



THE EGYPTIAN
COTTON PROJECT
مشروع القطن المصري

December 2020

RE.ACT

Environmental and economic
assessment of post-industrial
cotton waste recycling

EXECUTIVE SUMMARY

The Egyptian Cotton Project, funded by the Italian Agency for Development and Cooperation, is implemented by the United Nations Industrial Development Organisation, UNIDO, in cooperation with the Ministry of Trade and Industry and local and international textile private sector stakeholders.

The project aims at advancing the competitiveness and international market presence of the Egyptian cotton value chain, highlighting aspects of sustainability, inclusiveness and value addition. In this regard, UNIDO has developed a pilot project in a joint effort with Egyptian and Italian industry partners to test quality and market opportunities for recycled cotton yarns produced from post-industrial denim scraps from the Egyptian apparel industry. The pilot relates to operational trials of textile-to-textile recycling by transforming these scraps, which are otherwise considered waste, into spun yarns for weaving and knitting new garments.

Establishing post-industrial cotton recycling as a viable and scalable possibility of reducing cotton-textile waste, as well as to potentially reduce short staple cotton imports in Egypt, requires a solid fact base regarding the benefits and drawbacks of the process. Therefore, Circle Economy has been commissioned within this project to study the environmental and economic impacts of the recycling pilots as well as its potential for scaling.

The environmental assessment of the regenerated cotton yarn shows clear improvements in comparison to the virgin alternatives it has been compared to through the LCA. This is especially clear for the water consumption and the CO₂ emissions contributing to global warming in the scaled scenario. While the total energy demanded for the scaled scenario of the regenerated blended yarn is lower than for the virgin yarns, the fossil resource use

is comparable to the less impactful virgin alternatives. The scaled scenario shows significant improvements in comparison to the pilot trials due to efficiency increases in the recycling processes, while other improvements could still be leveraged further, such as the transition to renewable energy sources or the blending with virgin fibre with a lower environmental impact embedded.

The economic assessment sheds light on the attractive opportunity that bringing a recycled cotton yarn value chain to life at scale in Egypt may present, due to the partially averted cost from short-staple cotton fibre imports. Overall, the marketability of the yarn is promising in terms of quality to compete with other recycled yarns, and given the surge of the demand in Egypt export markets.

The highly positive outlook resulting from this assessment as well as the quality of yarns obtained calls for a continuation of this project to evaluate its scaling opportunities as well as the potential incorporation of these activities and technologies in the public funding roadmap for the coming years.

*Garments with recycled woven fabrics by Albini Group.
Photo: Alessandro Turra*



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1 INTRODUCTION

The Egyptian Cotton Project, funded by the Italian Agency for Development and Cooperation, is implemented by the United Nations Industrial Development Organisation, UNIDO, in cooperation with the Ministry of Trade and Industry and local and international textile private sector stakeholders.

The project aims at advancing the competitiveness and international market presence of the Egyptian cotton value chain, highlighting aspects of sustainability, inclusiveness and value addition. In this regard, UNIDO has developed a pilot project in a joint effort with Egyptian and Italian industry partners to test quality and market opportunities for recycled cotton yarns produced from post-industrial denim scraps from the Egyptian apparel industry. The pilot relates to operational trials of textile-to-textile recycling by transforming these scraps, which are otherwise considered waste, into spun yarns for weaving and knitting new garments.

Cotton is the second most utilised fibre for textiles and apparel, accounting for approximately 23% of the global fibres' market share in 2019.¹ High quality cotton fibre, as well as textiles and garments manufactured from this material, represent a relevant source of industrial output and exports in Egypt. The textiles and clothing sector in Egypt contribute to almost 3% of its GDP, accounting for 27% of the industrial output and 12% of Egypt's overall exports.² Further, the relevance of this sector in the country is supported by the Government of Egypt's vision to upgrade the cotton-based textile sector, which aims, amongst several priorities, to develop the local spinning and weaving industries further and improve their vertical integration, while also increasing

the amount of Egyptian fibre used by the industry. Modernising technologies, such as for ginning and spinning, creating employment, upskilling workers and increasing product exports comprise main priorities for the country.^{3,4} Additionally, this vision is further complemented by ambitions of the national government of increasing public green investment;⁵ as well as two European programmes aimed fostering a green recovery of the Egyptian economy from the Covid-19 crisis through loans for green investment in energy, water and resource efficiency.⁶

Establishing post-industrial cotton recycling as a viable and scalable possibility of reducing cotton-textile waste, as well as to potentially reduce short staple cotton imports in Egypt, requires a solid fact base regarding the benefits and drawbacks of the process. Therefore, Circle Economy has been commissioned within this project to study the environmental and economic impacts of the recycling pilots as well as its potential for scaling.

A life-cycle assessment of the environmental impact of the resulting regenerated blended cotton yarn is used to calculate the contributions to certain impact categories, thereby enabling comparison with alternative virgin cotton yarns. This study provides insights into the following impact categories:



CO₂ emissions (contributing to global warming)



Water consumption



Energy consumption (contributing to cumulative energy demand and fossil resource use)

An economic assessment helps provide a commercial rationale to the introduction of recycling operations in Egypt and sketch out how they could benefit the Egyptian cotton value chain at large. In particular, the focus is placed on three elements that constitute the business case: (1) an investigation of the different cost drivers across the processes; (2) an evaluation of profitability in comparison between a pilot scenario, a scaled scenario and the use of virgin fibre and (3) a broader apprehension of the market potential of the yarn.

These results hope to inform decision making on scaling up the pilot sustainably moving forward.



2

MAPPING THE CURRENT EGYPTIAN COTTON VALUE CHAIN

The textiles and clothing sector in Egypt contribute to almost 3% of its Gross Domestic Product, GDP. One of the most relevant sources for this is related to cotton. The sector is also the second largest industrial sector after agriculture and accounts for 27% of the industrial output and 12% of Egypt's overall exports.⁷

The largest portion of the export value currently comes from early on in the value chain.⁸ In the market year, MY, 2019/2020, around 67 kilo tonnes, kT, of cotton lint have been produced, from a planted area of 100,000 hectares of land.⁹ These fibres are famous for their premium quality of long-staple and extra-long staple, and are most commonly used varieties, Giza 86 and 94, return high yields and comply with quality properties required by spinners.¹⁰ Almost three quarters of this lint (48kT in MY 2019/2020) are exported and the remaining is used as input for the local spinning industry, mainly for home textile products.¹¹

This is because Egypt does not only export raw cotton fibre, but also hosts a mature local ginning, spinning, weaving, knitting, ready-made garment (RMG) and home textiles manufacturing industry. The sector encompassed, in 2017, around 2,153 textile factories, 657 home textile and 2,255 RMG factories, both in state and privately-owned companies.¹² Egypt produces around 105 kT of cotton yarns every year and exports 43% of it.¹³ Most yarns, however, are produced with imported short-staple fibre, used for the RMG sector.¹⁴ Yet, the home textiles sector continues to choose the preferential long-staple local fibres.

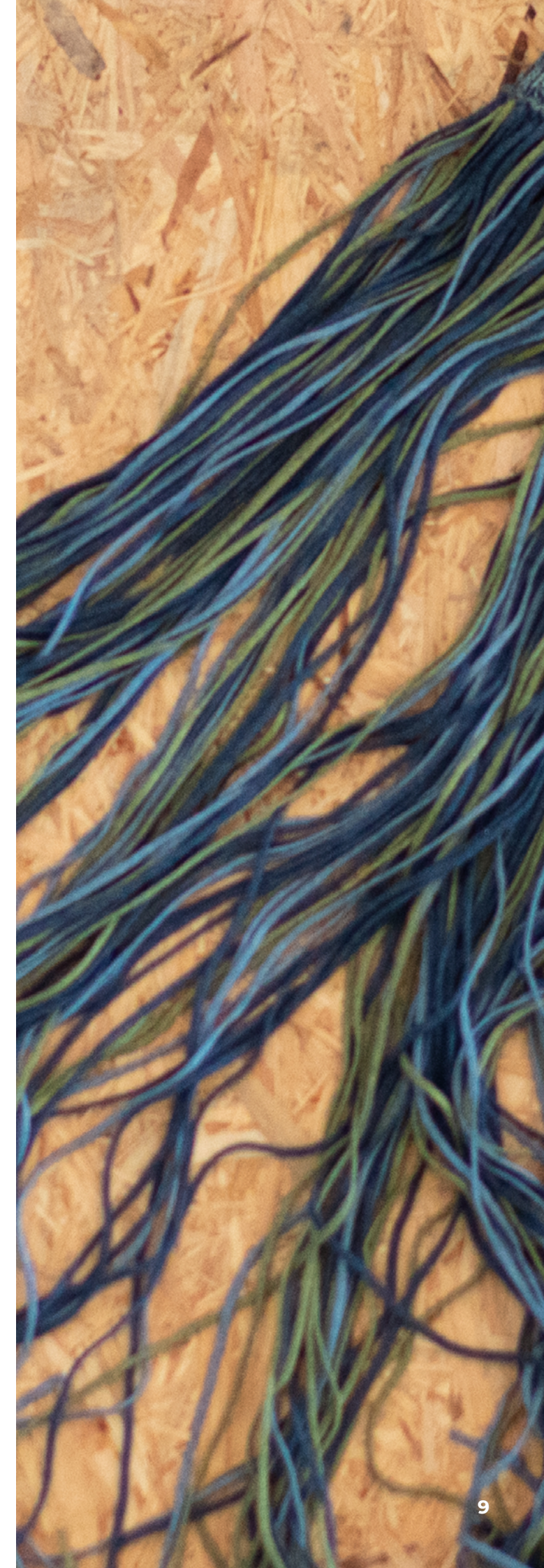
At a later stage in the value chain, around 137 kT of cotton fabrics are produced every year and Egypt is exporting approximately 16% of them in fabric form.¹⁵ The remaining are used for the local RMG and home textile industry, which manufactures 132 kT of

cotton products every year¹⁶ and exports 64% of them, while the remaining products are consumed locally.¹⁷ Although the Egyptian textile and apparel sector is small in comparison to large Asian market players such as China or India, its spinning industry is the largest in the North African region.¹⁸

While at the moment much smaller than the fibre cultivation stages, the development of value-added activities such as yarn, textile, clothing and home textile manufacturing represents a strategic priority supported by the Textile and Apparel Vision 2025, launched in 2015 by the Ministry of Trade and Industry. This is especially the case in relation to updating technology and reaching sizeable market requirements, such as those from the EU and US markets. This relates as well to the rising trend in the international market towards sustainability and circularity. On one hand brands and manufacturers consensus towards sustainability continues to grow, through industry commitments such as the Global Fashion Agenda 2020 Circular Commitments,¹⁹ The Fashion Pact,²⁰ the UN Fashion Industry Charter for Climate Action²¹ and the Ellen MacArthur Foundation Jeans Redesign Guidelines²². This industry movement is further supported by governments around the world that are also starting to roll out circular economy action plans, including the European Green Deal and Circular Economy Action Plan,²³ as well as the Chinese National Leading Action Plan on Circular Development.²⁴

In a time of increased pressures and economic distress driven by the current crisis resulting from the COVID-19 pandemic, Egypt is well positioned as one of the few countries around the world that expects a positive GDP for 2020 and 2021 (~3%).²⁵ This, coupled with a strong national roadmap (Egypt's Vision 2030 Strategy) towards economic competitiveness and diversification; the presence of the full textile and apparel value chain in Egypt; and

a growing market demand for sustainable textiles, further highlights the potential of the Egyptian cotton-textile value chain, its fibre and products, to largely improve the environmental and social sustainability of their production and its resource use to stay competitive within the market. Hence, the possibility to make use of currently wasted resources such as post-industrial cut-off waste generated in RMG or home textile factories, estimated at 23 kilo tonnes per year, to substitute part of imported short-staple fibre, may present itself as an interesting opportunity for the sector to assess both in terms of its economic opportunities, but also in terms of its potential environmental benefits, to support the roadmap of the sector towards a more sustainable future.



CURRENT
COTTON-TEXTILE
VALUE CHAIN

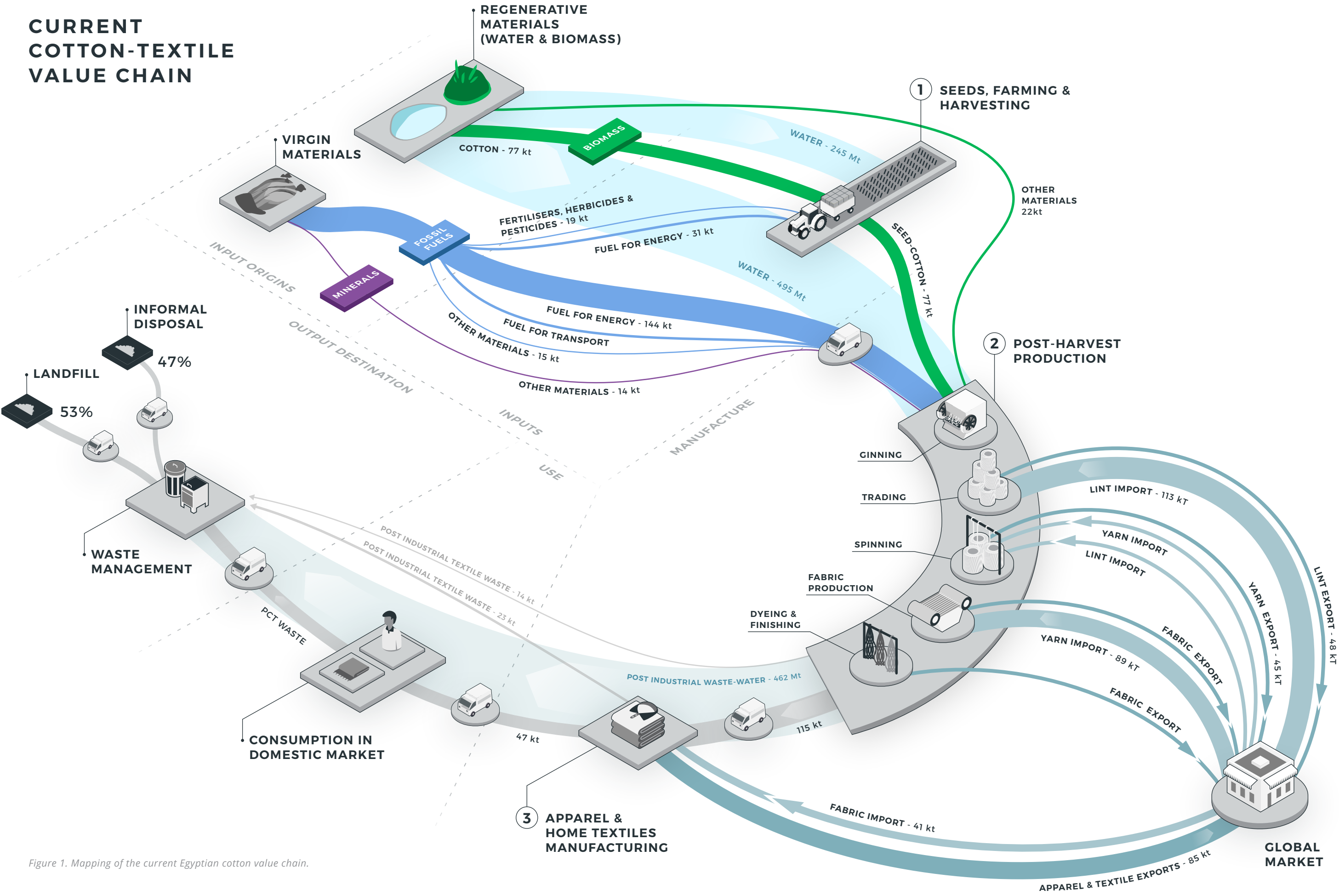


Figure 1. Mapping of the current Egyptian cotton value chain.

