Comparative Life Cycle Impact Assessment of Organic Cotton, Modal, Linen and Recycled PET fibre versus Conventional Alternatives
Analysis Overview

• The objective of this study is to compare the impact of Pact Apparel’s (Pact) organic and sustainable clothing against clothing made using comparable conventional fibers. The findings of the study are intended to be used as a basis for communication and future process improvements. The primary audience for this study is Pact, its investors and customers.

• This cradle-to-gate comparative life cycle inventory (LCI) encompasses the following upstream processes of apparel manufacture: farming, raw material acquisition, fiber manufacture and in-between transportation. All the relevant life-stages of sustainable and conventional fabric apparels are analyzed to estimate the net impact savings across three key metrics: GHG emissions, primary energy use, and blue water consumption.

Scope of study

• This is a cradle-to-gate comparative life cycle inventory study
• Functional unit is 1 kg of apparel for each of Pact and comparative conventional fabric types
• The fibers analyzed from Pact are organic cotton, linen, recycled polyester, and Modal. These are compared with regular cotton, virgin polyester and viscose fibers respectively.
• The study examines Pact’s apparel manufacturing in India and compares it with conventional apparel manufacturing in India. Post fiber manufacturing including knitting, dyeing, cutting & sewing, consumers transportation & use, and disposal are assumed to be equivalent for both Pact and conventional apparels.
Key Assumptions

Overall Fabric Assumptions

- All apparel analyses have a system boundary from cradle until fibre factory-gate and assume an identical supply chain and manufacturing post fibre production for Pact and conventional fabric apparel.
- Transportation is included until fiber production.
- Only non-biogenic carbon dioxide equivalence (CO2e) is taken into account for all fibers in this analysis as it is assumed that all biogenic CO2e stored in the apparel will be released back to the environment at end-of-life.
- For viscose and cotton fibers, the comparative are made against global averages.
- Wool production was not considered for either Pact or conventional for Blend 3, assuming identical production.
- Primary energy demand is total energy demand including both non-renewable and renewable energy sources.
The following blends were analyzed:

<table>
<thead>
<tr>
<th>Blend</th>
<th>Pact fibers</th>
<th>Conventional comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blend 1</td>
<td>100% organic cotton</td>
<td>100% conventional cotton</td>
</tr>
<tr>
<td>Blend 2</td>
<td>80% organic cotton/ 20% wool</td>
<td>80% conventional cotton/ 20% wool</td>
</tr>
<tr>
<td>Blend 3</td>
<td>75% organic cotton/ 25% linen</td>
<td>75% conventional cotton/ 25% India cotton</td>
</tr>
<tr>
<td>Blend 4</td>
<td>65% organic cotton/ 35% modal</td>
<td>65% conventional cotton/ 35% rayon</td>
</tr>
<tr>
<td>Blend 5</td>
<td>84% organic cotton/ 16% rPET</td>
<td>84% conventional cotton/ 16% polyester</td>
</tr>
<tr>
<td>Blend 6</td>
<td>60% organic cotton/ 40% rPET</td>
<td>60% conventional cotton/ 40% polyester</td>
</tr>
<tr>
<td>Blend 7</td>
<td>65% organic cotton/ 35% rPET</td>
<td>65% conventional cotton/ 35% rPET</td>
</tr>
<tr>
<td>Blend 8</td>
<td>80% organic cotton/ 20% rPET</td>
<td>80% conventional cotton/ 20% rPET</td>
</tr>
</tbody>
</table>
Analysis Overview

Other data
• Average electricity grid for India is used to model Pact apparel manufacturing and to model conventional global apparel manufacturing.
• Transportation distances were modeled using Pact inputs, Ecoinvent and ThinkStep databases based on manufacturing plant locations.

Data Audit
• No internal or external audit of resource utilization data provided by Pact was performed by Green Story for this study. It is assumed that data provided by Pact and its suppliers is factual and accurate.

