol development intensity; textile	Priced	R&D spend and cost-decline rates are set independently.

GFC priority action	How the modelling approach addresses it	Coverage	Gaps and caveats
and finance (linked to Strategic Objectives D and E)	chemicals substitution; and recycling technologies. Capital allocation includes replacement CAPEX with a green premium of 15% (central, low 7.5%, high 22.5%) on routine replacement; yield risk buffer for the 2–4 year biological reset; collection and sorting costs; and fibre-to-fibre recycling CAPEX + OPEX. Public/private split assigned per component (Low/Central/High).		
6. Capacity building (linked to Strategic Objective E)	Pest monitoring and scouting on 18.5 Mha, plus farmer field school training for 6.3M farmers (25% direct coverage) at $80/farmer. Consumer awareness and circularity capacity: assigned in the model to EPR scheme administration.	Partial	Covers farmers only. Costs of capacity building for mills, chemical managers, regulators, customs or laboratories are not modelled separately.

Coverage: The six overarching priority actions linked to GFC Strategic Objectives are all addressed structurally. Fifteen stakeholder-specific actions are modelled (either directly or within aggregate governance lines, Figure 1).

Governments and policymakers: policy establishment, traceability, and import controls are modelled as value chain governance costs. Several governance line items are sized using top-down heuristics (e.g. 1% of transition spend) that should be sensitivity-tested and benchmarked. Wastewater treatment and worker health and PPE are included as placeholders requiring verification against benchmarks. The degree to which these costs are borne by public or private finance is yet to be specified.

Agrochemical producers: has arguably the strongest coverage in the modelling approach. IPM input cost differentials, monitoring, farmer training, and biocontrol R&D are each priced as distinct cost drivers. Standards body establishment is modelled as a one-off cost. Pesticide-level traceability (SDS, use logs, batch tracking) is not separately priced and is represented within the single $/MT raw-cotton traceability cost. This cost could be disaggregated along the value chain and to different stakeholder groups subsequently.

Brands and retailers: chemical substitution (a 20% green premium (central, low 10%, high 30%) applied to the assumed share of cotton textile chemicals spend associated with chemicals of concern), value chain traceability, and EPR-funded circularity are

modelled. RSL/MRSL consolidation and standards development are absorbed within the policy establishment and institutional overhead lines rather than costed separately. Procurement policy incentives (certification costs, longer-term contract economics) are flagged as partially addressed but not individually priced.

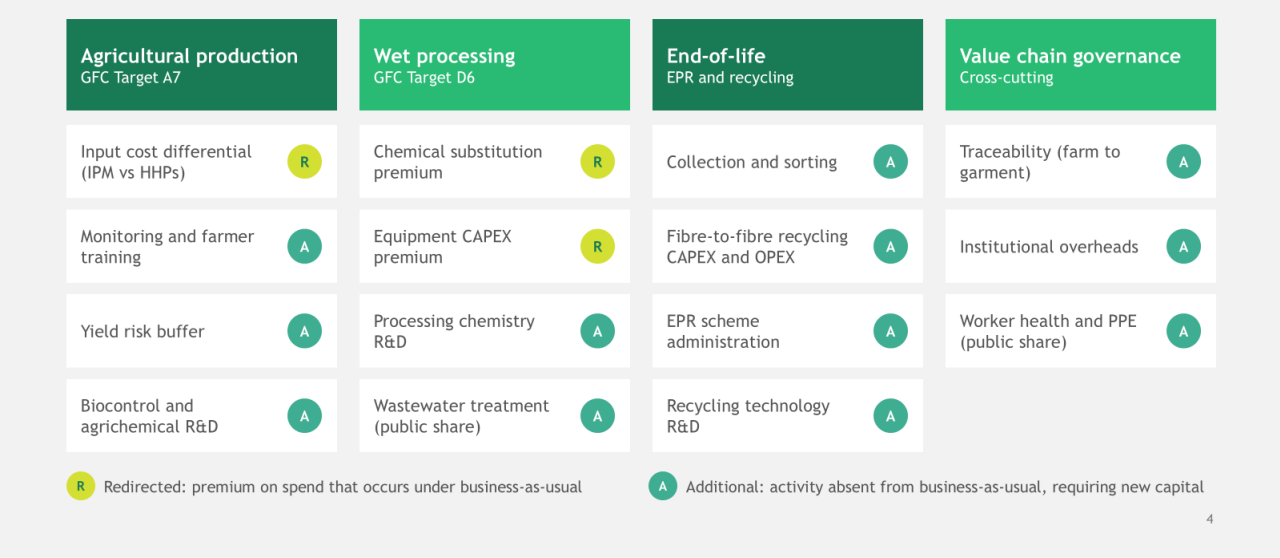


Figure 1. Representation of priority actions in the modelling approach.

1. Purpose and Scope

This document seeks to propose a modelling approach to estimate the financial needs for transitioning the global cotton textile value chain away from hazardous chemicals and towards safer alternatives, and for the reduction of hazard from chemical wastes, in alignment with the objectives and targets of the Global Framework on Chemicals (GFC; UNEP, 2023). It covers two interlinked transition requirements: the elimination of highly hazardous pesticides (HHPs) in cotton agriculture (GFC Target A7), and the substitution of chemicals of concern (CoCs) in textile wet processing (GFC Target D6), with a supplementary treatment of end-of-life, as well as cross-cutting value chain governance.

The analysis uses a top-down investment gap methodology, applying financial ratios, cost differentials from unit process calculations, and identified rates of change to known sector-level data. Where precise data are unavailable benchmarks from comparable regulatory transitions (principally EU REACH implementation; European Chemicals Agency [ECHA], 2021) and published field trial data are used, with explicit identification of uncertainty at each stage.

The scope covers the cotton-specific portion of the broader textiles value chain. Cotton represents approximately 19% of global fibre production by volume (Textile Exchange, 2025), but its share of chemical-intensive processing is disproportionately higher due to the agricultural pesticide burden and the intensive wet processing requirements of natural fibres (scouring, bleaching, mercerisation).

1.1 Value chain segments covered

Informed by the Phase 2 Report, the analysis decomposes the cotton value chain into five modules: (i) agricultural production; (ii) textile processing, including wet processing (dyeing, finishing, and functional treatments), chemical substitution, equipment replacement, and wastewater treatment; (iii) end-of-life (collection, sorting, recycling, and extended producer responsibility); and (iv) value chain governance, covering traceability, institutional overheads, import controls, and worker health. Retail margins, brand overheads, and consumer-facing costs are excluded, as are transportation and logistics costs between stages.

1.2 Key data anchors

Table 2. Key data anchors

Parameter	Value	Source
Global cotton harvested area	29.4 million hectares	Meyer & Dew, 2025
Global cotton production	~26.3 Mt	Meyer & Dew, 2026
Global cotton yield	~896 kg/ha	Derived; Meyer & Dew (2025) report 886 kg/ha
Cotton share of global fibre	~19% by volume	Textile Exchange, 2025
Cost of cultivation	~$1.32/kg	ICAC, 2025
Global textile chemicals market	~$29–31 billion/year	Grand View Research, 2025; Towards Chemical and Materials, 2025; Coherent Market Insights, 2025
Global cotton textile production	24.5 Mt/yr	Textile Exchange, 2025
Post-consumer cotton textile waste	~18 Mt/yr	Sajdeh et al., 2025 (120 Mt total)
Global crop protection market	~$80 billion/year	MarketsandMarkets, 2024
Fraction of cotton used for apparel	~80%	FAO, n.d.
Sector growth rate (CAGR)	1.7% per year (central)	Model assumption
Total workers in cotton apparel value chain	~350 million	UNIDO, 2024

1.3 GFC targets and critical parameters

Target A7: 'By 2035, stakeholders have taken effective measures to phase out highly hazardous pesticides in agriculture where the risks have not been managed and where safer and affordable alternatives are available, and to promote transition to and make available those alternatives' (UNEP, 2023).