3 CIRCULAR OPPORTUNITIES: RECYCLING POST-INDUSTRIAL COTTON WASTE

Post-industrial cotton waste is becoming more commonly used as an input for regenerated cotton yarns, although this is yet not a process at scale for the industry. Some companies in Egypt already have experience in incorporating cotton scraps from manufacturing back into yarns.²⁶ Others have set up recycling facilities with a capacity to recycle 8,000 tonnes of cotton waste every year.²⁷

There is also a clear market potential for the continued development of these regenerated yarns, as brands are already incorporating this content into their clothing and home textile collections. In 2018, the Inter IKEA Group, the H&M Group, Nike Inc., ALDI GmbH, and Decathlon were the brand groups using the largest volumes of recycled cotton, coming mostly from post-industrial sources, according to the

2018 Textile Exchange Corporate Fiber & Materials Benchmark.²⁸ The establishment of the regenerated content within fashion and textile products is further driven and supported by industry-wide commitments to circularity and sustainability such as the Global Fashion Agenda 2020 Circular Fashion System Commitment with 86 signatories,²⁹ the Denim Alliance with around 30 participating brands and manufacturers,³⁰ and the Jeans Redesign Guidelines with over 60 participating brands, manufacturers and mills.³¹ Moreover preferential benchmarking tools that assess and score the different fibres based on their environmental impacts further support the uptake of recycled cotton. Some of these tools are the HIGG, or the Textile Exchange Corporate Fiber & Materials Benchmark.³²

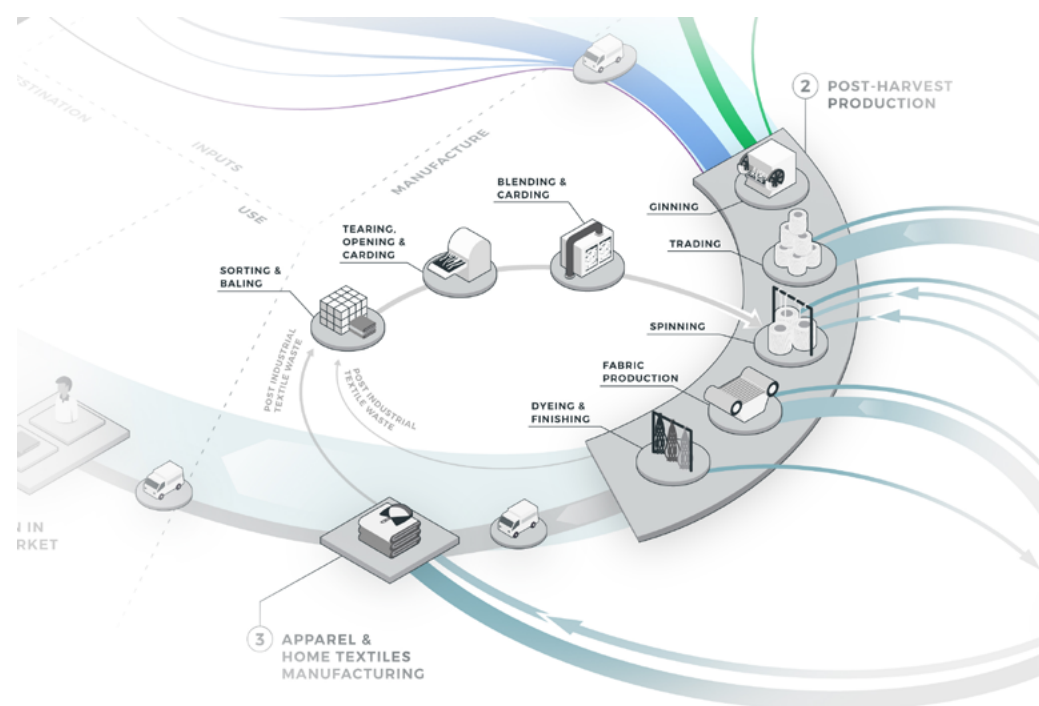


Figure 2. Value chain stages for post-industrial cotton recycling. The full flowchart for the processes involved in the pilot trial can be found in the Technical Annex of this report.

Post-industrial cotton comprises cotton textile by-products from the manufacturing stage, such as clipping waste, offcuts, roll ends and remnants. Within post-industrial cotton, denim provides a homogeneous feedstock to be recycled because of its fairly consistent indigo blue colour and its fibre composition chiefly composed of cotton. However, denim also poses certain challenges for mechanical recycling, such as its tight twill weave, or its limitation in terms of colour palette. Other promising post-industrial cotton feedstocks are knitted cotton garments such as t-shirts or the remnant fabrics from their production. The preference for coloured or undyed fabrics will depend on the final outcome sought and the colour palette that wants to be achieved.

3.1 THE PILOT

In order to assess the type and quality of yarns and fabrics that could be obtained with recycled post-industrial cotton from the Egyptian apparel industry, a pilot trial was conducted. More than 2 tonnes of pure cotton denim scraps and cotton/elastane scraps were collected from an Egyptian jeans manufacturer, T&C Garments,³³ sorted, baled and transported by sea from Egypt to Italy. In Italy, Marzoli Textile Engineering - Camozzi Group³⁴ together with a textile recycling partner teased, opened and carded the scraps into a regenerated cotton sliver.

The regenerated sliver obtained from the recycler was then shipped back to Egypt to a spinner, Filmar Nile textile, sister company of Filmar SpA,³⁵ who then blended it with Egyptian long-staple virgin fibres in a blowroom, carded once more, and spun it into yarn. An estimate of 16% of the total fibre input was lost as waste during the blending, carding and spinning process. During the pilot this fibre waste was not sold, however, when processing these materials in a larger scale, this current waste stream could have certain market applications as a byproduct for nonwovens for geotextiles and insulation.

The resulting yarn is a Ne 30/1 compact blended cotton yarn. It is composed of 50% recycled content and 50% virgin Egyptian

cotton input. This mix shows quite a high presence of recycled content compared to industry averages which are closer to the range of 15-40%.³⁶ However, considering that the virgin cotton (Giza 86) fibres were long-staple Egyptian fibres and could compensate for the shorter fibres from the recycled input, the performance of a higher percentage of recycled content wanted to be trialled by the partners. The final yarns were developed in three different colours by blending the recycled fibre with virgin fibres dyed in different colours. The resulting yarn colours were chosen by a fashion designer/product developer working for an important Italian luxury brand and according to fashion trends. The colours chosen were light blue, blue and green.

At a final stage, Albini Group,³⁷ a manufacturer of woven textiles received packages of each colour of the yarn and tested it in the weft of a woven fabric with a 3/1 twill structure. The warp of this fabric was made from a 60/2 raw virgin cotton yarn. Placing the recycled yarn only on the weft has been intentional in order to reduce warp breaks due to the weaving tension being too high for the strength of the recycled yarn. This entails that the final fabric has approximately 25% recycled content, as the warp is made from virgin yarn. Three fabrics with a rustic appearance, of about three metres each, were obtained. The yarns can be used for simple weaves and seem interesting for products that require a rustic or casual look. Their quality is comparable to other fabrics containing mechanically recycled yarns, with some visible irregularities. Additional tests could be conducted to evaluate the creation and performance of fabrics with higher percentages of recycled content, which could in turn increase the competitiveness of the fabrics in the market for recycled fabrics.

The twisting of the yarns was also tested by the spinner, and knitted into garments as a technical trial. The knitting of the garments was developed through workshops led by an Italian fashion designer, Marina Spadafora,³⁸ in collaboration with young designers from the Cairo Fashion Design Center.³⁹

3.2 THE SCALED SCENARIO

In order to assess the potential environmental and economic impact that recycling post-industrial cotton waste activities can have in Egypt, the pilot setup was scaled up to match a feasible industrial setup in the country. The key underlying assumption in this scenario is that all operations happen in Egyptian soil. Assumptions have also been made for the scale of the recycling and spinning operations, expecting the recycling operations to produce around 3 kilo tonnes per year of recycled fibre, that when considering a 50% recycled 50% virgin yarn, could feed around 25,000 spindles. This size of shredding unit would also be at the minimum end of what would be required to reach economic feasibility.

The recycling operations are proposed for a facility that can take up to 450 kg of material input per hour. The downtimes in the scaled scenario decrease by 17% in comparison to

those in the pilot scenario. Finally, textile waste from the recycling process has been significantly reduced due to gains in working experience and process efficiencies linked to operational scale. In this scaled scenario the share of fibre loss is 21%, whilst in the pilot the textile waste generated added up to 86% of the material input.

Moreover, an innovative process for refining the recycled carded fibre, with an additional vitamins injection was tested by the project partner during this project, and is recommended to be added when scaling these processes. Lastly, in the scaled scenario, the spinner receives the refined regenerated fibre from the recycler and first blends it in equal amounts with virgin dyed cotton fibre, which is later carded and spun to obtain an untwisted Ne 30/1 blended compact cotton yarn. The spinning facility has an estimated throughput of 722 kg/h of fibre input (361 kg virgin and 361 kg regenerated), and can serve 25,000 spindles in a 10,000 m² facility.

3.2.1 ENVIRONMENTAL ASSESSMENT

The environmental impact of the regenerated cotton yarn has been compared to a range of virgin cotton yarns through Life Cycle Assessment (LCA). The virgin yarns are already modelled in Ecoinvent database v.3.6,⁴⁰ and can be found in a range from a more sustainably cultivated one with lower impacts to another one with the largest environmental impacts available. The full LCA reporting with detailed explanations and descriptions can be found in the technical annex of this report.

Water consumption, CO₂ emissions contributing to global warming and energy consumption contributing to cumulative energy demand and fossil resource use are the impact categories chosen for this assessment. In this section an overview of the results obtained through this analysis as well as their interpretation is presented for a functional unit of 1 kg of untwisted cotton yarn.

certain renewable energies, such as the use of solar panels which is more present in Italy than in Egypt, requires additional water for the cleaning of the panels.

WATER CONSUMPTION

Reference unit: m³

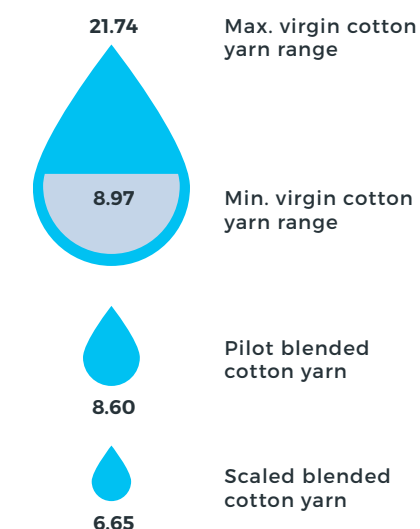


Figure 4. LCA results of all functional units for the water consumption impact category. For the virgin cotton yarns, data is extracted from the Ecoinvent database v.3.6

WATER CONSUMPTION

Water consumption for the regenerated blended yarn is significantly lower than the average water consumption per kg of virgin cotton yarn (Figure 4). This is due to a reduced need for growing new crops for producing fibre. Nevertheless, as the blended yarn is a combination of both virgin and regenerated cotton, the efficiency in the water used to grow and process virgin fibres for that blend is extremely important and influences the total impact of the blended yarn on water consumption. Further, the water consumption of the scaled set-up yarn is lower than that of the pilot due to process efficiency gains and changes in location from Italy to Egypt for some upstream processes. The impacts related to changes in location mainly relate to differences in the electricity grid mix of the countries, as

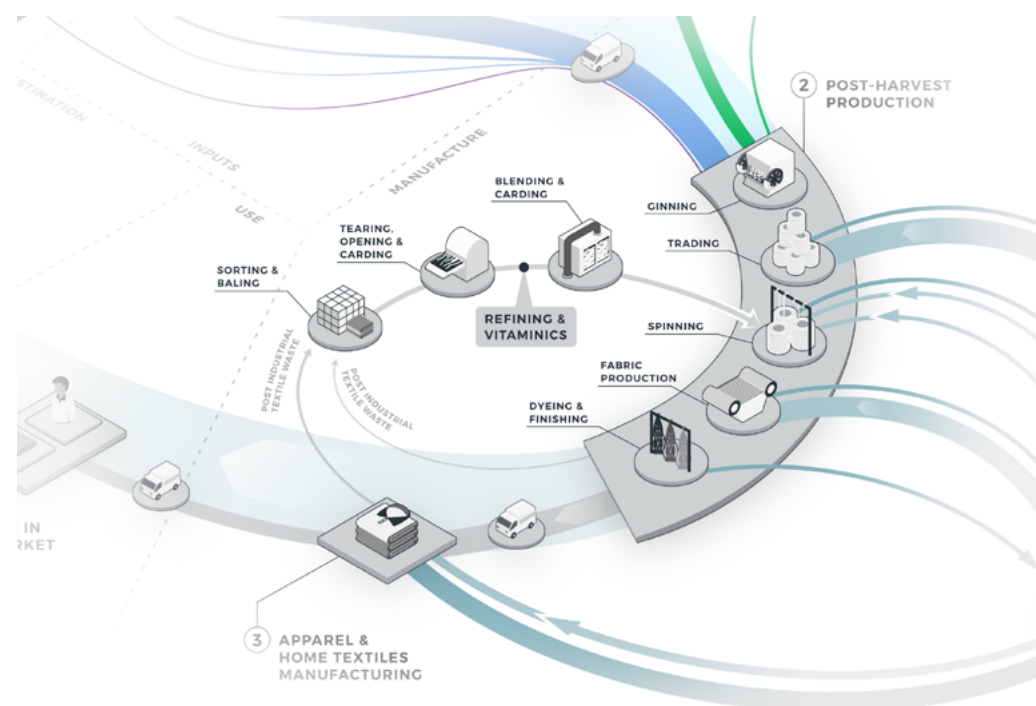


Figure 3. Post-industrial cotton recycling process with the addition of the refining process in the scaled scenario. The full flowchart can be found in the Technical Annex of this report.

CO₂-EQ EMISSIONS

CO₂-eq emissions also perform better and sit below the minimum virgin cotton yarn range for the blended cotton yarn in the scaled scenario (Figure 5). This is on one hand due to the reduced need for crop growing, as this stage as well as the yarn dyeing and spinning account for a significant portion of global warming contributions in virgin cotton yarn.⁴¹ On the other hand, and in comparison with the results from the pilot, the impact significantly lowers due to increased efficiency in the recycling and spinning processes, therefore reduced electricity consumption. The reduction of the waste produced per kg of fibre input, and the fibre waste from blending, carding and spinning processes turned into a byproduct with potential to be used in geotextiles and insulation for the construction sector further support this improvement.