Critical Review
• No third-party critical review has been performed for this study.
List of sources used across all materials

Secondary Sources

• Cotton Inc, 2012. Life Cycle Assessment of Cotton Fibre and Fabric. Prepared for VISION 21, a project of The Cotton Foundation and managed by Cotton Incorporated, Cotton Council International and The National Cotton Council. The research was conducted by Cotton Incorporated and PE Inter-national;
List of sources used across all materials

- NRCCA. “Northeast Region Certified Crop Adviser (NRCCA) Study Resources.” Certified Crop Advisor Study Resources (Northeast Region), 2010, nrcca.cals.cornell.edu/.
List of sources used across all materials


Primary Sources

- Pact supplier data
- Pact proprietary data
Organic cotton vs conventional cotton (blend 1 & 2) Comparative impact
Key Assumptions

- Farming and ginning inputs inventory for various organic cotton growing regions in India has been adapted from PE International, 2014, “Life Cycle Assessment (LCA) of Organic Cotton: A global average” study.
- Cow dung manure is a waste-product of the livestock industry and thus the burden is borne by that industry.
- No NH₄ is lost from neem cake as neem cake is covered in fertilizer for the purpose to reduce NH₄ losses.
- Neem kernel, leaves extract, and tricoderma upstream impacts are not considered as they are of insignificant impact.
- Infrastructure creation like shed, trailer and tractor are not considered.
- Heavy metals amount in soil are taken from the United States, Lubbock region and calculated with soil erosion rates in India.
- Soil carbon sequestration is not considered as to align to the PE International, 2014.
- Transport was assumed at 30 km via truck between fiber production and the ginning process.
- Economic allocation was used to assign burden between organic cotton linters and fibre for the ginning process.
- Proportions of various India regions for organic cotton cultivation were taken as follows:

<table>
<thead>
<tr>
<th>Region</th>
<th>% contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madhya Pradesh</td>
<td>11%</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>42%</td>
</tr>
<tr>
<td>Odisha</td>
<td>2%</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>45%</td>
</tr>
</tbody>
</table>
System Boundary – Organic/Conventional Cotton

**Inputs**
Cotton seed, water, fuel production, fertilizers, pesticides, CO₂ uptake

**Cradle to farmgate process**
- Field preparation
- Planting
- Field operation
- Harvesting
- Ginning and baling
- Yarn

**Outputs**
Fuel emissions, N₂O emissions, NH₃ emissions, Nitrate emissions, phosphate emissions, water, waste, wastewater (for inorganic cotton), Heavy Metals
## Pact’s organic cotton clothing vs. conventional cotton global comparative LCI (per kg of apparel)

### Net impact difference between organic cotton and conventional cotton

<table>
<thead>
<tr>
<th>Per kg of fabric</th>
<th>Unit</th>
<th>Pact organic</th>
<th>Conventional cotton</th>
<th>Percentage lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>kgCO2e</td>
<td>1.08</td>
<td>1.74</td>
<td>38%</td>
</tr>
<tr>
<td>Water consumption</td>
<td>litres</td>
<td>386</td>
<td>2120</td>
<td>82%</td>
</tr>
<tr>
<td>Energy</td>
<td>MJ</td>
<td>6.80</td>
<td>63.20</td>
<td>89%</td>
</tr>
</tbody>
</table>

### Net impact equivalence (difference between organic cotton and conventional cotton) per kg of apparel

- **2.5 kms** of driving emissions avoided
- **913 days** of drinking water conserved
- **1,205 bulbs** powered for an hour
Pact’s 80% organic cotton/20% wool vs. 80% conventional cotton/20% wool comparative LCI (per kg of apparel)

<table>
<thead>
<tr>
<th>Per kg of fabric</th>
<th>Unit</th>
<th>Pact organic</th>
<th>Conventional cotton</th>
<th>Percentage lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>kgCO2e</td>
<td>0.86</td>
<td>1.39</td>
<td>38%</td>
</tr>
<tr>
<td>Water consumption</td>
<td>litres</td>
<td>308.8</td>
<td>1696</td>
<td>82%</td>
</tr>
<tr>
<td>Energy</td>
<td>MJ</td>
<td>5.44</td>
<td>50.56</td>
<td>89%</td>
</tr>
</tbody>
</table>

Net impact equivalence per kg of apparel

- 2.0 kms of driving emissions avoided
- 730 days of drinking water conserved
- 964 bulbs powered for an hour
List of sources (cont.)