Key Lever: Share of area requiring transition (currently assumed at 80%)

- ~2.3% is certified organic (Textile Exchange, 2025) → excluded (no transition needed)
- ~22% is BCI-certified → partially transitioned, but BCI does not guarantee HHP elimination; most BCI area still needs investment to achieve full Target A7 compliance (Textile Exchange, 2024)
- ~4–5% may be under other certifications (e.g. CmiA, REEL, Fairtrade) with partial HHP management → partial credit (Textile Exchange, 2025)

- Remaining ~70–72% has no certification and is assumed to be on conventional chemical-intensive regimes

Rounding up to account for the fact that even most certified area still needs further transition investment gives approximately 75–85%, with 80% as a defensible central value. The OECD-FAO Agricultural Outlook 2025–2034 (OECD & FAO, 2025) notes that in 2022/23, programmes recognised by the Sustainable Cotton Challenge covered 29% of global cotton production, which is consistent with this framing — roughly 70% of cotton has no recognised sustainability programme at all.

Target D6: 'By 2030, sustainable chemical and waste management strategies have been developed and implemented for major economic and industry sectors that identify priority chemicals of concern and standards and measures, such as the chemical footprint approach, to reduce their impact and, where feasible, their input along the value chain' (UNEP, 2023).

Key modelling parameter: Assumed share of the cotton-specific chemicals market associated with chemicals of concern spend requiring substitution (central currently assumed at 50%, low: 30%, high: 70%)

The estimate of the proportion of the cotton-specific textile chemicals market (valued at ~$8.25 billion/year) used for modelling the costs of substituting chemicals of concern involves substances which are or may become subject to restriction or substitution under the GFC framework. The 50% central value assumes, for modelling purposes, that chemicals of concern account for half of the cotton-specific chemicals market and uses this share to estimate the costs of substitution. This parameter is used to estimate substitution costs relevant to the implementation of Target D6.

It should be noted that the 50% figure is consistent with the scope of some existing restriction frameworks (e.g. REACH Candidate List, various national RSLs, ZDHC MRSL) but *is not derived from a bottom-up market analysis*. It should also be noted that a lower value (e.g. 30%) would be appropriate if the scope is limited to substances already on restriction lists, while a higher value (e.g. 70%) could apply if the scope extends to substances with emerging hazard evidence or precautionary concern — and that Target D6's language ("*identify priority chemicals of concern*") implies the scope will expand over time as more data becomes available (which is also consistent with Target B1's call for comprehensive data on chemical properties by 2035; UNEP, 2023).

Key caveats include:

- REACH (EU) has placed hundreds of substances on its Candidate List (253 entries as of February 2026; ECHA, 2026) and Restriction Annex that are used in textile processing.

- The ZDHC MRSL (ZDHC Foundation, n.d.) already bans or restricts a substantial list of chemical substance groups from intentional use in textile manufacturing — including certain azo dyes, PFAS, APEOs, formaldehyde-based agents, heavy metal catalysts, chlorinated solvents, and various other substance classes.
- Not all textile chemicals are problematic. Basic commodities like soda ash, hydrogen peroxide (for bleaching), salt (for dyeing fixation), and many standard surfactants are not chemicals of concern.
- The 50% central figure assumes that approximately half of the chemicals market by value involves substances that are already on, or are likely to be added to, restriction or substitution candidate lists under GFC-aligned regulatory programmes.

No published source provides a definitive breakdown of the global textile chemicals market by "hazardous / non-hazardous" share on a value-weighted basis. The ZDHC MRSL covers substance groups (not individual formulations), and many common textile chemicals fall in grey areas where hazard classification depends on concentration, application method, and exposure pathway. The parameter annex flags it as requiring expert review.

Note: Other targets, for example Target B1 and A5 relating to adoptions and implementation of policies and availability of data and standards are dealt with through % of total spend parameters at value chain level.

2. Methodology

2.1 Top-down investment gap structure

The modelling approach follows a simple methodology: global sector-level quantities are the starting point, and these cascade through value chain-specific sub-calculations to produce a 10-year financial need for each activity (Figure 2).

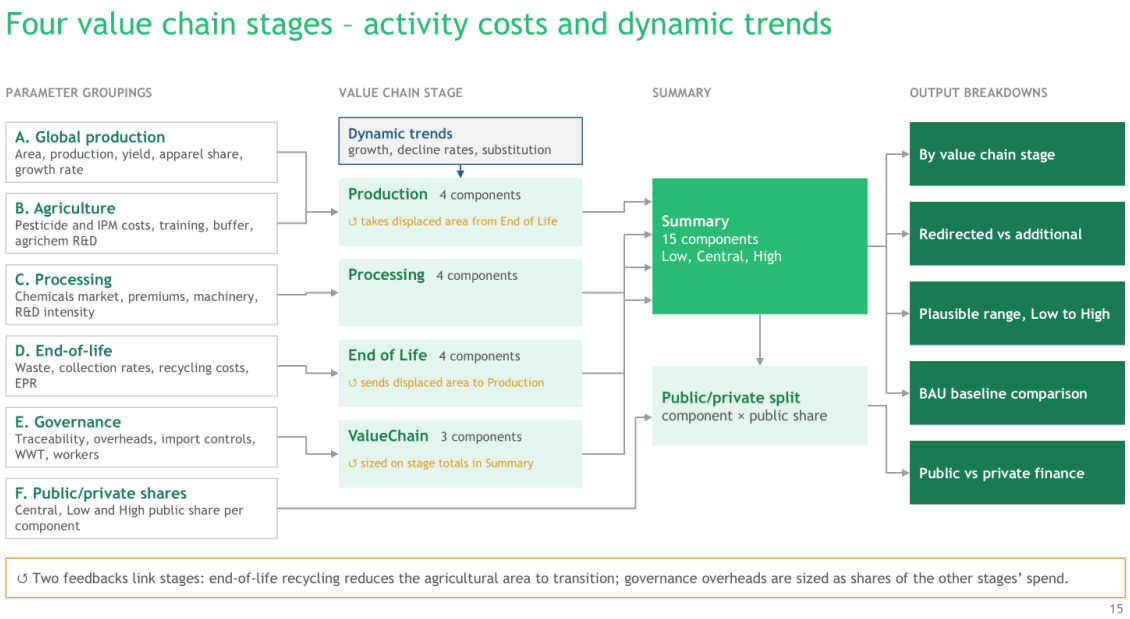


Figure 2. Modelling approach architecture

The overall flow is:

- **Global parameters**: cotton harvested area, yield, cost of cultivation, global textile chemicals market, installed machinery base, post-consumer waste volume, cotton textile production, global crop protection market, sector growth rate, and workforce size.
- **Activity-specific drivers**: unit costs, cost differentials, adoption shares, and transition durations for each identified activity — IPM adoption, chemical substitution, equipment replacement, traceability deployment, collection and recycling, EPR administration, wastewater treatment, worker health, institutional overheads, and R&D.
- **Value chain stage**: multiply global quantities by activity drivers, apply growth annuity and decline-rate adjustments, incorporate recycled fibre displacement where relevant, and aggregate to 10-year totals with Low / Central / High ranges.

- **Summary**: aggregates across stages and presents headline totals, share-of-total, the BAU-versus-transition decomposition, and verification checks against farm-gate revenue and retail value benchmarks.

This architecture means the entire modelling approach is driven from a single Parameters sheet. Changing any assumption propagates through all calculations.

2.2 Growth annuity

The modelling approach applies a sector growth rate (central 1.7% CAGR, range 1.0–2.5%) to project volumes forward over the 10-year horizon. Rather than assuming static annual costs, each cost line is multiplied by a growth annuity factor that reflects the compounding effect of sector expansion on annual financial needs. For cost lines subject to both growth and a declining unit cost (for example, the biopesticide input cost delta, which declines as scale economies emerge), the modelling approach uses a combined annuity formula that nets the growth rate against the price decline rate.