GLOBAL WARMING
Reference unit: kg CO₂ eq

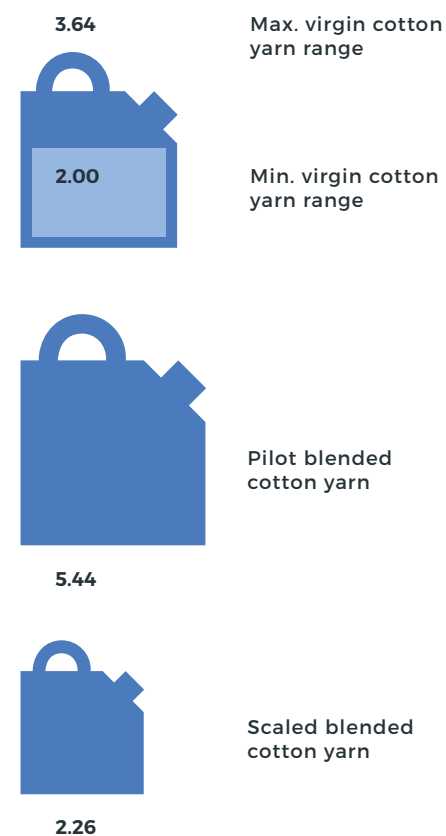


Figure 5. LCA results of all functional units for the global warming impact category. For the virgin cotton yarns, data is extracted from the Ecoinvent database v.3.6

ENERGY

The total energy demand in a scaled set up for the regenerated blended yarn requires less energy, beneath the virgin yarn ranges. **The fossil resource use** sits in the lower end of the virgin alternatives, achieving a great reduction in comparison to the pilot due to efficiency increases in the recycling processes (Figure 6). However, shifting all operations to Egypt currently prevents from more significant savings, as the electricity grid in the country is largely dependent on fossil fuels. Observing the pilot, its negative performance is highly driven by inefficiencies and waste generated during the piloting processes, which are understandable and expected within the scope of a pilot trial that aims to test and achieve a certain quality of yarn with a small volume of material input.

FOSSIL RESOURCE SCARCITY
Reference unit: kg oil eq



TOTAL ENERGY DEMAND
Reference unit: MJ

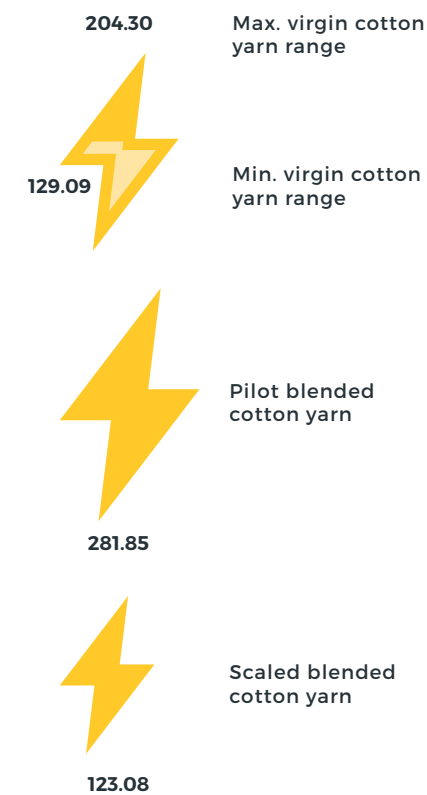


Figure 6. LCA results of all functional units for the total energy demand and fossil resource scarcity impact categories. For the virgin cotton yarns, data is extracted from the Ecoinvent database v.3.6

3.2.2 ECONOMIC ASSESSMENT

Having confirmed the environmental benefits of using a blended yarn consisting of both virgin and recycled fibres, the next step in affirming the initiative's value to the Egyptian industry has been to conduct an analysis into its commercial viability. In particular, this involved an assessment of the overall profitability of the operations of a recycled yarn value chain along with a deepdive into the profitability's main constituents: the operations' cost structure as well as the

ability of the final yarn to achieve competitive prices in the market. In this assessment, comparisons were drawn between the pilot scenario, a scaled up scenario highlighting also comparative costs of using conventional virgin yarn. The following sections aim to provide an overview of the results of the analysis. Detailed information on the system definition and life cycle perspective can be found in the technical annex.

3.2.2.1 COST BREAKDOWN

While the potential achieving higher prices on markets through differentiation is limited by their competitive, globalised nature, it is worthwhile exploring the potential to achieve additional efficiencies in the cost structure and thus improving the commercial opportunity associated with recycled yarn. Costs were calculated following a Life Cycle Costing (LCC) approach, meaning that the same system definition adopted in the Life cycle Assessment is applied with an economic focus. This entails all costs associated with the procurement, recycling and spinning operations of the fibre until sold as yarn. In contrast to the environmental impact assessment, the LCC approach also considers the building and accessories used as these represent considerable capital expenditures that need to be earned back. However, these considerations only apply to the recycling activities set up in Egypt as no new plant was set up specifically for the pilot and Egypt already has capacity to accommodate the processes associated with spinning.

Following the LCC approach therefore means that the cost breakdown presented below includes both the variable costs associated with each unit of production as well as a proportional share of the fixed costs which is calculated using their life cycle productivity. This section presents a breakdown of cost drivers per process, followed by a comparative analysis of key cost drivers.

In the **pilot scenario**, represented in *Figure 7*, the highest costs are accrued during the recycling operations. To give a clear indication of the share of electricity, labour, equipment and material costs pertained to each stage of the value chain, these are further distinguished in *Figure 7* below. In the pilot scenario, labour is the most significant cost driver contributing almost €7.50, or 55% of total costs followed by electricity costs (25%) and raw material costs (15%). The weight of labour and energy costs stems from the high demand for both of these during the pilot trials coupled with comparably higher costs of both labour and energy in Italy. Relatively high labour and energy costs incurred during spinning can be explained by the inclusion of preparation processes falling under spinning as well

as different test trials. While the costs of buildings and accessories were not considered under the pilot scenario, these are considered minimal.

This picture changes significantly under a **scaled scenario** of the operations. Significant efficiencies can be achieved and driven by lower costs for labour and electricity in Egypt, we can observe significant reductions in variable costs. These lead to an overall reduction in costs down to €2.70 per kg of yarn, corresponding to a decrease of more than 80% in comparison to the pilot scenario. The highest share of costs is accrued due to the procurement of virgin fibre.

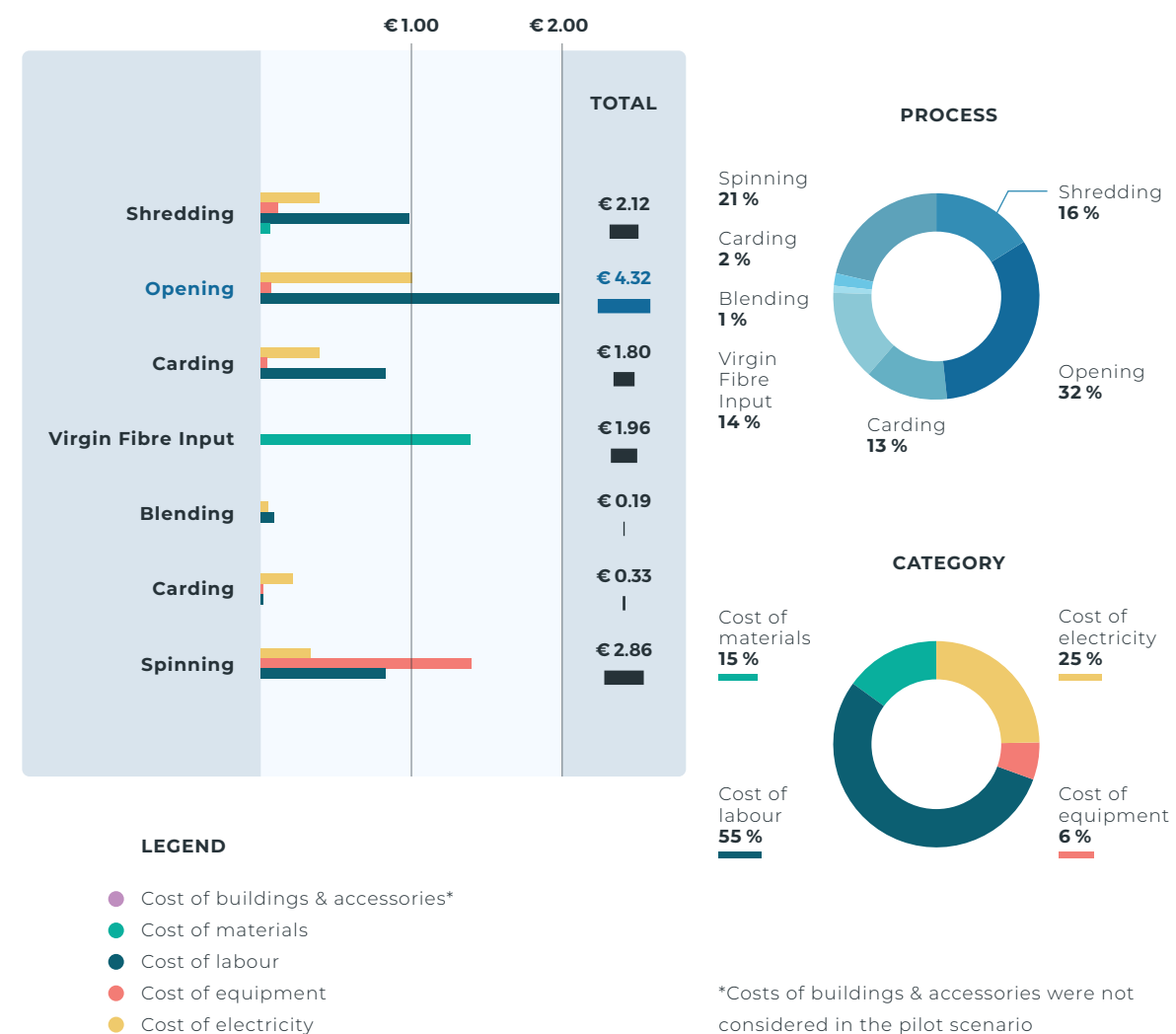


Figure 7: Comparison of key cost drivers in pilot scenario

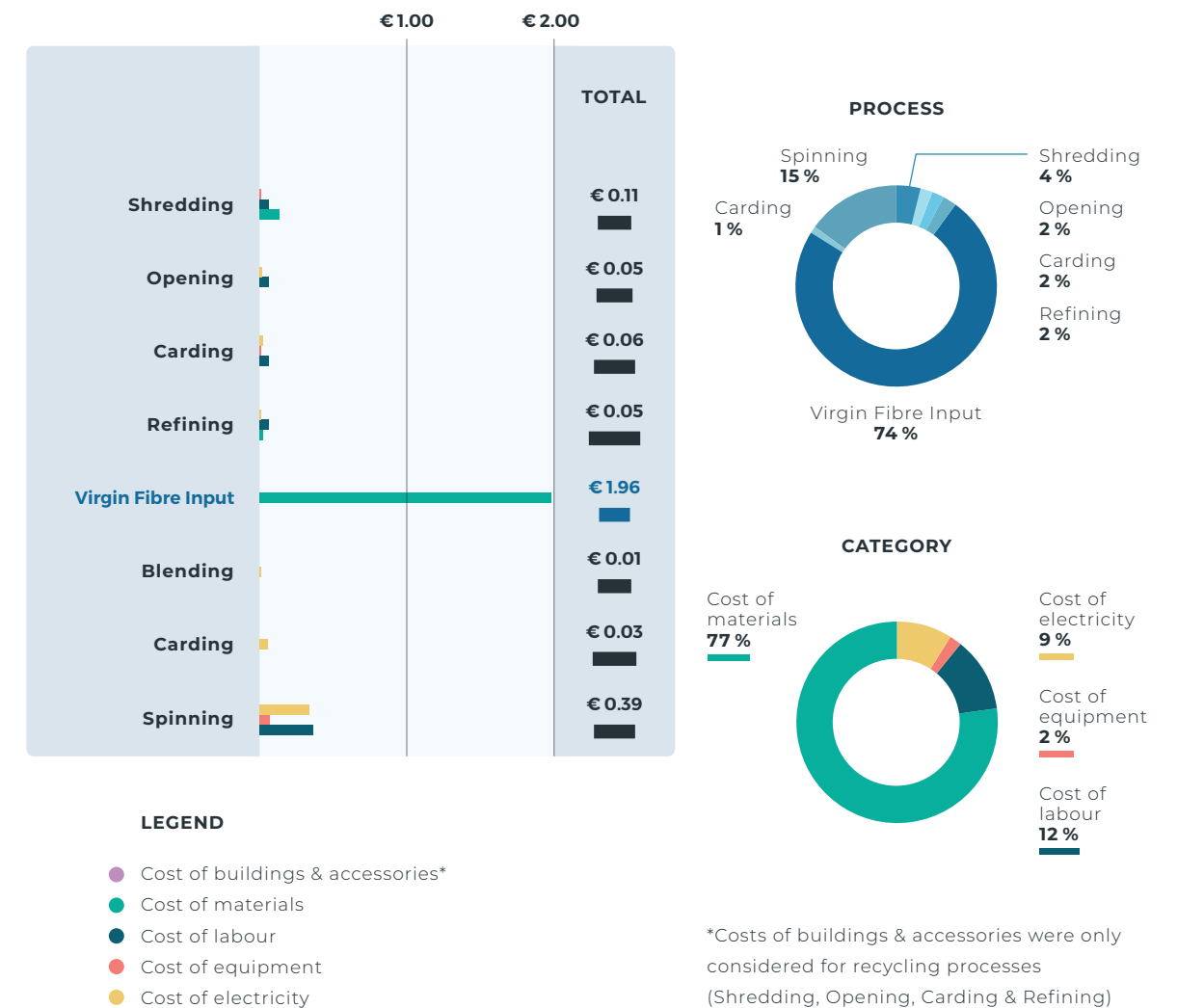


Figure 8: Comparison of key cost drivers in scaled scenario

To understand where potential for additional cost-reductions might lie, a breakdown into cost drivers was also performed on the scaled scenario, results are illustrated in *Figure 8*. This figure clearly points to two key cost drivers: (1) the cost of virgin fibre input (making up more than 70% of total costs) and, even though much less impactful, (2) the spinning process. Within the spinning process a high demand for labour and electricity and the included preparation processes are the source of this. Shifting to increasingly more cost-effective renewable energy sources could

help to reduce these even further. Costs for building & accessories were only considered for the recycling activities that would need to be set up in Egypt. When spread over the lifetime production capacity of the building & accessories are generally only marginal cost drivers as is exemplified by *Figure 8*.

As can be observed in the significant cost reductions, bringing a recycled cotton yarn value chain to life in Egypt presents an attractive opportunity due to relatively lower costs for labour and electricity.

In order to draw comparisons with the cost structure of virgin cotton yarns, the International Product Cost Comparison prepared by the International Federation of Textiles Manufacturers in 2018 was consulted. As is illustrated in *Figure 10*, the cost structure of conventional **virgin cotton yarn** is also characterised by a dominating cost of raw materials.