Data sets used

• GaBi:
  o IN: Electricity grid mix
  o IN: Thermal energy from natural gas
  o EU-28: Tap water
  o IN: Diesel mix at refinery
  o Truck-trailer, Euro 3, 34 - 40t gross weight / 27t payload capacity

• Ecoinvent 3.4:
  o RoW: Cotton seed production, for sowing
  o GLO: Market for phosphate rock, as P2O5, beneficiated, dry
  o US: Soybean meal and crude oil production (Meal Output)
  o GLO: Market for hexane
  o GLO: Market group for heat, central or small-scale, other than natural gas
  o GLO: Market group for heat, central or small-scale, natural gas
  o GLO: Market for linseed
  o GLO: Transport, freight, train with reefer, cooling
  o GLO: Transport, freight, sea, transoceanic ship
  o RoW: Transport, freight, lorry 16-32 metric ton, EURO6
  o US: Soybean meal and crude oil production Oil Output)
  o GLO: Diesel, burned in agricultural machinery
  o GLO: Market for potassium chloride, as K2O

• Cotton Inc. Database
  o GLO: Cotton fiber (bales after ginning)
Linen vs conventional cotton (blend 3) Comparative impact
Key Assumptions

Assumptions
- Flax cultivation, retting, and hackling process inputs and outputs are taken from BIO Intelligence Service S.A.S. (2007) for flax agriculture in France.
- Flax seed input was omitted due to lack of data and insufficiency.
- Retting emissions were incorporated from Kane (1840).
- No irrigation was used for cultivation as seen in BIO Intelligence Service S.A.S. (2007) and confirmed in Flax Industries & Research (2019).
- Diesel use for tractors was taken from Turunen & van der Werf (2006).
- Production of round bales on field was taken from GaBi 8.7 (2018).
- Distance for the transportation from field to retting, and retting to scutching was taken as per BIO Intelligence Service S.A.S. (2007).
- Electricity required for retting is taken from Turunen & van der Werf (2007).
- Economic allocation was used for retting and hackling as done in BIO Intelligence Service S.A.S. (2007), with prices taken from the same source.
- Environmental impacts for conventional seed cotton for India are taken from C&A Foundation, 2018 with India ginning practices from PE International (2014).
System Boundary – Linen

**Inputs**
Linen seed, water, fuel production, fertilizers, CO₂ uptake

**Cradle to farmgate process**

- Field preparation
- Planting
- Field operation
- Harvesting
- Retting, Scutching, Hackling

**Outputs**
Fuel emissions, N₂O emissions, NH₃ emissions, Nitrate emissions, phosphate emissions, water, waste, Heavy Metals

![System Boundary Diagram for Linen Production](image-url)
### Pact’s 75% Organic Cotton/ 25% Linen vs. 75% Global Cotton/ 25% Indian Cotton comparative LCI (per kg of apparel)

#### Net impact difference between 75% organic cotton/25% linen and 75% conventional cotton/25% India cotton

<table>
<thead>
<tr>
<th>Per kg of fabric</th>
<th>Unit</th>
<th>Pact organic cotton/linen</th>
<th>Conventional cotton/ India cotton</th>
<th>Percentage lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>kgCO2e</td>
<td>1.24</td>
<td>1.84</td>
<td>33%</td>
</tr>
<tr>
<td>Water consumption</td>
<td>litres</td>
<td>294.34</td>
<td>1838</td>
<td>84%</td>
</tr>
<tr>
<td>Energy</td>
<td>MJ</td>
<td>13.88</td>
<td>66.35</td>
<td>79%</td>
</tr>
</tbody>
</table>