2.3 Recycled fibre displacement of virgin cotton.

The modelling approach introduces a partial circularity feedback at the end-of-life stage: recycled cotton fibre that re-enters the apparel supply chain displaces a portion of virgin cotton demand, reducing the effective agricultural area that requires transition investment. This is implemented through two parameters:

- **Substitution factor**: the proportion of recycled cotton that substitutes directly for virgin cotton rather than serving additional demand. A factor of 1.0 assumes full substitution; a factor of 0.8 assumes 20% of recycled output serves demand that would not otherwise have been met by virgin cotton.
- **Substitution ramp**: the average fraction of the 10-year horizon over which recycled fibre displacement is effective, reflecting the time required for recycling capacity to reach steady-state. A ramp of 0.5 means that, on average, recycled displacement operates at half its ultimate level over the 10-year period.

The effective apparel area used in the agricultural calculations is therefore: total cotton area × fraction used for apparel, minus the area-equivalent of recycled fibre (recycled volume × substitution factor × ramp average, converted to hectares at prevailing yield).

2.4 Differential (incremental) costs versus redirected costs

The modelling approach distinguishes between additional and redirected costs. The distinction matters because it determines what kind of finance instrument is needed and who ultimately bears the cost.

Differential (additional) costs. These are costs that do not exist in the business-as-usual (BAU), they are new expenditures that arise only because of the transition. Examples include farmer training in IPM practices, pheromone trap networks, yield-risk buffers paid to farmers during the biological reset, traceability systems, collection and sorting infrastructure, EPR scheme administration, wastewater treatment (public share), worker health and PPE (public share), institutional overheads, and the incremental R&D required to mature safer alternatives. These costs require new capital to be mobilised.

Redirected costs. These are costs that already exist in the BAU but that need to be redirected toward GFC-compliant alternatives at points of routine replacement or purchase. The underlying capital flow would occur regardless of the transition — farmers will buy crop protection inputs, processors will replace worn-out dyeing machines on their natural 8–12 year cycle, and brands will purchase chemicals for finishing. What changes is the choice made at the point of expenditure, and the modest premium (typically 10–25%) attached to compliant options. The premium is the redirected cost captured in the modelling approach; the underlying BAU spend is not counted as a transition cost.

The practical implication is that redirected costs can be mobilised through demand-side policy — procurement standards, import requirements, eco-modulation, retailer specifications — whereas differential costs typically require supply-side finance (public funds, blended finance, concessional lending, R&D grants) because no natural market mechanism generates the activity.

Business-as-usual baseline identified by the modelling approach

The modelling approach implicitly defines a BAU baseline against which transition costs are measured. Making this baseline explicit helps readers see which portions of the total are genuinely new capital needs and which are redirections of flows that would happen anyway.

Table 3. Approximate business-as.-usual estimates

BAU flow (not counted as transition cost)	Approx. 10-yr BAU scale	How the modelling approach treats it
Conventional cotton crop protection ($80/ha × transition area)	~$15 B	Only the $150/ha delta to IPM is counted; the baseline $80/ha is BAU and excluded.
Cotton textile chemicals (current conventional spend subject to substitution)	~$41 B	Only the 20% green premium (central) on the ~$4.1B/yr subject to substitution is counted.
Routine wet-processing equipment replacement (10% of $100B installed base per year)	~$100 B	Only the 15% green premium (central) on replacement equipment is counted ($14.8B over 10 years).

BAU flow (not counted as transition cost)	Approx. 10-yr BAU scale	How the modelling approach treats it
Current textile chemicals R&D (~3% of the $30B market, cotton share)	~$2.5 B	Only the R&D gap to a 5.5% intensity parameter (cotton-attributable share) is counted.
Current agrochemical R&D (8.5% of $80B market, cotton share)	~$5 B	Only the R&D gap to a 13% intensity parameter (cotton share) is counted.
Existing limited post-consumer cotton collection and disposal	Small but non-zero	Only the incremental collection volume above the 20% baseline rate is counted.

2.5 Traceability along the value chain

Estimating the cost of a complete “farm-to-grave” traceability system for cotton is challenging. Traceability is a stack of digital and physical technologies, and the cost is highly dependent on the rigour of the verification (for example, paper-based versus DNA-tagging). Current industry data from organisations like Textile Exchange, Planet Tracker, and forensic technology providers (such as Haelixa or Applied DNA Sciences) allows to provide an estimated breakdown.

Cost Components of Traceability

To calculate the cost per metric tonne (MT), four distinct layers need to be summed: a digital layer (blockchain or SaaS platforms for document exchange), a physical layer (forensic markers such as DNA or isotope analysis to prevent substitution fraud), a compliance layer (analytical testing for pesticide residues to meet Maximum Residue Limits) and a disclosure layer (Digital Product Passports). These are summed and represented as a single parameter in the model.

Table 4. Cost components of traceability

Category	Technology / Method	Est. Cost (/MT)
Digital Tracking	Blockchain/SaaS (e.g., TrusTrace, FibreTrace)	$5 – $15
Forensic Marking	DNA Molecular Tagging (applied at the gin)	$7.50–$22.50
MRL Compliance	Pesticide Residue Multi-Screen (LC-MS/MS)	$7.5 – $15
End-of-Life	Digital Product Passports (DPP) / QR sorting	$5 – $10
TOTAL	Integrated Farm-to-Grave System	$25 – $62.50

Relevant Evidence and Analysis

Pesticide Residue (MRL) Testing. To track residues to MRL levels, lab verification is required rather than digital claims alone. A standard multi-residue screen covering 200–

500 active ingredients costs roughly $150–$300 per sample. In a robust system, one sample is typically taken per 20-tonne lot (one shipping container), yielding a range of $7.50-$15/MT.

Forensic Traceability (Physical Layer). Physical markers are the only way to ensure that the cotton in the final garment is actually the cotton from the certified farm. DNA tags applied as a spray at the ginning stage cost approximately 0.5% to 1.5% of the lint value. At a current price of ~$1,500/MT, this equals $7.50 $22.50/MT/MT. Since 2022, C&A has applied Haelixa DNA markers at ginning to organic cotton sourced through CottonConnect (Just Style, 2024); an earlier pilot found DNA tracers intact after spinning, chemical treatment and dyeing (Fashion for Good, 2019).

Alternative: Mass Balance versus Full Segregation. Mass balance (where sustainable cotton is mixed with conventional) costs approximately $1–$3/MT but cannot track pesticide residues back to a specific farm. Full segregation (keeping the physical cotton separate) adds logistics costs of approximately $20–$40/MT in operational overhead. As a reality check – if a metric tonne of cotton produces roughly 3,000 T-shirts, a traceability cost of $100/MT adds only $0.033 per garment.

Summary: Value Chain Traceability Cost

A comprehensive traceability system, capable of proving origin and MRL compliance, could cost approximately $25 to $62.50 per metric tonne of cotton lint, with $45/MT (mid-range). At a cost of production of ~$1,320/MT, this represents a 3.4% premium on the raw material cost. The modelling approach applies this cost to the full volume of cotton production destined for apparel (total production × 80% apparel fraction), with a 3% annual price decline as systems mature.

Key Caveats: Chemical Degradation: while DNA markers survive processing, pesticide residues can be partially washed out during scouring and bleaching, meaning MRL compliance must be checked at both the farm and the finished fabric stage. Infrastructure: traceability costs are significantly higher for smallholders compared to large-scale farms due to the “fragmentation tax” of collecting data from thousands of small units. The End-of-Life component is speculative: while Digital Product Passports (DPP) are being mandated by the EU under the Ecodesign for Sustainable Products Regulation (European Parliament & Council of the European Union, 2024), with textile requirements indicatively scheduled for adoption in 2027 (European Commission, 2025), the infrastructure to scan and sort these at scale in recycling facilities is still in its infancy.