Average total costs for NE30 yarns (Spinning Ring) vary significantly between different countries of origin ranging between €2.40 per kg in Pakistan and average total costs in Egypt exceeding €4.00 per kg.⁴² These average costs are subject to significant variance on a national level, but illustrate the significant differences in total costs and

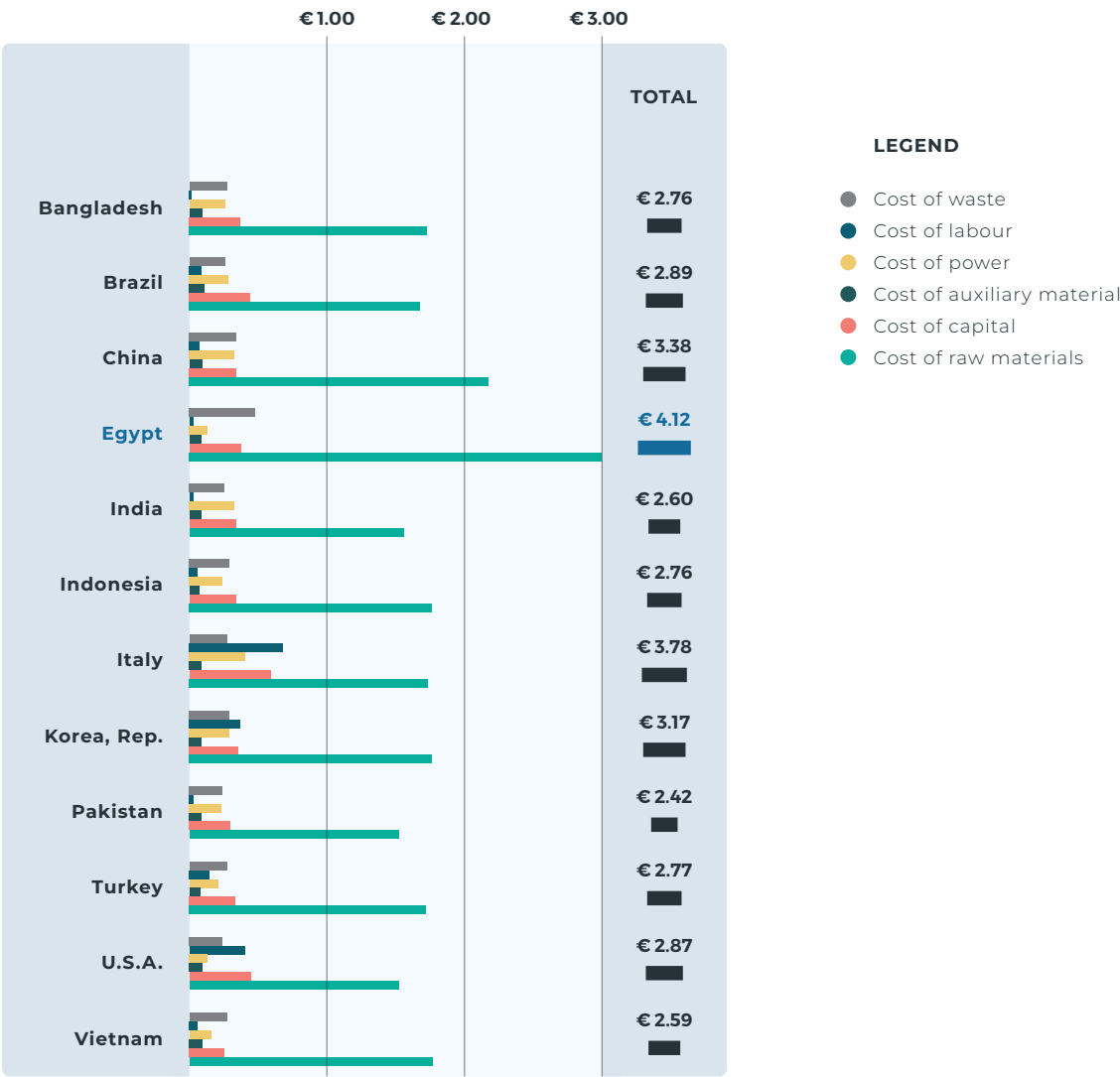


Figure 9: Comparison of key cost drivers in production of conventional virgin cotton yarn (Spinning Ring NE30) , Source: International Production Cost Comparison 2018, International Textile Manufacturers Federation

sketch a range within which these fluctuate. Given these values and the consistently dominating weight of raw material costs, from a purely commercial perspective already, there seems to be a clear benefit to replacing the need for costly raw materials as much as possible.

3.2.2.2 PROFITABILITY ASSESSMENT

A **profitability assessment** has been conducted for the overall operations in the pilot scenario as well as in a scaled scenario. In this report, attention will be focused on the profitability of the overall process, therefore, assuming that there are no value chain transactions between different partners that may charge additional margin.

Overall profitability was assessed on a per kilogram basis and calculated by deducting all costs associated with the production of the yarn from the expected price that could be achieved per kg of blended yarn. This is reflected in the waterfall diagrams in figures 10 and 11. *Figure 10* represents the profitability considering the parameters of the pilot scenario as described in section 4 of the technical annex.

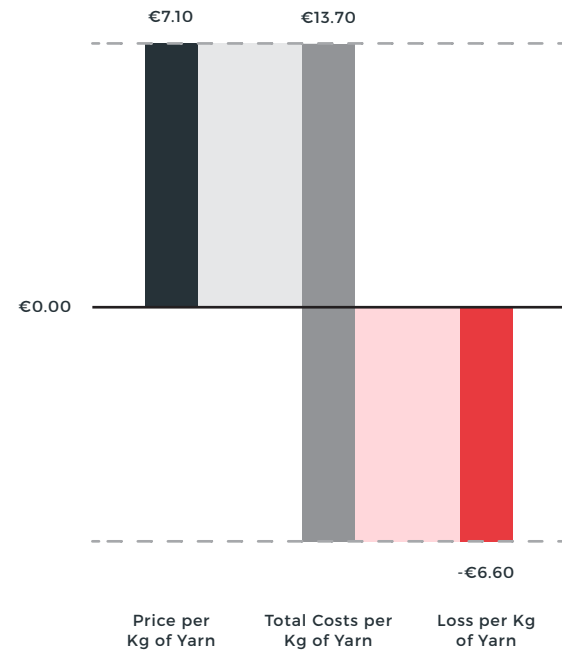


Figure 10: Profitability per kg of output in pilot scenario

The comparably low throughput volumes in the **pilot scenario** cause significant **inefficiencies** across operations that also materialise in the cost profile. Most prominently, these costs relate to production costs in Italy where both energy and labour costs far exceed those in Egypt. Deducting all costs considered, the pilot operations reach a **loss of 6.60€ per kilogram of yarn output**.

In contrast, *Figure 11* shows how once **scaled up**, the production of recycled yarn has a **positive business case**. Immense savings are achieved based on lower costs for energy and labour in the recycling steps of tearing, opening, carding and refining. By far the most significant cost under this scenario relates to the procurement of virgin cotton fibres. Overall, the scaled up version of the operations achieves an **estimated gross profit of €4,20** which translates to a **gross margin of 59%**. Given that national transport costs as well as existing buildings and accessories are not factored into this, the margin will be slightly lower in reality.

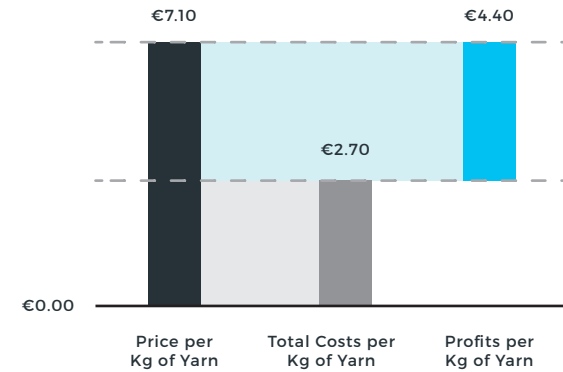


Figure 11: Profitability per kg of output in scaled scenario

Finally, the price that is assumed here may be subject to market fluctuations or competitive pressures. A break even (on a per-kg level) can be achieved at a price of €2.70 per kg, when assuming stable costs. The following section investigates what the key drivers of these costs are.

3.2.2.3 EVALUATION OF MARKETABILITY

Lastly, this economic assessment aims to shed some light on the marketability of the yarn that would result from the described and analysed activities. In this section we reference the main aspects affecting the marketability of the yarn as described in the results of the tests conducted by the operating partners of the spinning as well as the weaving activities.

The quality is similar to other recycled yarns with lower shares of recycled content. The pilot yielded yarn quality that is on par with recycled yarns that are currently available on the market. Crucially, though, these available yarns usually exhibit shares of recycled fibre of 15-40% as opposed to the 50% present in this pilot's output. Further testing with slightly lower shares of recycled fibre may therefore prove to deliver even higher quality and therefore be applicable to finer weaves, such as shirting. In addition, tests including fibre of higher quality cotton scraps or other, longer staple fibres such as wool or cashmere may further increase the quality of yarn outputs.

The quality is different to cotton yarns made from virgin fibres. In comparison to knitted and woven fabrics that are made exclusively using virgin cotton yarn, the quality of the pilot output exhibits irregularities and a more rustic appearance as is typical for fabrics based on recycled fibres. This relates to technical limitations that are found with any mechanically recycled yarn. With its current quality, as regards orthogonal fabrics, it can be used for simple weave applications such as more casual wear. It can therefore compete with more coarse yarns that are already on the market. Lastly, the blended nature restricts colouring of fabrics to melange tones.

There is growing demand for recycled yarn from the market. As the fashion industry continues to focus on alleviating the environmental issues caused by the sector, demand for recycled content is growing across market participants. This includes recycled yarns suitable for different types of garments ranging from casual wear to

high quality shirting as well as from medium price markets all the way to luxury brands. In particular, young designers and new labels tend to prioritise sustainability in sourcing and aim to leverage this as a differentiating factor on markets.

Current estimates from partners suggest that prices that can be achieved with the recycled yarn may broadly range from € 3 up to € 8 per kg on commercial markets. Based on the current cost structure, this indicates that, bearing in mind further testing is needed, the production of recycled yarn can be a profitable opportunity for Egypt and compete with comparable yarns on the market.

*Garments with recycled woven fabrics by Albini Group.
Photo: Alessandro Turra*

4 RECOMMENDATIONS FOR SCALING

The following recommendations emerge from the environmental and economic assessment of the development of regenerated cotton yarns at scale in Egypt. These recommendations have been further reviewed and validated by discussions with the pilot partners as well as a diverse group of Egyptian stakeholders participating in the Egyptian Cotton Project.

4.1 FOR INDUSTRY

- **Enhance and promote further testing to develop improvements in yarn and fabric performance, including aspects of both environmental performance and product quality.** The yarn quality obtained through the pilot is already comparable to other recycled yarns currently available on the market. However, mechanically recycled fibres usually exhibit significant fibre shortening. Therefore, trialing different shares of recycled content in the blended yarns may support in finding the best suitable yarn count for different markets and product groups. Performance improvements can also be tested by trialing different types of post-industrial cotton waste, including scraps coming from knitted cotton garments, and different types of material blends with other materials. In order to conduct these trials, **develop partnerships with brands and retailers to holistically design products for circularity, with a demand-driven approach.**
- **Ensure virgin cotton fibre used has the lowest possible environmental impact.** Sourcing the most sustainably grown virgin cotton available for the blend, or potentially other types of regenerated fibres, such as viscose from chemically recycled cotton waste, will have the best results in terms of environmental

impact. As the share of virgin fibre represents in this case 50% of the blend, it will still significantly influence the final environmental impact of the yarn.

Contribution of virgin fibre to the regenerated blends

The LCA results highlight that the contribution of the virgin dyed fibre to the environmental impacts carried by the regenerated blended yarn is significantly high. For water consumption the virgin fibre carries 97% of the impact, while for CO₂-eq emissions it carries 65% and for fossil resource scarcity 52% of the environmental impact.

- **Partner with chemical industries to trial low impact dyeing processes for regenerated yarns.** The dyeing of the virgin cotton fibre used for this scenario further worsens the environmental impact of the final yarn. Therefore, testing the quality and aesthetics of yarns using undyed raw virgin cotton or partnering with chemical industries to test lower impact dyeing processes is highly recommended.
- **Ensure the sustainability of by-products along the cotton value chain.** It is essential that the market for the byproducts of the cotton fibre value chain is sustained, as these byproducts provide value to what otherwise would be considered 'waste' to this specific value chain. All of these goods (main and by-products) share the environmental impacts embedded during the operations for the manufacturing of the yarns.

The loss of this market, hence, would also influence the consideration in terms of environmental impact of the regenerated yarns.

What if the waste generated in the recycling and spinning processes had no economic value?

The LCA results evidence that if the textile waste generated during the recycling and spinning of the regenerated yarns could not be used as a by-product for diverse industries and markets (construction, automotive, geotextiles, cosmetics), the impact embedded in the regenerated blended yarn would be higher. For the four impact categories assessed in this LCA (water consumption, global warming potential, fossil resource scarcity and total energy demand) there would be a 5-6% increase in the impacts embedded in the regenerated blended yarn.

4.2 FOR GOVERNMENT

- **Foster dialogue** among relevant public and private partners to assess and evaluate existing legislation related to waste handling, and the import and export of waste. Revisions of the end-of-waste criteria to match the current industry developments for materials previously considered waste may further support the handling of feedstock for recycling. Moreover, an **evaluation of collecting and sorting models** for post-industrial and eventually post-consumer textile waste that can be applicable to Egypt will support the development of the necessary infrastructure to conduct these recycling activities at scale.
- **Raise awareness** among industrial partners on the benefit to invest in circularity from raw material to design and production of finished garments. In this way, **promoting partnerships** with brands and retailers that make massive use of cotton and are committed to increase their uptake of recycled products is key for the scaling of these activities locally.
- **Leverage more systemic changes for the whole sector such as transitioning to renewable energy sources.** There is a great potential in hosting all operations within the same region or country ie. Egypt. However, considering long-term plans for renewable energy sources for (some of) the operations across the value chain may significantly improve the environmental performance of the yarns in terms of fossil resource scarcity, global warming potential and total energy demand. The feasibility of the implementation of the diverse types of renewable energy sources for the specific Egyptian context needs to be further assessed and understood, and these plans could build on existing initiatives in manufacturing sectors such as the 'Utilizing Solar Energy for Industrial Process Heat in Egyptian Industries (SHIP)' project.⁴³

What if the electricity grid mix in Egypt was further transitioned to renewable energy sources?

The results of a sensitivity analysis performed during the LCA show that if the operations for recycling and spinning of the regenerated cotton blend were to be supplied by a renewable energy source (in this case solar), the impacts for fossil resource scarcity will be lowered by 44%, as will those for global warming potential by 30%. The total energy demand will also be 21% lower in this scenario than in one fueled by fossil-based energy sources. On the other hand, specifically for solar energy, water consumption increases by 13% mainly due to water used for the cleaning of the panels.

- **Invest in the cotton-textile value chain and assess the availability of "green" public investment** in setting up recycling infrastructure in Egypt. Ambitious goals are in place to double the share of "green" public investments to a total of 30% by the forthcoming fiscal year. With the large share of the cotton-textile value chain that is publicly owned, there is an immense opportunity to attract funding for further trialing and scaling up the recycling operations. Driven by the Ministry of Economic Development and the Ministry of trade and Industry, criteria and guidelines for "green" investment projects are currently under development and expected to be available in the near future. On a global scale, several development initiatives are dedicating significant focus to the use of solar heat in industrial processes (SHIP) and the development of circular textile supply chains in the southern Mediterranean.^{44, 45}



Recycled yarns developed by Filmar Spa.