#### Net impact equivalence per kg of apparel

- **2.3 kms** of driving emissions avoided
- **813 days** of drinking water conserved
- **1,121 bulbs** powered for an hour
Data sets used

- **GaBi**:
  - EU-28: Diesel mix at refinery
  - IN: Diesel mix at refiner
  - IN: Electricity grid mix

- **Ecoinvent 3.4**:
  - RER: ammonium nitrate production
  - RER: triple superphosphate
  - RER: potassium chloride production
  - GLO: market for diesel, burned in agricultural machinery
  - RER: market for quicklime, milled, packed
  - RER: pesticide production, unspecified
  - RER: market for zinc concentrate
  - GLO: Truck-trailer, Euro 3, 34-40t gross weight / 27t payload capacity
  - BE: market for electricity
Modal vs conventional viscose (blend 4)
Comparative impact
Key Fiber Assumptions

- Modal fiber is functionally similar to a typical viscose fibre.
- Modal fiber impacts are modeled in accordance with Shen & Patel, 2010. This study only provides environmental indicators based on CML 2000 and does not provide LCI data. The CML 2000 baseline characterization factors are assumed to be equivalent to the CML 2000 – 2016 characterization factors as it was not possible to transform it without raw LCI data.
- The production system for modal is an integrated system, containing pulp and fiber production in one process. Production energy in integrated system for modal is recovered and does not require public electricity grid.
- The wood source for modal is European Beech.
- Modal pulp/fiber is produced in Lenzing, Austria and uses wood from managed forests in Europe (Shen & Patel, 2010).
- For the integrated pulp/fiber production, the process energy is supplied from external (purchased) and internal biomass, municipal solid waste incineration and external municipal waste and a very small percentage of fossil fuels (Shen & Patel, 2010).
- The cooling water for modal fiber production is assumed to exit the system in the same watershed after usage and thus is not taken into consideration.
- Transportation is taken into account for the modal apparel following the fiber production from Austria to India where the remainder of the production takes place. Transportation was considered from Trieben to Vienna (Euro 5 Truck-trailer), Vienna to Mumbai (Ship) and Mumbai to Madhya Pradesh (Euro 3 Truck-Trailer).
- Viscose fiber is taken as a global average production of viscose (Ecoinvent, 2018).
System Boundary – Conventional Viscose/Modal

**Inputs**
Eucalyptus (Viscose), European Beech (Modal), Caustic soda, water, sulphuric acid and zinc sulphate, carbon disulphide, energy production from municipal solid waste incineration, electricity

**Cradle to fibre**
- Wood production & harvesting
- Pulping
- Alkalization & preageing
- Dissolving & ageing
- Spinning and finishing
- Yarn

**Outputs**
Fuel emissions, sodium disulphate, water, waste, wastewater, byproducts (xylose, furfural, acetic acid, thick liquor)
Pact’s 65% organic cotton/35% modal vs. 65% conventional cotton/35% viscose global comparative LCI (per kg of apparel)

<table>
<thead>
<tr>
<th>Per kg of fabric</th>
<th>Unit</th>
<th>Pact organic cotton/modal</th>
<th>Conventional cotton/rayon</th>
<th>Percentage lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>kgCO2e</td>
<td>1.33</td>
<td>2.48</td>
<td>46%</td>
</tr>
<tr>
<td>Water consumption</td>
<td>litres</td>
<td>266</td>
<td>1410</td>
<td>81%</td>
</tr>
<tr>
<td>Energy</td>
<td>MJ</td>
<td>33.40</td>
<td>70.00</td>
<td>52%</td>
</tr>
</tbody>
</table>

Net impact difference between 65% organic cotton/35% modal and 65% conventional cotton/35% rayon