2.6 System-level change

Growth

The cotton sector is not static. Global cotton production, consumption, and trade are subject to long-run trends driven by population growth, income growth, fibre competition,

and policy. The modelling approach applies a sector growth rate (central 1.7% CAGR) to all volume-dependent cost lines through annuity formulas. This means that the 10-year total for, say, EPR administration is not simply the base-year cost multiplied by ten, but the base-year cost compounded at the growth rate — producing a modestly higher total that reflects the expanding scale of the sector over the horizon. The growth rate is parameterised (Low 1.0%, High 2.5%) and can be adjusted to reflect different demand scenarios.

Recycling substitution

As fibre-to-fibre recycling capacity builds out over the 10-year horizon, recycled cotton fibre re-entering the apparel supply chain displaces a portion of demand for virgin cotton. The modelling approach captures this effect by reducing the effective agricultural area requiring transition (see Section 2.3). At central parameters, the displacement is modest (approximately 0.2 million hectares), reflecting both the small current base of fibre-to-fibre recycling and the time required for new capacity to reach steady-state. Under a high-recycling scenario (higher collection rates, higher T2T share, faster ramp), the displacement could be materially larger, providing a meaningful offset to agricultural transition costs.

Governance

The transition requires institutional infrastructure that cuts across value chain stages: policy frameworks, standards bodies, import control regimes, and worker health regulation. These costs are collected in a dedicated value chain governance component (Section 6) rather than allocated to individual stages, because they serve the system as a whole. Governance costs are sized as percentages of anticipated transition spend (for example, policy establishment at 1% of annual-average transition spend) or as functions of trade value (for example, import controls at 0.25% setup plus 0.5% recurring of global cotton trade value), reflecting their nature as enabling conditions rather than direct transition activities.

2.7 Cost assignment

The modelling approach allocates costs across a public-private split, based on published information available from proxies, using a taxonomy of typical financing channels (grants, concessional/DFI, EPR fees, private CAPEX/VC).

Table 5. Cost assignment across public-private split

Component	Low/Cen/High (current)*	Rationale	Assessment
Input cost differential (ag)	10/20/30%	Blended finance: subsidy/Payments for Ecosystem Services (PES) partially offsets farmer premium; Public-private partnership	Reasonable

		(PPP) says polluter/farmer bears majority (OECD, 2008; Prabhakar et al., 2025)	
Monitoring & training (ag)	55/70/85%	FAO/MEAS: extension classically public-funded in developing countries (McNamara, 2014; Yang & Ou, 2023)	Reasonable
Yield risk buffer	35/50/65%	Climate-smart agri blended finance: public de-risks "missing middle" crop insurance (Mahul & Stutley, 2010; Prabhakar et al., 2025)	Reasonable
Biocontrol/agrochemicals R&D	10/30/50%	USDA ERS: private >70% of US ag R&D in 2013 (Clancy et al., 2016); globally the private share was 26% in 2014 (Beintema et al., 2020)	Large national variability reflected in range.
Chemical substitution premium	5/10/15%	PPP: mill OPEX private; small cleaner-production grants (OECD, 2008)	Reasonable
Equipment CAPEX	5/10/20%	ADB blended finance leverage; private CAPEX dominates (Attridge & Engen, 2019; Iyer & Vaze, 2024)	Reasonable
Processing R&D	60/70/80%	Globally the private share was 26% in 2014 (Beintema et al., 2020)	In agricultural and food industry.
WWT	30/50/70%	OECD PPP: polluter pays; public = permitting/enforcement only (OECD, 2008)	Reasonable
Collection & sorting	25/40/55%	OECD EPR garments: producer-funded but municipal systems share (Brown & Börkey, 2024)	Reasonable
Recycling CAPEX+OPEX	15/30/45%	OECD EPR: private recyclers + public grants for nascent T2T (Brown & Börkey, 2024)	Reasonable
EPR administration	65/80/90%	OECD EPR: regulator function = public by nature (Brown & Börkey, 2024)	Reasonable
Recycling tech R&D	35/50/65%	Public innovation funding early-stage; private VC	Reasonable
Traceability	5/15/25%	EU Digital Passport Product (DPP): mostly brand/mill-funded; some public infra (European Parliament & Council of the European Union, 2024)	Reasonable
Institutional overheads	75/90/95%	Governance/standards = public by nature	Reasonable
Worker health & PPE	30/50/70%	ILO C155/R164 + OSHA: employer pays PPE; public = regulation/subsidy (ILO, 1981a, 1981b; OSHA, 2007)	Reasonable

* the percentage indicates the proportion of public share

2.8 Key limitations

The top-down method is fit for a framework-level estimate but carries several intrinsic limitations that any reader should hold in mind and are described in further details in section 7:

- Unit costs and adoption shares are global averages; they mask large variation across countries, farm sizes, and processing facility scales.
- The method incorporates a sector growth rate but does not model projected growth or decline in cotton demand, substitution with synthetic fibres, or price-volume feedbacks induced by the transition itself.
- Circular feedbacks at the end-of life stage are partial: the modelling approach reduces agricultural area for recycled fibre displacement but does not net off the full reduction in agricultural transition need, nor does it model substitution into or out of cotton from other fibres.
- Cost of capital is ignored. Financing the transition through debt at prevailing interest rates in major producing regions would add materially to the nominal totals shown.
- Co-benefits (such as health, water, productivity, premium pricing) are not credited. A full cost-benefit frame would likely show a substantially smaller net cost.
- Wastewater treatment and worker health estimates are placeholders requiring verification against sector-specific benchmarks.

3. Eliminating HHPs in Cotton Production

Cotton production accounts for approximately 4% of global pesticide use despite occupying roughly 2.3% of global arable land (Kranthi, 2024). The concentration of hazardous pesticide use in cotton — particularly organophosphates, neonicotinoids, and older-generation synthetic pyrethroids — makes the crop a priority sector for Target A7, which calls for the global phase-out of HHPs by 2035 where the risks have not been managed and where safer and affordable alternatives are available (UNEP, 2023).

Financial needs for upstream transition are driven by four cost categories: the input cost differential between conventional HHPs and IPM-compatible alternatives, the investment in monitoring and extension infrastructure required for IPM, a yield-risk buffer to protect farmer incomes during the biological transition period, and the biocontrol/agrochemicals R&D uplift needed to commercialise safer alternatives.

3.1 Effective area and transition scope

Transition area parameter. The modelling approach assumes that 80% (18.8Mha) of global cotton area (29.4Mha) destined for apparel requires meaningful transition investment. This is a parameter held constant across Low, Central, and High scenarios. Only certified organic cotton (estimated at 2.3% of global production; Textile Exchange, 2025) is fully HHP-free today, but a broader set of sustainability certifications (e.g. Better Cotton, CmiA, organic conversion) may already embed partial HHP reduction. The 80% parameter reflects an assumption that balances ambition against the recognition that not all cotton area is equally chemical-intensive. This parameter can be adjusted via a drop-down in the modelling approach and uncertainty can be expressed using high, low ranges.

Recycled fibre displacement. The effective apparel area is further reduced by the displacement effect of recycled cotton fibre re-entering the supply chain (see Section 2.3). All agricultural cost categories cascade from this effective area of 18.5Mha.

3.2 Input cost differential

Basis. Published field trial data from South Africa (Malinga & Laing, 2023) provides the most detailed comparative cost analysis available for cotton pest management using biopesticides versus conventional chemical insecticides. The study found conventional chemical insecticides (chlorpyrifos, karate) cost under $100 per hectare for a full spray programme of 10 applications, while biopesticide alternatives (e.g. Bolldex, Delfin, Eco-Bb) ranged from $226 to $602 per hectare for comparable programmes.