5 WAY FORWARD

The environmental assessment of the regenerated cotton yarn shows clear improvements in comparison to the virgin alternatives it has been compared to through the LCA.

This is especially clear for the water consumption and the CO₂ emissions contributing to global warming in the scaled scenario. While the total energy demanded for the scaled scenario of the regenerated blended yarn is lower than for the virgin yarns, the fossil resource use is comparable to the less impactful virgin alternatives. The scaled scenario shows significant improvements in comparison to the pilot trials due to efficiency increases in the recycling processes, while other improvements could still be leveraged further, such as the transition to renewable energy sources or the blending with virgin fibre with a lower environmental impact embedded.

The economic assessment sheds light on the attractive opportunity that bringing a recycled cotton yarn value chain to life at scale in Egypt may present, due to the partially averted costs from short-staple cotton fibre imports. An overall reduction in costs is possible for a scaled scenario down to €2.76 per kg of yarn, as well as an estimated gross profit of €4,20 which translates to a gross margin of 59%. Given that national transport costs as well as existing buildings and accessories are not factored into this, the margin will be slightly lower in reality.

Overall, the marketability of the yarn is promising in terms of quality to compete with other recycled yarns, and given the surge of the demand in Egypt export markets. The potential testing of lower shares of recycled content as well as the blending with virgin undyed cotton will assess whether the regenerated yarn developed in this pilot has the potential to outperform other recycled yarns.

A strong national roadmap (Egypt's Vision 2030 Strategy) towards economic competitiveness and diversification, coupled with a good position to attract nearshoring from Asian countries due to the disruption of the global textile value driven by the crisis resulting from the COVID-19 pandemic, places Egypt in an attractive position to develop its cotton-textile value chain to its full potential.

Further, the full vertical integration of the cotton-textile industry and capacity to make use of currently wasted resources such as post-industrial waste generated in RMG or home textile factories, allows Egypt to improve the environmental sustainability of the sector and raise competitiveness.

The highly positive outlook resulting from this assessment calls for a continuation of this project to evaluate its scaling opportunities as well as the potential incorporation of these activities and technologies in the public funding roadmap for the coming years.



*Recycled knitted design by Marina Spadafora.
Photo: Alessandro Turra*

1. INTRODUCTION

a. Context

The Egyptian Cotton Project, funded by the Italian Agency for Development and Cooperation, is implemented by the United Nations Industrial Development Organisation, UNIDO, in cooperation with the Ministry of Trade and Industry and local and international textile private sector stakeholders. The project aims at advancing the competitiveness and international market presence of the Egyptian cotton value chain, highlighting aspects of sustainability, inclusiveness and value addition. In this regard, UNIDO has developed a pilot project in a joint effort with Egyptian and Italian industry partners to test quality and market opportunities for recycled cotton yarns produced from denim scraps from the Egyptian apparel industry.

However, establishing cotton recycling as a viable and scalable alternative to virgin cotton requires a solid fact base regarding the benefits and drawbacks of the process. Therefore, Circle Economy has been commissioned to study the environmental and economic impacts of the recycling pilot as well as its potential for scaling. The pilot relates to operational trials of textile-to-textile recycling by transforming denim scraps which are otherwise considered waste, into spun yarns for weaving and knitting new garments. An in-depth life-cycle analysis of the environmental impact of the recycled cotton yarn was used to calculate the contributions to the relevant impact categories, thereby enabling comparison with an alternative virgin cotton yarn. Based on these results, the consortium hopes to inform decision making on scaling up the pilot sustainably going forward.

b. Pilot description

The pilot has been conducted to assess the type and quality of yarns and fabrics that could be obtained with the recycled post-industrial cotton inputs. 2218 kgs of pure cotton denim scraps and cotton/elastane scraps were collected from T&C Garments,⁴⁶ an Egyptian jeans manufacturer. These were sorted, baled and transported by sea from Egypt to Italy. Once the scraps arrived at the facilities of Marzoli Textile Engineering - Camozzi Group,⁴⁷ they coordinated with a textile recycling partner to tear, open and card the scraps into a regenerated cotton sliver. For the purpose of the pilot, this processing was conducted in Italy. Through an initial trial, 294 kgs of scraps were used to create 40 kgs of regenerated cotton sliver, indicating a throughput efficiency of approximately 14%. During the tearing process, 11% of the total input material was lost as waste that could not be valorised. During the opening and carding processes, the remaining 75% of the total initial material input remained in the machinery as filtration unit waste. Nevertheless, this material was sold and repurposed as a by-product for use in nonwovens (eg. insulation or geotextiles) as well as hydrophilic cotton (eg. for hygiene and cosmetic products such as swabs).

The regenerated sliver was shipped back to Egypt to Filmar Nile textile, sister company of Filmar SpA, an Italian spinning group with operations in both Egypt and Italy.⁴⁸ The regenerated sliver was blended with Egyptian long-staple virgin fibres in a blowroom, carded once more, and spun into yarn. The resulting Ne 30/1 compact cotton yarn was a 50% recycled 50% virgin blend.

This mix shows quite a high presence of recycled content compared to industry averages which are closer to the range of 15-40%.⁴⁹ The estimate of another 16% of the total fibre input was lost as waste during the blending, carding and spinning process. During the pilot this fibre waste was not sold, however, when processing these materials in a larger scale, this current waste stream can have market applications as a byproduct for nonwovens for geotextiles and insulation.

The final yarns were developed in three different colours by blending the recycled fibre with virgin fibres dyed in different colours. The resulting yarns were light blue, blue and green. The comparison for this assessment is based on single ply yarns.

At a final stage, Albini group,⁵⁰ producer of woven textiles, received 0.5 kg packages of each colour of the Ne 30/1 recycled compact cotton yarn. They tested the yarn in the weft of a woven fabric with a 3/1 twill structure, while the warp of this fabric was made from a 60/2 virgin cotton yarn. Placing the recycled yarn only on the weft was intentional in order to reduce warp breaks due to the weaving tension being too high for the strength of the recycled yarn. This entailed that the final fabric had approximately 25% recycled content, as the warp was made from virgin yarn.

Three fabrics with a rustic appearance, of about three metres each, were obtained. The weaver suggested that the yarns can be used for simple weaves and seem interesting for products that require a rustic or casual look. Their quality is comparable to other fabrics containing mechanically recycled yarns, with some visible irregularities. Further, additional tests could be conducted to evaluate the creation of fabrics with better performances, which could in turn increase the competitiveness of the fabrics in the market for recycled fabrics.

Additionally, twisted yarns have been used for the production of knitted garments designed by Italian and Egyptian designers, selected by the Fashion design center in Cairo⁵¹ and trained by the fashion designer Marina Spadafora.⁵²

c. Life Cycle Assessment (LCA)

A life cycle assessment (LCA) quantifies the environmental effects of all the activities in the value chain. LCA is generally applied to products in a specific use context and is an emerging practice to compare two or more alternatives on their difference in environmental performance. A LCA is comprehensive, usually time-consuming in data collection and requires a well-defined scope. A LCA study generally is used to identify the highest environmental impact for a given set of impact categories.

This study has been performed as a 'simplified LCA'. This type of study, as defined by the Handbook on Life Cycle Assessment⁵³ entails "a simple variety of detailed LCA conducted according to guidelines not in full compliance with the ISO 1404X standards. LCAs are best applied to very specific contexts. In this environmental assessment, substantial amounts of primary data have been used for modelling the foreground processes, which is highly desirable to gain valuable insights. To the best of the researchers' knowledge, no comparable studies have been conducted before for these specific products in the Egyptian specific context."

2. GOAL AND SCOPE DEFINITION

a. Goal definition

The aim of the study is to provide a comparative assertion on the basis of an attributional LCA of (1) conventionally produced dyed virgin cotton yarn, and (2) blended dyed cotton yarn using regenerated virgin yarn from textile scraps in a pilot set-up and (3) doing so in a scaled up set-up, both using textile scraps from the Egyptian apparel manufacturing industry. The outcome of the study can be used by all involved parties to assess if and/or in which ways blended regenerated cotton is likely to be a more sustainable alternative to fully virgin cotton use.

b. Scope definition

This attributional LCA will assess the associated environmental impact differences between virgin cotton yarn and blended cotton yarn with regenerated inputs (for pilot and scaled set-ups). These systems are thereby compared for an equivalent functional unit.

For the **virgin** cotton yarn, the transformation of virgin fibre to virgin yarn encompasses the following. The activity starts from opening of bales and the activity ends with spinning and winding the yarn. Batch dyeing service, for dyeing the virgin fibre, has been added to the transformation.

For the **blended** regenerated cotton yarn, the transformation of textile scraps and fibre to blended yarn encompasses the following. The activity starts from tearing the textile scraps and the activity ends with spinning and winding the yarn. Batch dyeing service, only for dyeing the virgin fibre - not the regenerated fibre-, has been added to the transformation.

The system boundaries and cut-off criteria are applied equally on both systems to make the study as comparable as possible. For example, the environmental impact of the equipment itself in the virgin fibre-to-yarn processes are not included, nor is it included for the blended cotton yarn production, because this mainly refers to the same equipment.

3. FUNCTION, FUNCTIONAL UNIT, ALTERNATIVES, REFERENCE FLOWS

The function is producing average quality cotton yarn that is used for textile knitting and weaving.

The functional unit is producing 1 kg of average quality cotton yarn for textile knitting and weaving.

The alternatives are:

1. 1 kg of conventionally grown, dyed cotton yarn, average quality, produced in India, Bangladesh or Global averages

- Circular elements: none; linear production system
- Operations: minimum downtime
- Location: India, Bangladesh, Global averages
- Quality: average

The average quality has been defined as yarns that are neither premium nor at a lower-end, and they are comparable between each other either in yarn count (30/1) or performance. The range of virgin yarns selected encompass a range available within the Ecoinvent Database v.3.6 and adhere to the definition above.

2. 1 kg of blended dyed cotton yarn from the pilot set-up using regenerated cotton from the Egyptian apparel manufacturing industry

- Circular elements: Avoided virgin cotton fibre production, valuable use for certain byproducts
- Operations: relatively high downtime due to small scale operation
- Location: Italy (tearing, opening, carding) and Egypt (blending, carding, spinning)
- Quality: average, Ne 30/1

3. 1 kg of blended dyed cotton yarn from the scaled set-up using regenerated cotton from the Egyptian apparel manufacturing industry

- Circular elements: Avoided virgin cotton fibre production, valuable use for byproducts

- Operations: minimum downtime
- Location: Egypt
- Quality: average, Ne 30/1

The reasoning behind the functional unit (1 kg of cotton yarn) is that existing LCA studies covering cotton yarn have used kilogrammes as a unit. This is evidenced in the existing processes modelled in the Ecoinvent database, as well as in studies such as Bevilacqua et al (2014).⁵⁴ Cotton yarn is an intermediate product, in its wide majority not reaching end consumers. As its use can differ wildly between diverse products (apparel, home textiles, etc), the quantity of kilogrammes for the functional unit is defined arbitrarily to 1kg to enable comparison.

4. INVENTORY ANALYSIS

a. System boundaries

i. Economy-environment system boundary

The stages that are included in the system boundary are the processes required to create yarn from only cotton fibre or from cotton fibre and cotton textile scraps. Since this study is looking into environmental impact differences between the alternatives, all processes that are likely to be the same for each system are out of scope. For example, dyeing processes required for the virgin yarns are assumed equal, and hence, applied to the relevant virgin cotton inputs for each of the alternatives. Similarly, all following steps after the yarn production, such as weaving or apparel manufacturing, will be very similar processes for both virgin and blended yarns and are therefore not included within the system boundary. The comparison emerging from this LCA is then only extrapolable to later stages under the assumption that the virgin yarn is used for the same applications as the blended yarn.

ii. Cut-offs

The following cut-offs are made:

- **Textile scraps.** The upstream burdens from the garment manufacturing industry, which produce the textile scraps are not taken into account, in line with the Ecoinvent cut-off model.⁵⁵ The assumption in our model is that these impacts were allocated to the function already delivered by the denim during its first use cycle. So the impacts until this point were fully “owned” by the producers/consumers of the original denim. The trials constitute an end-of-life alternative for the denim scraps, other than its usual final disposal. When we cut-off and look only at the alternative trial, it is as if the impacts of the original denim up to that point were allocated 100% to the first function they had. Insofar as recycling is not built into the system or guaranteed to a certain extent, the first user consumes without knowing whether the denim scraps will be recycled or not. Therefore, they are not allocated any environmental burden in the model. Within the consistency check performed, an indication for the magnitude of impact carried by the denim scraps in a scenario where the recycling is widely built into the system is presented.
- **Equipment.** As mentioned before, the environmental impact of equipment and machinery is not taken into account, as the existing processes for virgin cotton fibre-to-yarn do not include this either.
- **Short distance transport.** Any short distance national transport is left out as inputs, since the existing Ecoinvent unit process that covers different steps does not include this either, while it is likely that the goods must be transported to the site and within the site. For these virgin cotton fibre processing plants it is also usually the case that the yarn manufacturing is situated close to the cotton fibre production sites. The same assumptions are made for the

alternative of blended cotton yarn in the scaled-up set up. In the blended cotton pilot scenario, textile waste is shipped from Egypt to Italy and regenerated cotton sliver is shipped back from Italy to Egypt. International transport within fibre-to-yarn processing is a deviation from the standard chain, and therefore international shipping will be included in the system boundary.

b. Flowcharts

ALTERNATIVE 1: VIRGIN COTTON YARN PRODUCTION FROM FIBRE TO YARN - MINIMUM TO MAXIMUM RANGE OF IMPACT

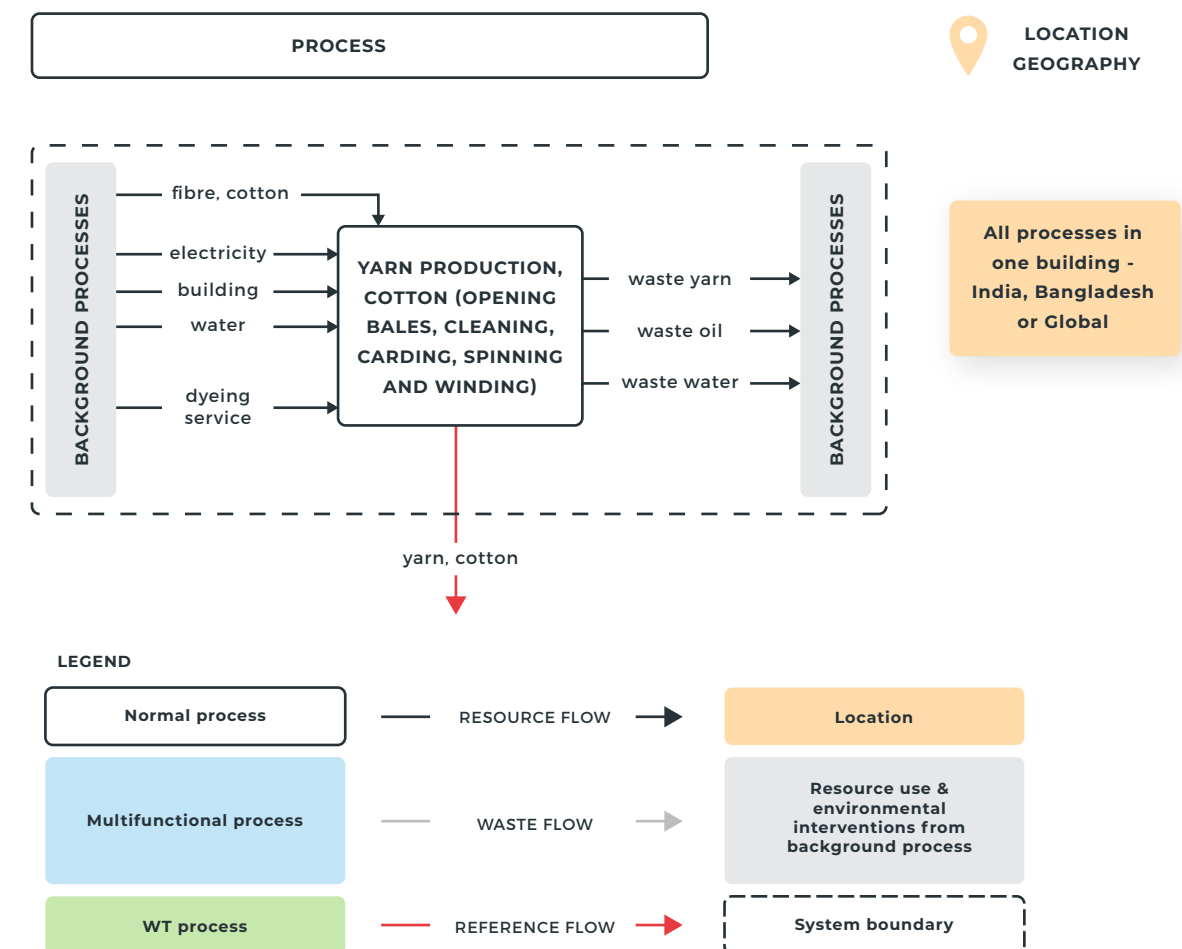


Figure i. Virgin cotton yarn production flow chart.

