

# EXECUTIVE SUMMARY

## Life Cycle Assessment Comparing Ten Sources of Manmade Cellulose Fiber

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*Prepared by:*

**Tobias Schultz** | Manager of Corporate Sustainability Services

**Aditi Suresh** | Corporate Sustainability & Life Cycle Assessment Associate  
Corporate Sustainability Services

*Contact Person:*

Tobias Schultz, +1-510-452-6389, [tschultz@scsglobalservices.com](mailto:tschultz@scsglobalservices.com)



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## Executive Summary

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This Life Cycle Assessment (LCA) study evaluates the life cycle impact profile of manmade cellulose fibers (MMCF), made from pulp originating from ten different sources. It examines MMCF derived from five completely different material feedstocks (wood from different forest regions, bamboo pulp, cotton linter, flax by-products, recycled clothing), with supply chains stretching across four continents. This study is the first to date which looks at 10 scenarios of MMCF production, with a focus on analyzing impacts associated with fibers from different locations, supply chains, and manufactured using different mill technologies.

The LCA provides information useful in the development of environmentally sustainable sourcing strategies for apparel companies, by evaluating the differences in the relative environmental performance of the different fiber sources considered (particularly in relation to terrestrial and freshwater ecosystem impacts). It also provides quantitative information to identify fiber sources which have improved environmental performance for specific impact categories.

This LCA study was conducted in conformance with ISO 14044<sup>1</sup>, the draft LEO-S 002 standard,<sup>2</sup> and the Product Category Rule Module for Roundwood.<sup>3</sup> This study is a comparative assertion intended to be disclosed to the public. The study has been critically reviewed by a panel of four expert stakeholders representing academia, LCA experts, textile industry experts, and the environmental community.

### 1. Goal and Scope of the Study

A key goal of the study is to understand the relative level of impacts on ecosystems associated with the production of each source of MMCF. An additional goal is to understand the unit processes which are the biggest contributors to environmental impacts.

The scope of this LCA is cradle-to-gate, including all relevant impacts involved in raw material extraction, dissolving pulp (DP) production, and production of MMCF (including viscose staple fiber, lyocell staple fiber, and flax fiber). Impacts associated with the use and end-of-life of MMCF are excluded (these stages are similar for all products considered). Due to the potential use of MMCF in various applications (e.g. yarns, embroidery threads, blended fabrics, apparel, and upholstery), a specific functional unit cannot be clearly defined and a declared unit is used; the production of 1,000 tons of staple fiber (MMCF).

The geographical and technological scope including ten different scenarios for MMCF made in different regions are presented in Table 1 below.

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<sup>1</sup> ISO 14044:2006 Environmental management – Life Cycle Assessment – Requirements and guidelines

<sup>2</sup> LEO-SCS-002 Standard Draft Dated June 2014. Leonardo Academy.  
<http://www.leonardoacademy.org/programs/standards/life-cycle.html>

<sup>3</sup> PCR Module for Roundwood Production:  
[https://www.scsglobalservices.com/files/resources/pcr\\_final\\_wood-products\\_101816.pdf](https://www.scsglobalservices.com/files/resources/pcr_final_wood-products_101816.pdf)

**Table 1.** Scope of the LCA study including 10 different scenarios of MMCF production.

Scenario Name	Type of Manmade Cellulose Fiber (MMCF)	Type and Source of Dissolving Pulp	Location of Dissolving Pulp (DP) Mill	Location of Staple Fiber (MMCF) Mill
1. German Production from Swedish Managed Forest Pulp	Viscose staple fibers	Softwood pulp from Sweden	Sweden	Germany
2. Asian Production from Canadian Boreal Forest Pulp <sup>4,5</sup>	Viscose staple fibers	Softwood pulp from Canada	Canada	China
3. Chinese Production from Indonesian Rainforest Pulp <sup>5</sup>	Viscose staple fibers	Mixed tropical hardwood pulp from Indonesia	Indonesia	China
4. Chinese Production from Indonesian Plantation Pulp <sup>5</sup>	Viscose staple fibers	Eucalyptus pulp from Indonesia	Indonesia	China
5. German Production from Recycled Pulp	Viscose staple fiber	Recycled pulp from clothing inputs	Sweden	Germany
6. Chinese Production from Chinese Bamboo Pulp	Viscose staple fiber	Bamboo pulp from China	China	China
7. Chinese Production from Indian Cotton Linter Pulped in China	Viscose staple fibers	Cotton linter* sourced from India and pulped in China	China	China
8. Chinese Production from South African Plantation Pulp	Viscose staple fibers	Eucalyptus pulp from South Africa	South Africa	China
9. Austrian Production from mixed South African Plantation & Austrian Managed Forest Pulp	Lyocell fibers	Mix of beechwood and eucalyptus pulp from Austria	Austria/ South Africa	Austria
10. Belgian Flax Production	Flax fibers*	Not Applicable**	Not Applicable	Belgium