However, a full transition to IPM does not require wholesale replacement of all chemical inputs with commercial biopesticides. IPM integrates cultural controls (crop rotation, intercropping), biological controls (beneficial insect conservation), mechanical

interventions (pheromone traps), and targeted use of reduced-risk pesticides, with commercial biopesticides as one component among several. The per-hectare cost of a mature IPM system is therefore lower than the cost of a pure biopesticide regime.

Estimation approach. Global average conventional pesticide expenditure on cotton is estimated at $80/ha (central), with $50–$120/ha as the parameter range. A transition to an IPM-based system — including biological inputs, pheromone traps, and reduced-risk targeted sprays — is estimated to cost $230/ha (central), with $160–$350/ha as the parameter range. The central input cost delta is therefore $150/ha.

Uncertainty: HIGH. The $150/ha delta is a weighted global average derived from South African field trial data, which may not be representative of conditions in India (11.2 Mha), China (2.95 Mha), Pakistan (2.0 Mha), Brazil (2.1 Mha) (Meyer & Dew, 2026; USDA Foreign Agricultural Service, 2026), West Africa or other regions or countries. Regional variation could range from $80/ha in areas with lower pest pressure to $300/ha in areas with heavy bollworm infestation.

3.3 Monitoring, extension, and training

Basis. Effective IPM requires field-level monitoring (pest scouting to determine economic thresholds), farmer training (typically through farmer field schools), and extension support. Published IPM programme evaluations from Asia and Africa (Pretty & Bharucha, 2015) indicate that across 85 projects pesticide use fell on average to 30.7% of its original level while mean yields rose by 40.9%, but well-implemented programmes require sustained investment in human capital.

Pheromone trap networks for bollworm monitoring cost approximately $15–30/ha per season. Pest scouting labour requirements are approximately 1 scout per 40–50 hectares, at prevailing agricultural wages of $7–$13/day in major producing regions (Malinga & Laing, 2023), yielding approximately $1.8–$4.5/ha/year. Farmer field school programmes typically cost $50–$120 per farmer over a 2–3 year training cycle.

Direct training coverage. The modelling approach assumes 25% direct training coverage (central, range 15–40%), reflecting evidence that sector-wide impact can be achieved through peer diffusion even with limited direct coverage. The Mali cotton FFS programme (Settle et al., 2014) achieved ~20% direct coverage with sector-wide results; Better Cotton's field facilitator cascade reaches 2.1 million farmers through a Producer Unit/Lead Farmer model (Better Cotton, 2024).

Uncertainty: MODERATE. Monitoring and training unit costs are reasonably well-documented. The principal uncertainty is the number of farmers requiring training (estimated at 31.5 million enterprises estimated globally) and the intensity of extension support needed across smallholder versus large-scale commercial systems.

3.4 Yield risk buffer

Basis. Transition from chemical-intensive pest management to biological and integrated approaches involves a "biological reset" period of 2–4 years during which beneficial insect populations recover and biological control agents establish. It also typically involves a yield reduction that is observed to range between 5 and 15% (central: 10%) (Pretty & Bharucha, 2015).

Uncertainty: MODERATE to HIGH. Yield risk is highly variable by region and pest ecology. In Bt cotton areas, the shift away from HHPs may have minimal yield impact because primary bollworm control is already genetic. In non-Bt cotton areas (for example West Africa), the transition period may be longer and more volatile.

3.5 Biocontrol and agrochemicals R&D

Basis. The global crop protection (agrochemicals) market is valued at approximately $80 billion per year (MarketsandMarkets, 2024). The major agrochemicals companies (Bayer, Syngenta, Corteva, BASF) currently invest at an R&D intensity of approximately 8–11% of sales (BASF SE, 2025; Corteva, 2024; Syngenta Group, 2024). Achieving the transition to safer biocontrol alternatives requires an uplift in R&D intensity, particularly to accelerate the commercialisation of biopesticides (which are already growing at 14.6% CAGR; MarketsandMarkets, 2025) and to develop novel bio-based active ingredients through the 7–10 year regulatory approval cycle.

Uncertainty: MODERATE. The R&D intensity gap is anchored by public filings of the major agrochemicals companies. The principal uncertainty is the cotton share of the overall market (range 5–10%) and the pace at which biocontrol R&D translates into commercially available products.

4. Wet Processing and Chemical Substitution

Wet processing — encompassing scouring, bleaching, mercerisation, dyeing, printing, and finishing — is the most chemical-intensive stage of the cotton textile value chain. Chemicals of concern used in cotton wet processing include azo dyes (some of which release carcinogenic aromatic amines), PFAS-based water and stain repellents, formaldehyde-based finishing agents, alkylphenol ethoxylates (APEOs) used as surfactants, and various heavy metal-containing catalysts and mordants (ZDHC Foundation, n.d.).

Financial needs for processing transition are driven by four cost categories: the incremental cost of safer chemical alternatives (the “green premium”), capital expenditure for equipment retrofitting or replacement, R&D investment to develop and scale viable alternatives, and the public share of wastewater treatment costs.

4.1 Sizing the cotton-specific downstream market

The global textile chemicals market is valued at approximately $29–31 billion in 2025 (Coherent Market Insights, 2025; Grand View Research, 2025; Mordor Intelligence, 2026; Towards Chemical and Materials, 2025). Cotton accounts for approximately 19% of global fibre production by volume (Textile Exchange, 2025), but cotton’s share of chemical consumption in wet processing is disproportionately higher than its fibre volume share because natural fibres require additional processing steps not needed for synthetics (scouring to remove natural waxes and oils, bleaching, mercerisation). We estimate cotton-related chemical consumption at approximately 27.5% of the total textile chemicals market (range 20–35%).

4.2 Chemical substitution premium (the green premium)

Basis. Safer alternatives to chemicals of concern in textile processing currently carry a cost premium over conventional hazardous inputs. The modelling approach estimates premiums of 10–30% for compliant alternatives across the main chemical categories: bio-based dyes, PFAS-free water repellents, formaldehyde-free crosslinkers, and APEO-free surfactants. PFAS-free functional finishes carry the highest premiums, while surfactant substitution is relatively cost-neutral. A central 20% premium is used.

Not all chemicals currently used in cotton processing are chemicals of concern. For modelling purposes, the share of the cotton-specific chemicals market associated with chemicals of concern is assumed to range from 30% to –70% (central 50%) and is used to estimate substitution costs.

4.3 Equipment CAPEX for processing transition

Basis. Transitioning to safer chemistry requires equipment modifications or replacements. Examples include low-liquor-ratio dyeing machines to reduce chemical and water consumption, digital printing equipment to replace conventional screen printing with hazardous inks and closed-loop chemical recovery systems.

The number of cotton-processing wet processing facilities globally is large (estimated 50,000–80,000 dyeing and finishing operations concentrated in China, India, Bangladesh, Vietnam, Pakistan, and Turkey), but most are SMEs with limited capital for equipment upgrades. The modelling approach applies an incremental CAPEX factor to the cotton-attributable machinery capex base. The uncertainty associated with this capex estimate is considerable and is reflected in the initial range of suggested values ($70/100/140 B). Estimates of this parameter may be more readily available at national level and will require further analysis.

4.4 R&D and innovation investment

The textile sector has historically had low R&D intensity (estimated 1–2% of revenue) compared to the specialty chemicals sector (5–8% of revenue) or pharmaceuticals (15–20%). Achieving the GFC transition — particularly in areas where viable safer alternatives do not yet exist at scale (for example, affordable PFAS-free durable water repellents, non-toxic flame retardants) — requires accelerated R&D investment. However, R&D for textile chemicals is principally conducted by chemical suppliers (e.g. Archroma, Huntsman, DyStar, BASF) rather than by textile manufacturers themselves.