Net impact equivalence (difference between 65% organic cotton/35% modal and 65% conventional cotton/35% rayon) per kg of apparel

- **4.4 kms** of driving emissions avoided
- **602 days** of drinking water conserved
- **782 bulbs** powered for an hour
List of sources

Additional Data sets used

• **Ecoinvent 3.4**:
  - GLO: Transport, freight, train with reefer, cooling
  - GLO: Transport, freight, sea, transoceanic ship
  - RoW: Transport, freight, lorry 16-32 metric ton, EURO4
  - GLO: Market for viscose fibre
RPET vs polyester (blends 5 - 8)
Comparative impact
Key Fiber Assumptions

- Recycled PET granulate and PET granulate production processes are taken as Switzerland processes from Ecoinvent and adapted to India through fuel, electricity grid and other input raw materials’ geographical source changes.
- Bottle collection process and sorting for recycled PET are also based on Swiss data, and modified to India through key process and fuel source substitutions.
- Transportation from granulate factory to fabric manufacture plant is not taken into account for both recycled and virgin polyester fibers due to uncertainty in location of the granulate factory.
System Boundary – Virgin polyester

**Inputs**
Electricity, diesel, water, organic chemicals, sulphuric acid, sodium hydroxide, Petrochemicals, natural gas

**Cradle to fibre**
- Resource extraction
- Polymerization
- Granulate production
- Fiber extrusion
- Yarn

**Outputs**
Fuel emissions, methanol, water, waste, wastewater
System Boundary – rPET

**Inputs**
Electricity, diesel, water, sulphuric acid, sodium hydroxide

**Cradle to fibre**
- Bottle collection
- Sorting
- Recycling treatment
- Granulate production
- Fibre extrusion

**Outputs**
Fuel emissions, water, waste, wastewater

Yarn
Pact’s 84% organic cotton/16% rPET vs. 84% conventional cotton/16% polyester LCI (per kg of fabric)

<table>
<thead>
<tr>
<th>Per kg of fabric</th>
<th>Unit</th>
<th>Pact organic cotton/ rPET</th>
<th>Conventional cotton/ polyester</th>
<th>Percentage lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>kgCO2e</td>
<td>1.13</td>
<td>2.03</td>
<td>44%</td>
</tr>
<tr>
<td>Water consumption</td>
<td>litres</td>
<td>325</td>
<td>1790</td>
<td>82%</td>
</tr>
<tr>
<td>Energy</td>
<td>MJ</td>
<td>8.48</td>
<td>66.00</td>
<td>87%</td>
</tr>
</tbody>
</table>

Net impact equivalence (difference between 84% organic cotton/16% rPET & 84% conventional cotton/16% polyester) per kg of apparel

- 3.5 kms of driving emissions avoided
- 771 days of drinking water conserved
- 1,229 bulbs powered for an hour
Pact’s 60% organic cotton/40% rPET vs. 60% conventional cotton/40% polyester LCI (per kg of fabric)

Net impact difference between 60% organic cotton/40% rPET and 60% conventional cotton/40% polyester

<table>
<thead>
<tr>
<th>Per kg of fabric</th>
<th>Unit</th>
<th>Pact organic cotton/rPET</th>
<th>Conventional cotton/polyester</th>
<th>Percentage lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>kgCO2e</td>
<td>1.21</td>
<td>2.47</td>
<td>51%</td>
</tr>
<tr>
<td>Water consumption</td>
<td>litres</td>
<td>234</td>
<td>1290</td>
<td>82%</td>
</tr>
<tr>
<td>Energy</td>
<td>MJ</td>
<td>11.00</td>
<td>70.30</td>
<td>84%</td>
</tr>
</tbody>
</table>

Net impact equivalence (difference between 60% organic cotton/40% rPET & 60% conventional cotton/40% polyester) per kg of apparel