ALTERNATIVE 2: BLENDED COTTON YARN WITH REGENERATED INPUTS - PILOT SET-UP

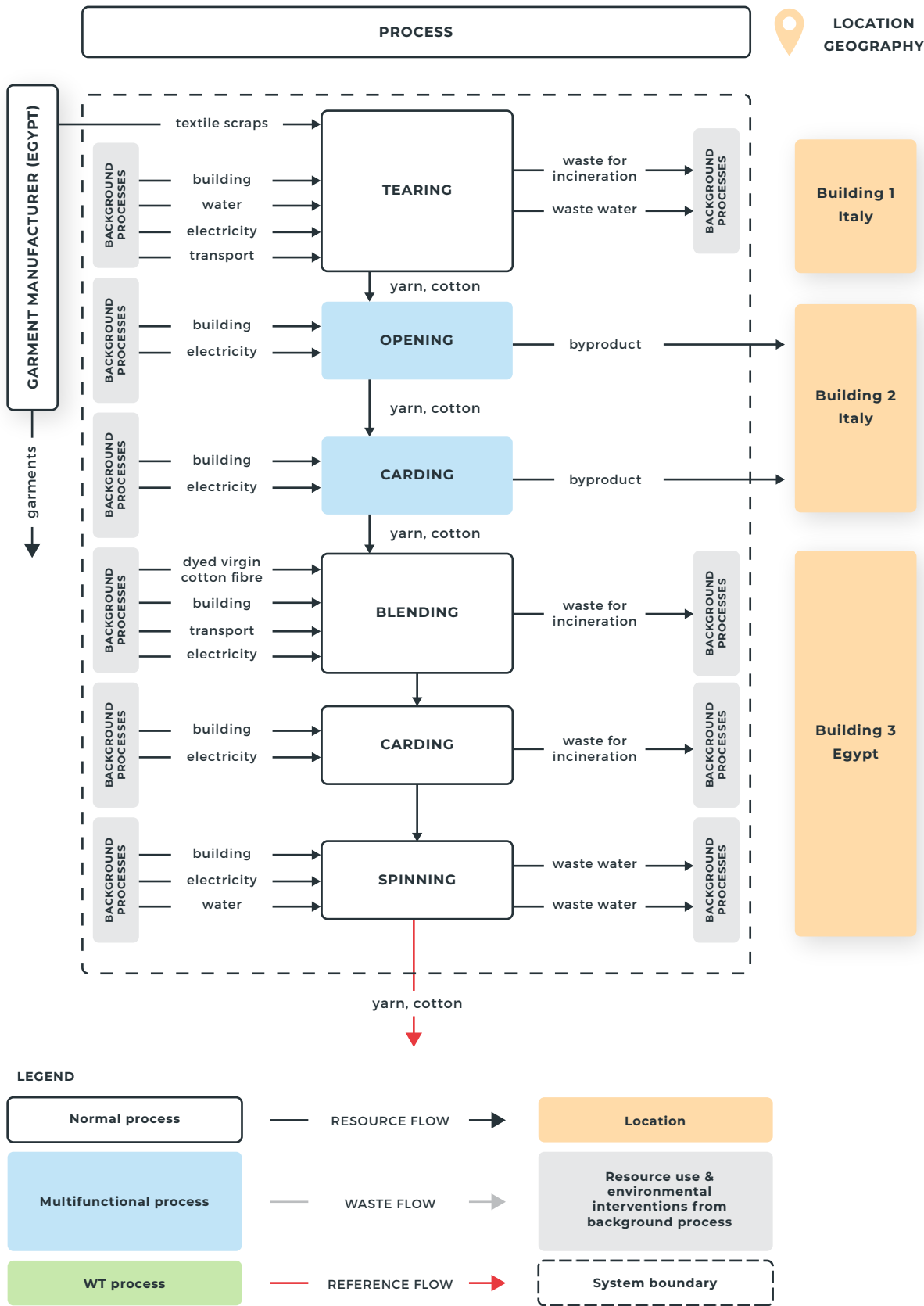


Figure ii. Regenerated blended cotton yarn pilot production flow chart.

ALTERNATIVE 3: BLENDED COTTON YARN WITH REGENERATED INPUTS - SCALED SET-UP

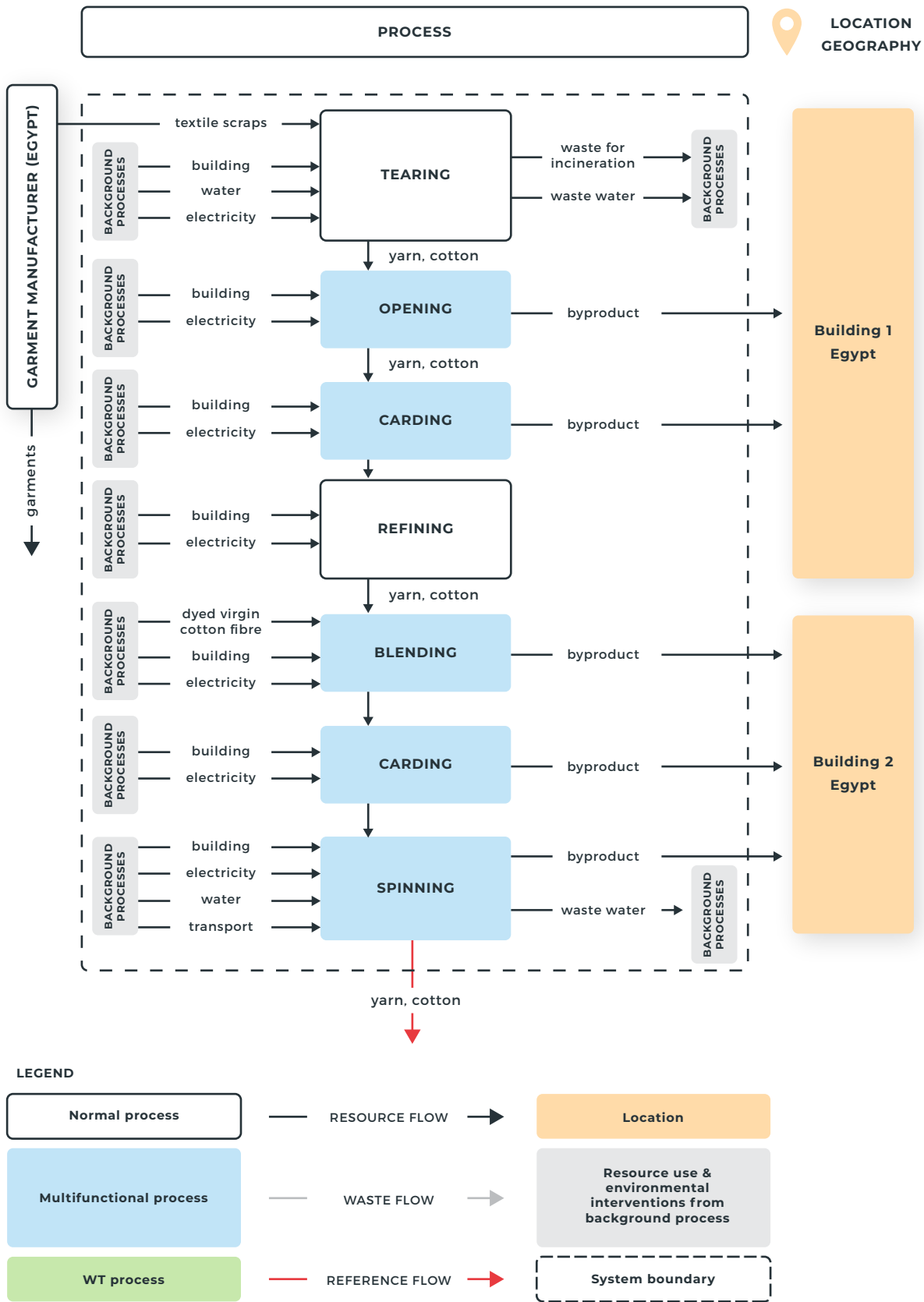


Figure iii. Regenerated blended cotton yarn scaled production flow chart.



c. Data collection

The data collection for this study consisted mainly of two different types of sources:

- **Primary data collection from the partners involved in the blended cotton yarn pilot**
- **Data from the Ecoinvent database v.3.6., which consists of a mix of curated primary and secondary data**

Data for the virgin cotton is solely based on the existing Ecoinvent data. Unfortunately, Egyptian cotton yarns are not available in the existing Ecoinvent dataset. Instead, there are three different unit processes available for virgin cotton yarn:

- **Virgin cotton yarn from India**
- **Virgin cotton yarn from Bangladesh**
- **Virgin cotton yarn, a global average**

Using the datapoint from the three types of virgin cotton yarn production, a range profile has been created, using the minimum and maximum performances of all types for each impact category assessed. However, characterization data from a study by Bevilacqua et al. (2014) allow for potential comparison with Egyptian cotton yarns.

The modelled processes for the blended cotton pilot set-up is built with primary data collection. The scaled set-up for the blended cotton yarn value chain scenario uses the pilot model as a baseline, but builds assumptions around downtimes, process efficiencies and the repurposing of waste flows into byproducts that would be likely to occur as a result of scaling up operations, as well as of setting up the full operation of the processes solely in Egypt. The following assumptions are key to the scaled scenario⁵⁶:

1. All operations occur in Egypt. The local transport between facilities is disregarded in the modelling, as explained in section 4.a.ii. Cut-offs.

2. The recycling facility is envisioned as a 1214 m² facility, processing 450 kg/h of material input. The dimensions of the plant are based on assumptions of a potential investment in land and building of 850,000 euros and investment costs in land and building of 700 euros per square metre.
3. The input material for this scale of scenario is readily available in manufacturing facilities in Egypt.
4. Losses during the recycling process include:
 - **9% waste at tearing**
 - **6% waste at opening, sold as by-product to be used for non-wovens and hydrophilic cotton**
 - **6% waste at carding, sold as by-product to be used for non-wovens and hydrophilic cotton**
 - **0% waste at refining**

The spinning (including preparation for spinning and finishing) is envisioned as a 10000 m² facility, processing 360 kg/h of regenerated fibre input. In this scenario where yarns developed are 50/50% virgin/regenerated, this entails the facility processes 720 kg/h of fibre input. This facility is expected to serve 25,000 spindles.

Losses during the preparation for spinning, spinning and finishing include:

- **0.05% waste at blending room; sold as by-product to be used for non-wovens**
- **11.5% waste at carding, sold as by-product to be used for non-wovens**
- **8% waste at spinning (incl. preparation for spinning and winding), sold as by-product to be used for non-wovens**

In terms of environmental impact categories, several clarifications need to be made:

- The midpoint global warming impact category from the IPCC is used in this study. The impacts are assessed both for

the ReCiPe midpoint (h) as well as for the IPCC characterisation for global warming, to allow (future) comparison, but for sake of this report, these results are not included in the analysis of the results. This is because the IPCC characterisation does not cover the non-EU countries as comprehensively as the ReCiPe midpoint (h) impact assessment method does. The IPCC characterisation results for all alternatives and scenarios are found in section 5.b of this appendix.

- For the use of water in the processes, it is assumed that this does not come from a natural source and has been filtered/processed before using. Local tap water is used to represent the water use in the processes.
- In the pilot set-up, production waste at several steps is incinerated. It is assumed that this incineration process resembles municipal incineration, for lack of a process modelling non-hazardous commercial/industrial waste incineration in Ecoinvent 3.6.

d. Multifunctionality and allocation

- For the pilot set-up, two multifunctional foreground processes are identified:

Opening and carding: Filtration unit waste, or processing waste, is a cotton byproduct from these processes at the recycling stage. The application of the byproduct can vary from use for non-woven textiles for insulation, automotive or geotextiles; to use as hydrophilic cotton for personal care items such as cotton pads. Economic allocation is then used because the main product and the byproducts are both functional, economic flows.

- For the scaled set-up, five multifunctional foreground processes are identified:

Opening, carding, blending and spinning: Equally to the pilot set-up, filtration unit waste, or processing waste, is a cotton byproduct from **opening, carding (recycler), blending, carding (spinner) and spinning**. An economic allocation is applied for the aforementioned reason.

5. IMPACT ASSESSMENT

a. Impact categories

The inventory results of the environmental interventions are used to calculate the quantified contributions to relevant impact categories, thereby enabling comparison of the alternatives. For this study, insights are required on the following:

- **Water use**
- **CO₂ emissions (contribution to global warming)**
- **Energy use**

There are a variety of different impact assessment methods that can provide these insights with different underlying models. The following three impact assessment methods are applied to provide useful insights:

ReCiPe midpoint 2016 (H). This impact assessment method has the best global coverage in terms of measuring effects outside of the EU, while many impact assessment methods are more geared solely towards the EU. Since the geography of the different alternatives changes between the EU and non-EU, this is an important aspect to take into account. From ReCiPe midpoint 2016 (H), the following impact categories have been used:

- **Global warming (kg CO₂ eq)**
- **Water consumption (m³)**
- **Fossil resource scarcity (kg oil eq)**

Cumulative Energy Demand LHV (MJ). This impact assessment method analyses the total cumulative (i.e. upstream) energy used for all resource use and processes. The results provide detailed insight on the following six categories, although they will more often be represented by the sum of these categories, i.e. total energy demand, for reduced complexity.