4.5 Wastewater treatment (public share)

Basis. Cotton wet processing generates significant volumes of wastewater containing chemical residues. The cost of adequate filtration and effluent treatment is borne primarily by private operators, but a public share arises from permitting, enforcement, monitoring, and in some jurisdictions, subsidies for treatment infrastructure. This component estimates the public share of wastewater treatment costs as a placeholder requiring verification against existing standards such as EU Best Available Techniques (BAT-AEL) standards (European Commission, 2022) and ZDHC Wastewater Guidelines (ZDHC Foundation, 2024).

Uncertainty: HIGH. All three parameters (cost per tonne, volume, and public share) are placeholders. The public share in particular is important to reflect: in countries with strong environmental regulation, the public share may be lower (5%) because compliance is enforced privately; in countries with less mature environmental regulation, public investment in treatment infrastructure may be higher (25%).

5. End-of-Life

The end-of-life stage addresses the GFC's broader mandate on hazard reduction from chemical wastes and the emergence of extended producer responsibility (EPR) schemes globally. The modelling approach calculates four cost categories over the 2025–2035 period: collection and sorting infrastructure, fibre-to-fibre recycling capacity, Extended Producer Responsibility (EPR) schemes administration and recycling technology R&D.

5.1 Collection and sorting infrastructure

Lifting the global post-consumer cotton textile waste collection rate from a baseline of 20% to a 50% rate in 2035 (close to e.g. a 50% collection base case; Hedrich et al., 2022) implies an additional 2.7 Mt/year (linear-ramp average) of cotton textile collection.

5.2 Fibre-to-fibre recycling capacity

The transition will require building industrial-scale mechanical and chemical recycling infrastructure to process an estimate of approximately 0.56 Mt/year of collected cotton textiles (25% of the incremental collected volume) with estimated CAPEX of $3,500/tonne of installed capacity and OPEX of $2,000/tonne processed.

5.3 Extended Producer Responsibility administration

EPR schemes are now mandatory in the EU (Waste Framework Directive 2025/1892, entered into force October 2025, with EPR schemes operational by April 2028; European Parliament & Council of the European Union, 2025) and being adopted across major markets (Lüttin, 2026). The modelling approach scopes this line to EPR scheme overhead only, covering PRO governance, registry, reporting, audit, and eco-modulation, at $20/tonne of cotton textile produced (central estimate, range $10–$35/t). This represents approximately 10–15% of the headline producer fee; collection, sorting, and recycling infrastructure costs are captured separately in Sections 5.1 and 5.2. The broader EPR fee revenue that funds collection and recycling is largely endogenous to the supply chain once schemes are designed — it passes through to producers and ultimately to prices — rather than representing an external finance gap.

5.4 Recycling technology R&D

The modelling approach seeks to estimate financial needs to close the gap between current R&D spend on cotton-specific recycling technologies and the funding required to mature fibre-to-fibre processes to commercial scale. This is estimated at approximately $0.3 billion/year (cotton's ~38% share of the textile recycling market (Kaitwade, 2025); cross-checked against a 69.1% cotton share of recycling volume by material (Grand View Research, 2026)).

6. Value Chain Governance

Several categories of cost cut across individual value chain stages and serve the transition system as a whole. These are collected in a dedicated governance component covering traceability, institutional overheads (including policy establishment, standards body establishment, and import controls), and the public share of worker health and PPE.

6.1 Traceability and chain of custody

Basis. Supply chain traceability is needed to verify HHP-free cotton from farm to final product. The modelling approach applies traceability as a value chain-wide cost, priced per metric tonne of raw cotton destined for apparel. This reflects the reality that traceability systems need to span the full chain from farm to finished garment. The traceability cost is distinct from monitoring activities in the agricultural production component, which relate to pest and disease monitoring as part of IPM.

6.2 Institutional overheads

The transition requires institutional infrastructure that does not currently exist at the required scale. The model prices four components, each sized using top-down heuristics in the absence of bottom-up estimates.

- **Policy establishment (one-off).** Developing national and international regulatory frameworks, chemical restriction lists, and enforcement capacity requires a substantial but largely fixed upfront investment. The modelling approach sizes this at 1% of annual-average transition spend. The 1% heuristic reflects the observation that policy-design effort has a large fixed-cost component and should not scale proportionally with implementation magnitude; the parameter is held constant across Low, Central, and High scenarios for this reason. The estimate covers framework development and does not include ongoing compliance or enforcement costs, which are captured under institutional overhead and import controls below.
- **Standards body establishment (one-off).** Creating or strengthening international standards bodies for safer pesticides and pesticide management is sized in the modelling approach at 1% of the annual average agricultural transition spend. This is analogous to the policy establishment heuristic but applied to the narrower agrochemical base, reflecting the more specialised scope of standards work.
- **Institutional overhead (recurring).** Ongoing administration of policy frameworks and coordination between national authorities is sized in the modelling approach at 1.5% of total annual transition spend. This covers the recurring cost of

maintaining regulatory infrastructure once established, including inter-agency coordination, reporting, and programme management.

- **Import controls (one-off setup and recurring).** The model anchors import control costs to the global cotton trade value, estimated at $53 billion per year based on UN Comtrade-aggregated 2024 cotton exports under HS-52 (Workman, n.d.). A one-off setup rate of 0.25% of trade value covers the establishment of customs sampling capacity, testing registries, and border enforcement infrastructure for restricted-substance compliance. A recurring rate of 0.5% of trade value per year covers ongoing inspection, sampling, and laboratory testing of cotton consignments against chemical restriction lists. Both rates are sized by analogy to WTO/OECD trade-facilitation programme costs (1–3% of trade flow for capacity-building) and to estimates that direct and indirect trade transaction costs each amount to 1–15% of the value of traded goods (OECD, 2003).

All four institutional cost lines are subject to an annual decline rate (3% central, range 1.5–4.5%) reflecting learning and efficiency gains as systems mature.

6.3 Worker health and PPE (public share)

Basis. The cotton apparel value chain employs an estimated 350 million workers globally (UNIDO, 2024). The transition to safer chemistry requires investment in personal protective equipment (PPE), ventilation systems, and health surveillance to protect workers during and after the transition. The majority of this cost is borne by private employers; the model estimates only the public share arising from regulation, inspection, and training subsidy.

Uncertainty: HIGH. All three parameters (workforce size, per-worker uplift, and public share) are placeholders. The workforce estimate of 350 million is taken from UNIDO (2024) and includes the full cotton apparel value chain from farming to retail. The per-worker uplift and public share require verification against ILO and WHO occupational safety benchmarks and any other relevant benchmark.

7. Key limitations and proposed additions

Regional or national disaggregation. This approach produces global aggregates that mask significant regional variation. For instance, the cost of transition can differ fundamentally in India (11.2 million hectares, predominantly smallholder), Brazil (2.1 million hectares, large-scale commercial), Australia (0.47 million hectares, highly mechanised; USDA Foreign Agricultural Service, 2026), or West Africa (fragmented smallholder systems). A subsequent phase of work could produce regionally or nationally disaggregated estimates. Regional farm size and worker data are included in the Parameters sheet for this purpose.

Critical parameter values need reviewing. The cotton share of textile chemicals consumption (27.5%), the share of the chemicals market requiring substitution (50%, see below), the installed machinery base ($100 billion), the EPR administration cost per ton ($20/t), and the share of cotton area requiring transition (80%) — are indicative estimates that require verification against other textile value chain modelling activities and against proprietary industry data which are not publicly available. Uncertainty on the area requiring transition can be expressed through low and high range values.

The proposed transition activities themselves require expert review. The modelling approach currently assumes a single representative transition pathway for agriculture (IPM adoption with biopesticide and pheromone-based inputs) and for processing (chemical substitution with a 20% green premium (central) plus equipment upgrades). Alternative pathways, sequencing, and regional variations are not reflected at this stage in the modelling approach and would require further analysis.