- **4.8 kms** of driving emissions avoided
- **556 days** of drinking water conserved
- **1,267 bulbs** powered for an hour
### Pact’s 65% organic cotton/35% rPET vs. 65% conventional cotton/35% polyester LCI (per kg of fabric)

#### Net impact difference between 65% organic cotton/35% rPET and 65% conventional cotton/35% polyester

<table>
<thead>
<tr>
<th>Per kg of fabric</th>
<th>Unit</th>
<th>Pact organic cotton/rPET</th>
<th>Conventional cotton/polyester</th>
<th>Percentage lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>kgCO2e</td>
<td>1.19</td>
<td>2.37</td>
<td>50%</td>
</tr>
<tr>
<td>Water consumption</td>
<td>litres</td>
<td>252.56</td>
<td>1398</td>
<td>82%</td>
</tr>
<tr>
<td>Energy</td>
<td>MJ</td>
<td>10.48</td>
<td>69.33</td>
<td>85%</td>
</tr>
</tbody>
</table>

#### Net impact equivalence (difference between 65% organic cotton/35% rPET & 65% conventional cotton/35% polyester) per kg of apparel

- **4.5 kms** of driving emissions avoided
- **603 days** of drinking water conserved
- **1,257 bulbs** powered for an hour
Pact’s 80% organic cotton/20% rPET vs. 80% conventional cotton/20% polyester LCI (per kg of fabric)

Net impact difference between 80% organic cotton/20% rPET and 80% conventional cotton/20% polyester

<table>
<thead>
<tr>
<th>Per kg of fabric</th>
<th>Unit</th>
<th>Pact organic cotton/ rPET</th>
<th>Conventional cotton/ polyester</th>
<th>Percentage lower</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>kgCO2e</td>
<td>1.14</td>
<td>2.1</td>
<td>46%</td>
</tr>
<tr>
<td>Water consumption</td>
<td>litres</td>
<td>309.75</td>
<td>1707.5</td>
<td>82%</td>
</tr>
<tr>
<td>Energy</td>
<td>MJ</td>
<td>8.9</td>
<td>66.7</td>
<td>87%</td>
</tr>
</tbody>
</table>

Net impact equivalence (difference between 80% organic cotton/20% rPET & 80% conventional cotton/20% polyester) per kg of apparel

- **3.7 kms** of driving emissions avoided
- **736 days** of drinking water conserved
- **1,235 bulbs** powered for an hour
List of sources

Data sets used

• Ecoinvent 3.4:
  o CH: treatment of waste polyethylene terephthalate, for recycling, unsorted, sorting
  o India-Northern grid: market for electricity, low voltage
  o CH: polyethylene terephthalate production, granulate, bottle grade, recycled
  o India-western grid: market for electricity, low voltage
  o RoW: market for waste polyethylene terephthalate, for recycling, unsorted
  o RoW: market for wastewater, average
About Green Story

The Green Story team is led by Akhil Sivanandan and Navodit Babel. Both members received their sustainability reporting training from the Global Reporting Initiative.

- Navodit has 10+ years of experience in consulting and product management with global corporations. He has successfully overseen the launch of national card strategies in Canada. During his MBA at the University of Toronto, he developed a sustainability ranking algorithm for mining projects for Sustainalytics which used in the company’s global operations.

- Akhil has worked on sustainability projects for companies such as Philips Lighting and given presentations and interviews on the topic for multiple publications including the New York Times. He was also intimately involved in the Ontario Cap and Trade and Offsets programs as part of the Government. Akhil received his MBA from the University of Toronto.

Green Story’s mission is help companies communicate environmental and social impact to stakeholders in a clear, credible and relatable manner.

We work with a range of companies from waste management firms to one of North America’s largest bottled water manufacturers to engage stakeholders and measure and communicate impact.

Green Story is a Ministry of Environment Agent of Change, Social Capital Markets scholarship recipient, a member of the MaRS Centre for Impact Investing and of Ryerson University’s Social Venture Zone

Contact: akhil@greenstory.ca