- **Non-renewable fossil**
- **Non-renewable biomass**
- **Non-renewable nuclear**

- **Renewable biomass**
- **Renewable water**
- **Renewable wind, solar, thermal**

IPCC 2013 (IPCC 2013 is the successor of the IPCC 2007 method). This will enable the comparison with blended cotton and Egyptian cotton, using the results from Bevilacqua et al., 2014. The following category is used for this study:

- **Climate change (GWP 100a)**

b. Characterization results and discussion

The table below presents the results from the life cycle assessment for the different impact categories assessed for all functional units in scope. In the main report, water consumption, global warming potential, resource scarcity and total energy demand are introduced. Additionally, and for means of comparison with other studies, the IPCC Global Warming Potential 100a is added within the results. The detailed breakdown of the total energy demand for each type of energy source can also be found in the table below.

IA method	Impact category	Reference unit	Minimum virgin cotton yarn range	Maximum virgin cotton yarn range	Pilot blended yarn	Scaled blended yarn
ReCiPe	Water consumption	m ³	8.97	21.74	8.60	6.65
ReCiPe	Global warming	kg CO ₂ eq	8.57	14.82	17.93	8.22
IPCC	IPCC GWP 100a	kg CO ₂ eq	8.30	14.55	17.64	8.05
ReCiPe	Fossil resource scarcity	kg oil eq	2.00	3.64	5.44	2.26
CED	Total energy demand	MJ	129.09	204.30	281.85	123.08
CED	Non renewable, fossil	MJ	84.16	156.43	227.37	94.72
CED	Non-renewable, biomass	MJ	0.00	0.02	0.00	0.01
CED	Non-renewable, nuclear	MJ	1.85	8.21	8.76	2.50
CED	Renewable, biomass	MJ	38.96	47.28	29.00	22.72
CED	Renewable, water	MJ	1.25	3.73	10.48	2.52
CED	Renewable, wind, solar, geothermal	MJ	0.34	1.33	6.22	0.61

Table 1. Full LCA results of all functional units for the selected impact categories.



Garments with recycled woven fabrics by Albini Group.
Photo: Alessandro Turra

WATER CONSUMPTION

Water consumption for the regenerated blended yarn is significantly lower than the average water consumption per kg of virgin cotton yarn. This is due to a reduced need for growing new crops for producing fibre. Nevertheless, as the blended yarn is a combination of both virgin and regenerated cotton, the efficiency in the water used to grow and process virgin fibres for that blend is extremely important and influences the total impact of the blended yarn on water consumption. Further, the water consumption of the scaled set-up yarn is lower than that of the pilot due to process efficiency gains and changes in location from Italy to Egypt for some upstream processes. These impacts mainly relate to differences in the electricity grid mix of the countries, as certain renewable energies, such as the use of solar panels which is more present in Italy than in Egypt, requires additional water for the cleaning of the panels.

CO₂-EQ EMISSIONS

CO₂-eq emissions, in relation to global warming potential, also performs better and sits below the minimum virgin cotton yarn range for the blended cotton yarn in the scaled scenario. This is on one hand due to the reduced need for crop growing, as this stage accounts for a significant portion of global warming contributions in virgin cotton yarn.⁵⁷ On the other hand, and in comparison with the results from the pilot, the impact significantly lowers due to increased efficiency in the recycling and spinning processes, therefore reduced electricity consumption. The reduction of the waste produced per kg of fibre input, and the fibre waste from blending, carding and spinning processes turned into a byproduct with potential to be used in geotextiles and insulation for the construction sector further support this improvement.

ENERGY DEMAND

The total energy demand in a scaled set up for the regenerated blended yarn requires less energy, beneath the virgin yarn ranges. **The fossil resource use** sits in the lower end of the virgin alternatives, achieving a great reduction in comparison to the pilot due to efficiency increases in the recycling processes. However, shifting all operations to Egypt currently prevents from more significant savings, as the electricity grid in the country is largely dependent on fossil fuels. Observing the pilot, its negative performance is highly driven by inefficiencies and waste generated during the piloting processes, which are understandable and expected within the scope of a pilot trial that aims to test and achieve a certain quality of yarn with a small volume of material input.

Figure 4 shows a representation of the performance of the regenerated blended cotton yarn for the pilot and scaled set-ups in comparison to the range of performance of the virgin yarns. This visual representation evidences an improved performance (ie. lower environmental impact) of the blended cotton yarn with regenerated inputs in a scaled scenario for all impact categories except for fossil resource scarcity, where it is comparable with virgin yarns with the lowest impact available for comparison.

Normalised impact assessment results

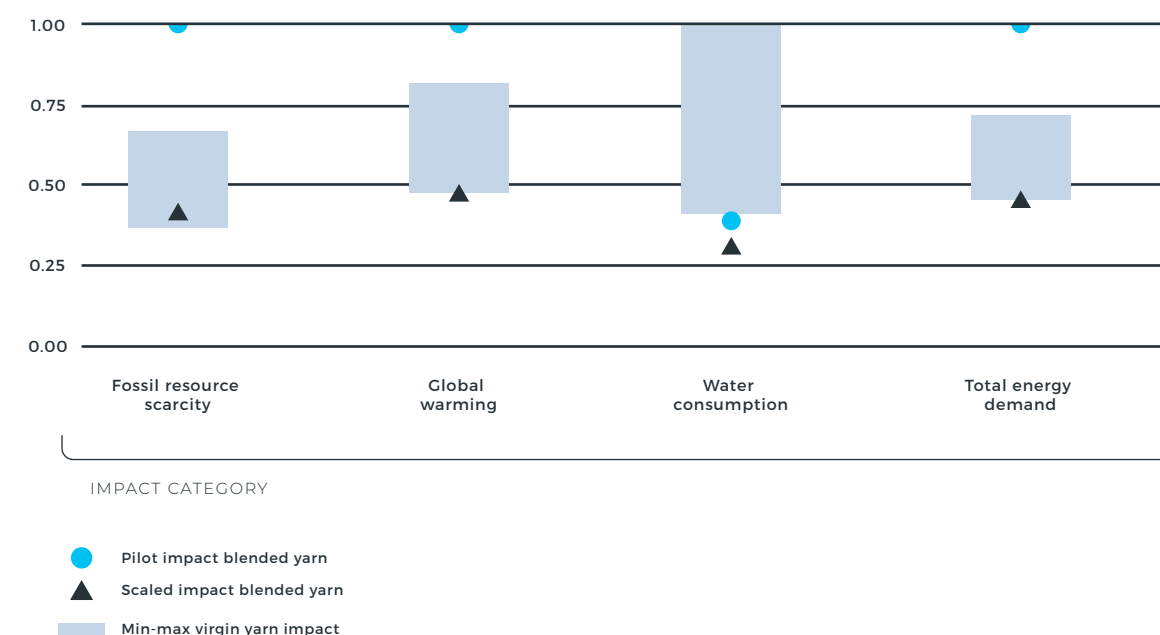


Figure 4. Normalised impact assessment results for the comparison between a range of virgin yarns and the pilot and scaled scenarios of the regenerated blended compact cotton yarn developed. Normalization in this context means to scale a variable to have a value between 0 and 1.

6. INTERPRETATION

a. Consistency check

The consistency check is used to determine if the assumptions, data, models and methods are consistent across the study and informs comparison with other previous or future studies.

Firstly, not including the impact of the production of textile scrap is motivated due to this stream currently considered waste by the majority of the industry. However, if this stream becomes a byproduct with a substantial market, this exclusion needs to be checked for consistency once again. It can be considered an inconsistency that the upstream burdens of the textile waste from the garment industry is cut-off, while the byproducts from the cotton opening, spinning, carding get allocated the process' burden on an economic basis. This is due to the aforementioned byproducts having an

established market demand, while for the textile scraps this is not necessarily the case.

Nevertheless, an estimated calculation of the potential environmental burden that these scraps could carry once there is an established market was performed, utilising existing results from previous LCA studies conducted for denim jeans. These calculations show that the consideration of the scraps within this life cycle assessment should not have great influence on the final result. Firstly, the economic allocation share of the scraps is defined. While the average import price of denim jeans to the EU in 2019 was 11 euros per unit,⁵⁸ the price for the scraps is 0.03 euros per unit. This means that the scraps would be allocated 0.23% of the environmental burden of a pair of jeans.

- For the global warming potential category, an indication of 33.4 CO₂ eq. Is selected from a previous LCA study on denim jeans.⁵⁹ The share of the scraps impact for this category would be 0.069 CO₂ eq., which would suggest that the

consideration of the environmental impact of the scraps leads to a 0.8% increase in the full impact of the recycled yarn.

- In terms of water consumption, an indication of 7,63 m³ is selected from a previous LCA study on denim jeans.⁶⁰ The share of the scraps impact for this category would be 0.017 m³ which would suggest that the consideration of the environmental impact of the scraps leads to a 0.3% increase in the full impact of the recycled yarn.
- Finally, for fossil resource use, an indication of 5,56 kg oil eq. is selected from a previous LCA study on denim jeans.⁶¹ The share of the scraps impact for this category would be 0.013 kg oil eq., which would suggest that the consideration of the environmental impact of the scraps leads to a 0.6% increase in the full impact of the recycled yarn.

An inconsistency between the virgin cotton yarn and the regenerated blended cotton yarn is the aggregation of the different production steps in the modelled processes. For the virgin cotton yarn, many different steps are aggregated into one, whereas for the blended cotton the individual stages at recycler and spinner have been duly split. In theory this should not affect the impact assessment results, but does show an inconsistency between the way the alternatives are modelled. For the virgin cotton the existing processes in Ecoinvent are used as well as the results from Bevilacqua et al. (2014), since modelling the virgin fibre-to-yarn in a consistent way to the blended cotton yarn would be a time-intensive exercise, with not necessarily carrying a substantial impact on the assessment results. Building upon the previous point; the blended cotton yarn alternatives are modeled with primary data, while the data for the virgin cotton yarn alternative is provided by Ecoinvent.

One of the challenging aspects of comparing different yarns, is the difference in their quality. Existing studies on the environmental impacts of cotton yarn are done on mass rather than the quality of the

yarn (e.g. Bevilacqua et al, 2014). For this study, it is therefore assumed that the yarns assessed are from a comparable average quality. Finally, There is a difference in data age between the alternative for virgin cotton yarn and the alternatives for blended cotton yarn. The alternative for virgin cotton yarn is based on 2015-2019 data (Ecoinvent 3.6) and 2005 - 2012 (Bevilacqua et al, 2014), while the alternatives for the blended cotton yarn are based on recently collected data in 2020.

b. Contribution analysis

The stages (processes) that provide the highest impact to each category in both the pilot and scaled set-ups can be identified through a contribution analysis. This is performed for three of the impact categories: water consumption, global warming and fossil resource scarcity.



Contribution results for water consumption

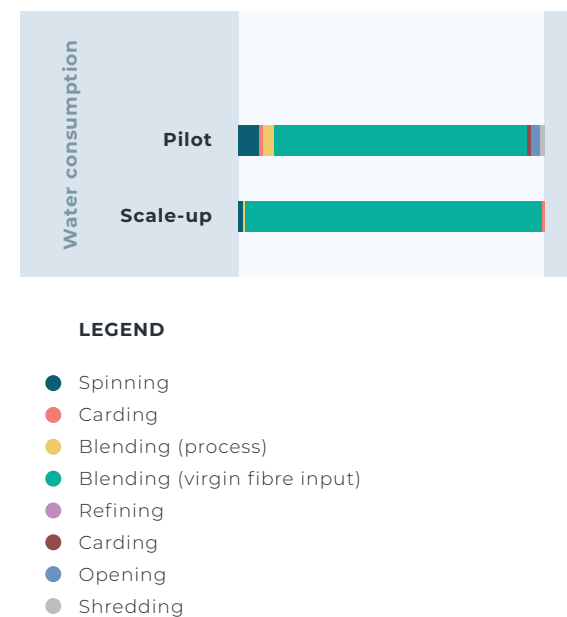


Figure 5. Contribution analysis results for pilot and scaled set-ups for the regenerated blended cotton yarn for the water consumption impact category.



Contribution results for global warming

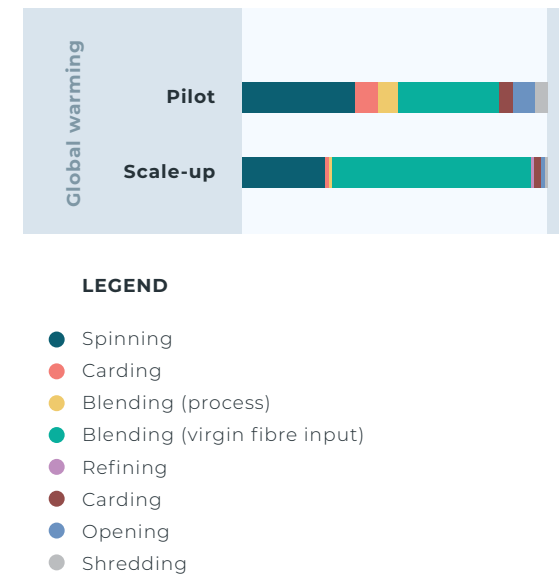


Figure 6. Contribution analysis results for pilot and scaled set-ups for the regenerated blended cotton yarn for the global warming impact category.



Contribution results for fossil resource scarcity

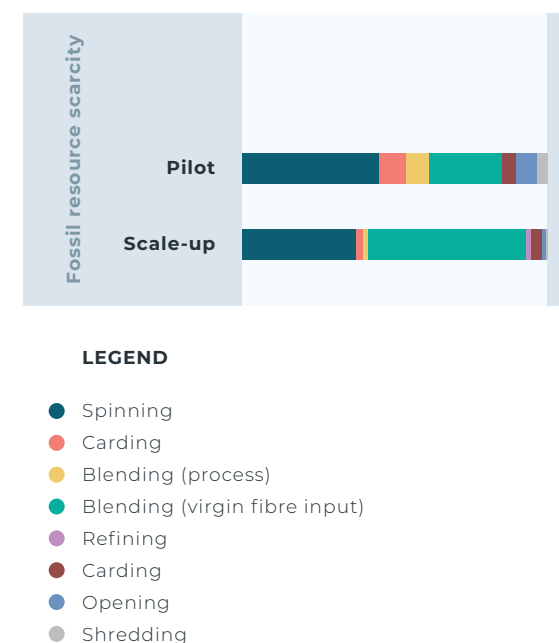


Figure 7. Contribution analysis results for pilot and scaled set-ups for the regenerated blended cotton yarn for the fossil resource scarcity impact category.

The blending process introduces dyed virgin cotton fibre, which increases impacts across the three assessed impact categories as it carries embedded fossil resource consumption, water consumption and greenhouse gas emissions from prior stages up to cultivation. This can be easily spotted in the barcharts above, as the virgin input for the blending process is split from the impacts of the blending process itself. The dyed virgin cotton fibre in this assessment was calculated based on the global average for virgin cotton available in Ecoinvent database (v.3.6.). This highlights that if a more sustainably sourced virgin fibre is used, the impacts may be even lower than in this assessment.