Not all chemicals currently used in cotton processing are chemicals of concern. In the modelling approach, the share of the cotton-specific chemicals market associated with chemicals of concern is assumed to range from 30% to 70% (central 50%) and is used to estimate substitution costs.

Cost of capital. The analysis does not incorporate the cost of capital (interest rates, WACC) for financing the transition. In many major cotton-producing countries, particularly in South Asia and Sub-Saharan Africa, the cost of capital is significantly higher than in OECD economies, which means the effective cost of the transition may be higher than nominal estimates not incorporating the cost of capital.

The modelling approach distinguishes between additional and redirected costs. It assigns a public share of required or redirected finance based on publicly available information relevant to each value-chain stage and summarized in Section 2.7 of this report and requires validation. This allows the modelling approach to represent redirected costs that could be mobilized through demand-side policy — procurement standards, import requirements, eco-modulation, retailer specifications — versus differential costs

that typically require supply-side finance (public funds, blended finance, concessional lending, R&D grants) because no natural market mechanism generates the activity.

Representation of financial instruments. The modelling approach estimates who pays (public versus private) but not through which instruments. It may be possible to consider allocating the main cost lines to financial-institution types (banks, investors, insurers, DFIs) and to instruments such as blended finance, guarantees, sustainability-linked loans and concessional lending. This could inform how to bridge the bankable risk-sharing structures gap outlined in the report '*Financial institutions' role in driving the transition to safe and sustainable chemicals*' (GFC, 2026b).

The modelling approach incorporates a sector growth rate (1.7% CAGR, central) to project volumes forward but does not incorporate at this stage more complex dynamics such as shifts in regional production, changes in the cotton/synthetic fibre mix, or price and yield trajectories.

Partial circular feedback at the end-of-life stage. The modelling approach introduces recycled fibre displacement of virgin cotton, but at this stage does not close the full circularity loop or consider alternative textile fibres. It does not net off the full reduction in virgin cotton production need that would follow from all recycled cotton displacing virgin fibre over the horizon. It also does not model substitution into or out of cotton from other fibres. Both feedbacks would reduce the gross transition cost. Note: a green premium on cotton chemistry could push brands towards alternatives which carry their own chemical and microplastic burden. This would represent a regrettable substitution at the fibre level.

System-level transaction costs are introduced through a dedicated value chain governance component. This covers institutional overheads, import controls, and standards body establishment. However, transaction costs at the individual farm or processing facility level remain implicit.

Disclosure and reporting costs are not priced. The traceability line covers digital, DNA, MRL testing and DPP, but not corporate chemical disclosure, data systems or assurance (GFC Targets D3 and B2). Estimates of costs may be derived using GRI/ESRS E2-type disclosures as the basis for the metrics.

Placeholder estimates. Wastewater treatment (public share) and worker health and PPE (public share) are placeholder estimates requiring verification against sector-specific benchmarks (e.g. EU BAT-AEL, ILO/WHO occupational safety standards, ZDHC Wastewater Guidelines; European Commission, 2022; ZDHC Foundation, 2024).

Dynamic policy effects. Regulatory acceleration (for example, GFC mandates driving rapid adoption), technology breakthroughs (for example, affordable PFAS-free alternatives), or market shocks (for example, cotton price volatility) could significantly alter the trajectory and timing of financial needs but are not considered.

Savings and co-benefits not credited. The analysis estimates gross financial needs without crediting potential savings from reduced healthcare costs from pesticide poisoning, reduced water treatment costs from cleaner processing effluent, improved worker productivity and safety, premium pricing achievable for verified chemical-safe textiles, and reduced remediation liabilities. A full cost-benefit analysis would need to account for these offsets. They could be informed by the outcome of the work which may be developed as described in the scoping paper 'The Benefits of Action for the Sustainable Management of Chemicals' mentioned in UNEP/GFC/IC.1/INF/7.

Non-linear cost dynamics. Cost curves for "green premiums" may be non-linear and front-loaded. In future versions of the modelling approach, users could be presented with a choice of cost curve (linear, log-linear, custom). For instance, for Target D6 due in 2030 model users could be presented with a phased profile (for example, a simple front-loaded sensitivity) to capture this dynamic.

8. References

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Annex 1: Parameter Values and References

Central, Low and High are the modelling approach's three scenario values. Rows marked ↳ (italic) are calculated in the modelling approach from the inputs above them. Bracketed numbers refer to the Sources section. Parameters require expert review.

Parameter values (and ranges)

Table 6. Model input parameters

Parameter	Central	Low	High	Unit	Source and basis
A. Global cotton production					
Global cotton harvested area	29.4	28	31	M ha	[1] p.2: 29.4 M ha (72.8 M acres). FAOSTAT 2024 cross-check ≈30 M ha.
Global cotton production	121	115	125	M bales (480 lb)	[2] p.1: 121.0 M bales; [1]: 119.8 M bales (pre-revision).
↳ Global cotton production	*26.3*	*25.0*	*27.2*	*Mt*	*Derived: bales × 217.72 kg/bale.*
Fraction used for apparel	80%	75%	85%	share	[38] FAO cotton market page (URL only; no figure cited).
↳ Cotton yield per hectare	*896*	*840*	*920*	*kg/ha*	*Central derived (production ÷ area). [1] p.2 reports 886 kg/ha. Low/High are inputs.*
Cost of cultivation	1.32	0.92	2.67	$/kg	[24] ICAC Cotton Production Data Portal; outliers excluded (Uganda 0.26, Malawi 3.42).
↳ Cost of cultivation per hectare	*1,183*	*773*	*2,456*	*$/ha*	*Derived: yield × cost per kg.*
Sector growth rate (CAGR)	1.7%	1.0%	2.5%	per yr	User input; no external source.
B. Cotton agriculture					
Share certified organic	2.3%	2.3%	2.3%	share	[4]: 2.3% certified organic; 22% Better Cotton (BCI).
Share of area requiring transition	80%	80%	80%	share	[4] cited without a specific figure. Parameter held constant across scenarios.

Parameter	Central	Low	High	Unit	Source and basis
Area requiring transition	18.8	16.8	21.1	M ha	Derived: area × share requiring transition × apparel fraction (Not accounting for recycle-fibre displacement)
Conventional pesticide cost	80	50	120	$/ha	[5] Tables 1–2: chemical insecticides <$100/ha.
IPM system cost (full regime)	230	160	350	$/ha	[5] Table 3; [6] Table A1 (85 IPM projects, mean +40.9% yield).
↳ Input cost delta (IPM − conventional)	*150*	*110*	*230*	*$/ha*	*Derived.*
Monitoring infrastructure cost	20	15	30	$/ha/yr	No numbered source: “IPM programme data; pheromone trap/lure costs from field trial budgets”.
Scouting labour cost	2.7	1.8	4.5	$/ha/yr	[5] p.49: $10.87/day × ~10 visits ÷ 40 ha per scout.
Number of farm enterprises	31.5	15	40	million	[14] ICAC (cited by name in the model).
Number of farm workers	190	90	241	million	[14]; Low/High scaled to the enterprise range.
Training cost per farmer	80	50	120	$/farmer	[6] §3.2: Farmer Field Schools, 3-year cycle.
Yield risk buffer	10%	5%	15%	of revenue	[6] Table 2: 5–15% yield variability in IPM transition years.
Biological reset duration	3	2	4	years	Standard IPM transition period; consistent with [6].
Annual biopesticide price decline	3%	1%	5%	per yr	Estimate (economies of scale); no external source.
Direct training coverage rate	25%	15%	40%	share	[39] Settle et al. 2014 (Mali FFS, ~20% direct coverage); [40] Better Cotton field-facilitator cascade.
Global crop protection (agrochemicals) market	80	70	100	$ B/yr	[25]: $79.3 B (2024); aggregator range $67–104 B.

Parameter	Central	Low	High	Unit	Source and basis
Cotton share of agrochemicals market	7%	5%	10%	share	Estimate: ~5% of arable area × 1.4–1.6 pesticide intensity (FAOSTAT, CropLife).
Current agrochemicals R&D intensity	8.5%	8%	11%	of sales	[26] Big Four annual reports 2023/24.
Agrochemicals R&D intensity	13%	11%	15%	of sales	Policy driven uplift; consistent with [25] biopesticide CAGR of 14.6%.
C. Cotton processing					
Global textile chemicals market	30	27	32	$ B/yr	[7] $27.3 B; [8] $30.2 B; [9] $31.4 B.
Cotton share of chemicals consumption	27.5%	20%	35%	share	Estimate: 19% fibre share [4] × ~1.45 processing-intensity factor.
↳ Cotton-specific chemicals spend	*8.25*	*5.40*	*11.20*	*$ B/yr*	*Derived: market × cotton share.*
Share assumed to be associated with chemicals of concern	50%	30%	70%	share	[10]; [11] ZDHC MRSL informs the scope; modelling assumption .
Average green premium	20%	10%	30%	share	[11]; [12]; [9].
Annual premium decline rate	2%	1%	4%	per yr	Estimate modelled on REACH compliance cost curves; no specific reference.
Installed cotton machinery base	100	70	140	$ B	Estimate; no external source.
Annual equipment replacement rate	10%	5%	15%	per yr	Standard 8–12 year industrial replacement cycle; no external source.
Equipment green premium	15%	7.5%	22.5%	share	Manufacturer indications (Thies, Fong's, Monforts); no formal reference.
Current textile chemicals R&D	3%	1.5%	4.5%	of market	Estimate: mature specialty-chemicals benchmark; [9].
R&D intensity for transition	5.5%	2.75%	8.25%	of market	[12] REACH-era specialty-chemicals R&D benchmark.

Parameter	Central	Low	High	Unit	Source and basis
Equipment premium annual decline rate	2%	1%	3%	per yr	Assumption mirroring chemicals premium decline; no external source.
D. End-of-life					
Post-consumer cotton textile waste	18	14	23	Mt/yr	[16]: 120 Mt textile waste; cotton ~19% share [4].
Collection rate by 2035	50%	25%	75%	share	[15] Exhibit 1 (base case 50%); [17] separate collection mandatory from Jan 2025.
Collection & sorting cost	350	200	550	$/t	[17]; Refashion (France EPR) ~€417/t; WRAP UK; developing-country discount applied.
Share of collected cotton to fibre-to-fibre recycling	25%	12.5%	37.5%	share	[16]: <1% today, >30% achievable; [15]: 18–26% by 2030.
Fibre-to-fibre recycling CAPEX	3,500	2,000	5,000	$/t capacity	[16]; [15] p.7: €6–7 B EU recycling CAPEX.
Recycling OPEX	2,000	1,200	2,800	$/t/yr	[15]: inferred from €1.5–2.2 B profit pool.
EPR scheme overhead (governance only)	20	10	35	$/t produced	[18]: NL €0.20/kg, France €0.01–0.06/item; [17]. Scoped to ~10–15% of headline fee.
Cotton textile production (EPR base)	24.5	22	27	Mt/yr	[4]: 24.5 Mt (19% of 132 Mt fibre).
Recycling technology R&D gap	0.30	0.15	0.50	$ B/yr	[16]: >$250 M VC to date; [19]; [20].
Current baseline collection rate	20%	10%	30%	share	[16] Exhibit 1; cross-check [19], [20].
E. Institutional overheads, traceability and public-sector enabling spend					
Traceability	80	50	110	$/t raw cotton	[41] Digital $5–15, forensic $30–60, MRL testing $10–25, Digital Product Passport $5–10 per t.

Parameter	Central	Low	High	Unit	Source and basis
Traceability annual price decline	3%	1.5%	4.5%	per yr	Estimated
Policy establishment	1%	1%	1%	share	[27] cited (trade value only). Parameter held constant.
Institutional overhead	1.5%	1.5%	1.5%	share	[28]: by analogy to WTO/OECD trade-facilitation costs (0.1–0.3% of trade).
Institutional annual cost decline	3%	1.5%	4.5%	per yr	[28] Derived by analogy. UN Global Survey on Digital and Sustainable Trade Facilitation 2023 (UNECE, ECA, ESCAP, ECLAC, ESCWA, UNCTAD): full digital implementation reduces trade costs ~14% (≈1.5%/yr over 10 years, Low). UNECE case: 11% import-cost reduction 2014–2016 (≈5%/yr, High). Central 3% is the midpoint. These figures describe trader-side costs and are a proxy for administrative cost decline.
Standards body establishment	1%	1%	1%	share	Assumption by analogy to policy establishment.
Global cotton trade value	53	45	60	$ B/yr	[27]: HS-52 exports $52.6 B (2024), $53.3 B (2023), $47.7 B (2020).
Import controls — setup	0.25%	0.125%	0.375%	of trade value	Assumption; no external source.
Import controls — recurring	0.5%	0.25%	0.75%	of trade value/yr	Assumption; no external source.
Waste water treatment CAPEX + OPEX	80	40	150	$/t processed	PLACEHOLDER in model: to verify against e.g. ZDHC Wastewater Guidelines / EU BAT-AEL.
Cotton textile wet-processed volume	24.5	22	27	Mt/yr	Proxy: cotton textile production [4].
Public share of WWT spend	10%	5%	15%	share	PLACEHOLDER in model: sensitivity lever.
Workers in cotton apparel value chain	350	250	450	million	[29] UNIDO World Cotton Day 2023 report.

Parameter	Central	Low	High	Unit	Source and basis
PPE, ventilation, health surveillance	15	8	30	$/worker/yr	PLACEHOLDER in model: to verify against e.g. ILO/WHO benchmarks.
Public share of worker-health spend	15%	7.5%	22.5%	share	PLACEHOLDER in model: sensitivity lever.

Table 2. Public financing shares by cost component

Cost component	Central	Low	High	Source and basis
Public share of each cost component (private share = 1 − public)				
Input cost differential (agriculture)	20%	10%	30%	[36]; [33]. Subsidy/PES partially offsets farmer premium.
Monitoring and training (agriculture)	70%	55%	85%	[30]. Extension services classically public-funded.
Yield risk buffer (agriculture)	50%	35%	65%	[33]; [36]. Blended public–private de-risking.
Biocontrol / agrochemicals R&D (agriculture)	40%	25%	55%	[31]; [37]. Private >70% of agricultural R&D.
Chemical substitution premium (processing)	10%	5%	15%	[34]. Polluter Pays: mill bears OPEX.
Equipment CAPEX (processing)	10%	5%	20%	[33]. MDB leverage ~1.00:0.75 public:private.
R&D and innovation (processing)	30%	20%	40%	[31].
Wastewater treatment (public slice)	100%	100%	100%	[34]. Public slice only; pinned at 100% within slice.
Collection and sorting (end-of-life)	40%	25%	55%	[32]. Municipal systems; EPR shifts cost to producers.
Recycling CAPEX + OPEX (end-of-life)	30%	15%	45%	[32]; [33].
EPR administration (end-of-life)	80%	65%	90%	[32]. PRO/regulator function.

Cost component	Central	Low	High	Source and basis
Recycling technology R&D (end-of-life)	50%	35%	65%	[32]; [33].
Traceability (value chain)	15%	5%	25%	[32]. Mostly brand/mill funded.
Institutional overheads (value chain)	90%	75%	95%	[32]. Governance and standards bodies.
Worker health & PPE (public slice)	50%	30%	70%	[35].

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