Additionally, the spinning stage accounts for more intensive electricity use than the other stages in recycling, and therefore accounts for a large amount of contributions to the global warming and fossil resource scarcity categories. This contribution will be highly dependent as well on the energy mix of the country and the facility where the operations are located.

c. Sensitivity analysis

To execute this study, assumptions have been made in order to reach a quantified impact comparison. These assumptions may influence the result of the study, therefore, a sensitivity analysis is conducted on the scaled set-up: future scenarios with different energy sources, locations and use of byproducts are explored.

The assumptions that were modified for this sensitivity analysis are the following:

- **Allocation:** what would be the impacts of the blended cotton yarn at scale if no economic value was allocated to any of the textile waste streams (in the study considered byproducts with monetary value).
- **Location:** what would be the impacts of the blended cotton yarn at scale if the recycling operations were conducted in Italy instead of in Egypt.

- **Avoided waste:** what would be the impacts of the blended cotton yarn at scale if all textiles scraps used would have otherwise been landfilled.
- **Energy source:** what would be the impacts of the blended cotton yarn at scale if the energy used was all solar.

There have also been other assumptions for data and modelling choices in the LCA that are not subjected to a sensitivity analysis, for example the size of the recycling and spinning facilities and the volumes they can handle. These assumptions were created and reviewed together with the pilot partners to ensure their feasibility. All assumptions cannot be subjected to a sensitivity analysis in this research due to a limited scope of time to perform the assessment as well as a clear objective to investigate the key environmental impacts and potential savings or losses of the recycled yarns.

ALLOCATION

An economic allocation was chosen for this study, because almost all byproducts have a clear role within the industry or other industries (e.g. short fibre cotton waste for non-wovens or hydrophilic cotton pads).

This allows the environmental burden to be shared between the main product and its byproducts. The bar chart (Figure 8) shows that, if there were no useful applications for these byproducts, the scaled set-up for the blended yarn would perform worse for fossil resource scarcity, global warming and total energy demand, and water consumption. The pricing of the goods and by-products is very important in environmental accounting and the valuable application of the byproducts should be guaranteed.

Allocation sensitivity analysis results (scaled set-up)

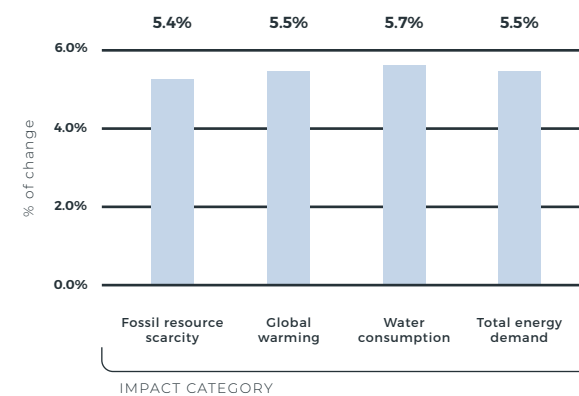


Figure 8. Sensitivity analysis results for selected impact categories when allocating no economic value to by-products in the scaled scenario.

Nevertheless, observing the comparison between this scenario and virgin yarn ranges (Figure 9), the results also show that the worsened performance of the yarns, when their byproducts have no economic allocation, would still sit slightly below the impact of the range of virgin cotton yarn.

Allocation sensitivity analysis results (scaled set-up)

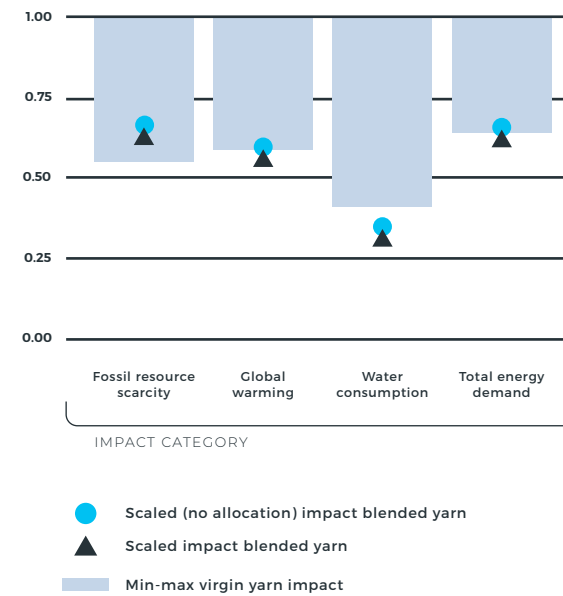


Figure 9. Normalised sensitivity analysis results comparing virgin and scaled scenarios for selected impact categories when allocating no economic value to by-products. Normalization in this context means to scale a variable to have a value between 0 and 1.

LOCATION

The impact assessments both in the scenario fully operational in Egypt, as well as the scenario operating recycling in Italy and spinning in Egypt offer very similar results. Although Italy's electricity grid mix contains more renewables than that of Egypt, and this should lower the yarn's impact for most categories, these improvements are offset almost completely due to the Egyptian scenario not including any cross-border transportation.

Plant location sensitivity analysis results (scaled set-up)

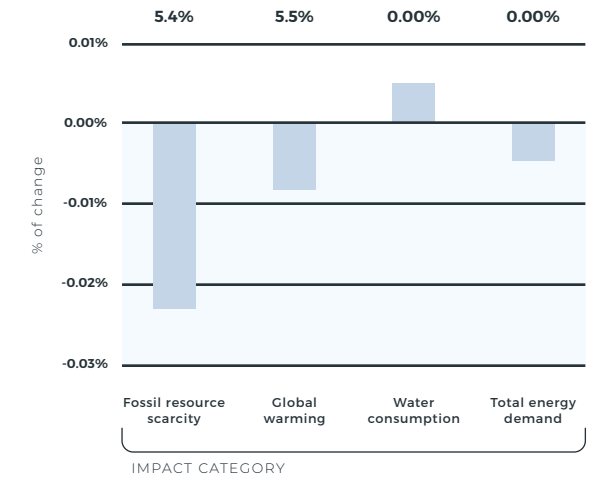


Figure 10. Sensitivity analysis results for selected impact categories when modifying plant location in the scaled scenario.

Plant location sensitivity analysis results (scaled set-up)

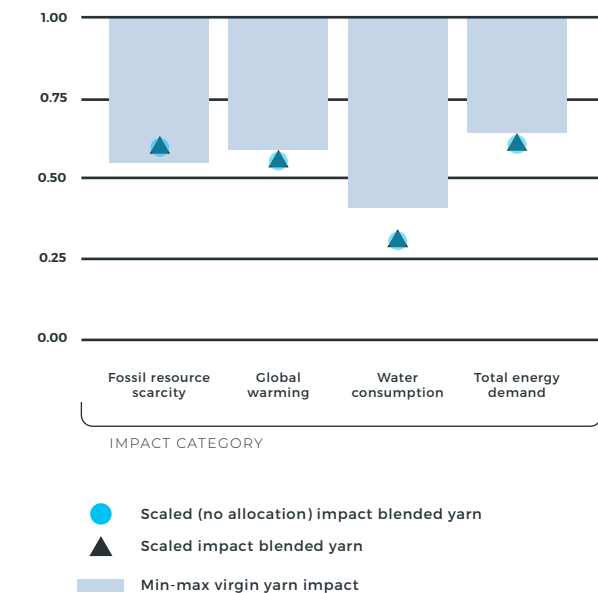


Figure 11. Normalised sensitivity analysis results comparing virgin and scaled scenarios for selected impact categories when modifying plant location. Normalization in this context means to scale a variable to have a value between 0 and 1.

AVOIDED WASTE

Moving all textiles scraps, that would have otherwise been landfilled, into a value-adding chain to produce blended cotton yarn would reduce global warming impacts for the scaled scenario. No effects were found for fossil resource scarcity, total cumulative energy demand and water consumption.

Sensitivity analysis results landfilled textile waste (scaled set-up)

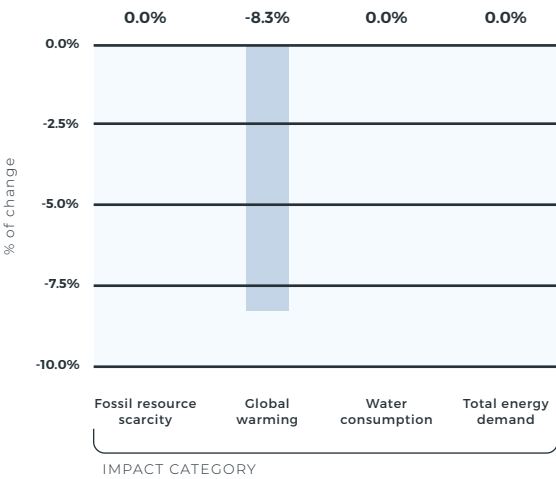


Figure 12. Sensitivity analysis results for selected impact categories when avoiding textile waste in the scaled scenario.

Sensitivity analysis results landfilled textile waste (scaled set-up)

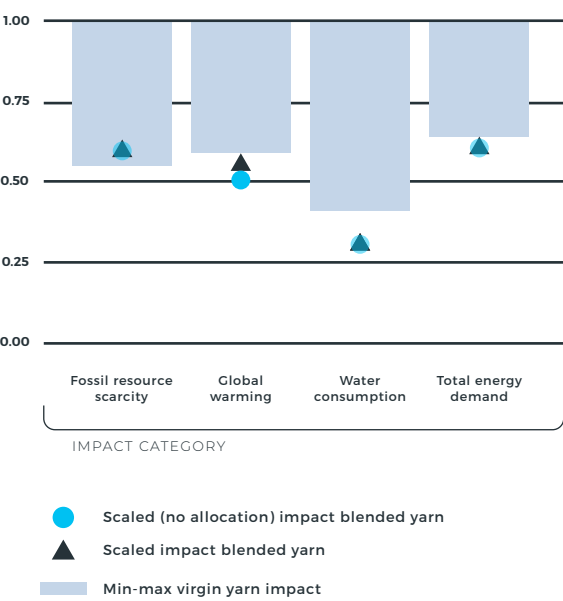


Figure 13. Normalised sensitivity analysis results comparing virgin and scaled scenarios for selected impact categories when avoiding textile waste. Normalization in this context means to scale a variable to have a value between 0 and 1.

ENERGY SOURCE

The results for the pilot and scaled set-up compared to those when fully powered by solar energy are staggering; the electricity source has a great impact on the impact assessment results. When shifting to more renewable energy sources in operations, the blended cotton yarn will greatly outperform the virgin cotton yarn on fossil fuel use, global warming and cumulative energy demand. In this comparison, the virgin cotton yarn ranges are calculated on current energy sources, with low presence of renewables. This scenario does not take into account the similar effect that shifting to renewable energy sources would have for the virgin cotton value chain.

Water consumption will increase for cleaning the panel's surfaces for optimal efficiency, but will stay well below the levels of the virgin cotton yarn.

Sensitivity analysis results energy source (scaled set-up)

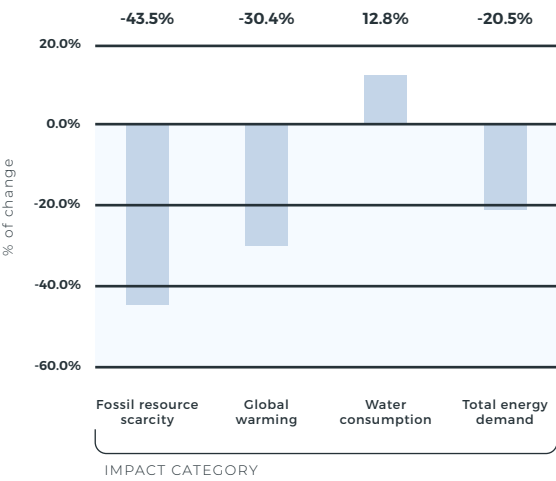


Figure 14. Sensitivity analysis results for selected impact categories when switching to solar energy in the scaled scenario.

Energy source - Sensitivity analysis results for solar energy

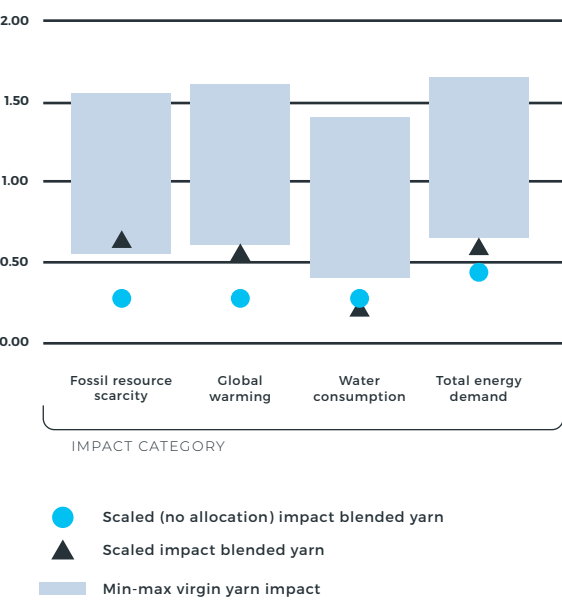


Figure 15. Normalised sensitivity analysis results comparing virgin and scaled scenarios for selected impact categories when switching to solar energy. Normalization in this context means to scale a variable to have a value between 0 and 1.



CONCLUSION

The environmental impact of the regenerated cotton yarn has been compared to a range of virgin cotton yarns through Life Cycle Analysis (LCA).

Water consumption, CO₂ emissions contributing to global warming and energy consumption contributing to cumulative energy demand and fossil resource use are the impact categories reported in this assessment. **Water consumption and CO₂-eq emissions (global warming potential)** for the regenerated blended yarn perform better than the virgin yarn and in the scaled scenario sits below the minimum virgin cotton yarn range. This is due to a reduced need for growing new crops for producing fibre as well as due to increased efficiency in the recycling and spinning processes. Nevertheless, the contribution analysis shows that the presence of virgin cotton fibre in the blended yarn is the main driver for both categories. Therefore, the way the virgin fibres are cultivated and processed for that blend is extremely important and influences the total impact of the blended yarn on water consumption.

The total energy demand in a scaled set up for the regenerated blended yarn requires less energy, well beneath the virgin yarn ranges. **The fossil resource use** is comparable to the less impactful virgin alternatives due to efficiency increases in the recycling processes. However, shifting all operations to Egypt currently prevents from more significant savings, as the electricity grid in the country is largely dependent on fossil fuels. Through a sensitivity analysis with a shift to renewable energy sources (eg. solar) it is evident that this shift may bring further benefits to this impact category.

While the improvement in comparison to the average performance of virgin yarns is a clear outcome of this assessment, there are several recommendations that could further improve the performance of the regenerated blended yarn.



*Recycled knitted design by Tiziano Guardini.
Photo: Alessandro Turra.*

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ACKNOWLEDGEMENTS

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PUBLICATION

December 2020

UNIDO Egypt would like to thank private sector partners for their contribution to the implementation of the pilot and the support to the research activities and data collection. The partners played an instrumental role in creating this report.

The partners who made this pilot a reality:



T&C Garments

<https://tolbagroup.com/tc-garments/>



Textile Engineering

Marzoli Textile Engineering - Camozzi Group

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Filmar SpA

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