\* Scenario 7 and Scenario 10 consider co-products of cotton (cotton linter) and flax fibers (short fibers from combings and card waste) respectively.

\*\*Scenario 10 (Belgian Flax Production) does not involve any pulping process. The flax fibers are chemically processed using proprietary technology to produce fibers that are functionally equivalent to MMCF

The dissolving pulp mills and MMCF mills were identified carefully, based on characteristics including location of the mill, current supply chain of the MMCF mills and production capacities, and overall representativeness of local industry in the considered scenario. The mills included were reviewed in consultation with experts and thus serve as representations adequate to achieve the goals of the study, but it should be recognized use of different mills could affect results. The temporal scope includes production of MMCF in 2016.

<sup>4</sup> Scenario 2 considers sourcing of pulp from a hypothetical dissolving pulp mill located in Canada, which is projected to be transformed from a pulp/paper mill to a dissolving grade pulp mill.

<sup>5</sup> The forests in Scenarios 2 and 3 from which timber is extracted are “ancient and endangered forests” as defined by the [CanopyStyle](#) initiative; Scenario 4 includes plantations which are present in regions where such forests were cleared recently.

## 2. Methodology Summary

A life cycle inventory (LCI) analysis was conducted in conformance with ISO 14044, draft LEO-S-002 and the Roundwood PCR<sup>6</sup>. The openLCA software<sup>7</sup> was used to model and analyze the complete set of inputs and outputs associated with all production stages in each product system, by unit process. The complete set of inputs and outputs is called the LCI for each product system. The LCI of product systems are modeled based on primary data of dissolving pulp mills and staple fiber mills for three of the ten scenarios, and supplemented with site-level data from third party databases such as RISI and Chinese market research firms for other scenarios. Representative data from the Ecoinvent v3.1 database was used to model background processes.<sup>8</sup> Data for category indicators assessed for Terrestrial Ecosystem Impacts is sourced from government forest inventories and threatened species lists, the NatureServe Explorer Database,<sup>9</sup> IUCN Red list species,<sup>10</sup> and literature.

It is important to note that this is a cradle-to-gate study, which ends at the MMCF production facility and is subject to certain key assumptions and limitations discussed in Section 4.3 of the main LCA report. Furthermore, it is to be noted that impacts during downstream processing (e.g. weaving, knitting, dyeing, finishing, etc.), use and waste management stages may differ depending on the source of MMCF.

## 3. Results Summary

The number of selected impact categories is intended to comprehensively reflect all impacts relevant to MMCF production. The LCA methodology contains a relatively larger number of impact categories (over twenty impact categories considered in five groups) than previous LCAs of MMCF. Some new impact categories include:

- Effects on the Climate Hot Spots present in Indonesia, East Asia (China), and Africa. In these regions, ambient pollution from the aerosols, mostly driven by black carbon and sulfate aerosols, has greatly disrupted regional climates.
- An in-depth evaluation, using site-specific data, of impacts on Terrestrial and Freshwater Ecosystems, which are of major concern for most sources of MMCF. This considers quantitatively, the ecological conditions of forest ecosystems, compared with undisturbed conditions. It evaluates the implications of differing land use management regimes, the potential consequences in the absence of harvest and the "opportunity cost" of ongoing

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<sup>6</sup> PCR LCIA Methodology:

[https://www.scsglobalservices.com/files/resources/pcr\\_final\\_lcia-methodology\\_101816.pdf](https://www.scsglobalservices.com/files/resources/pcr_final_lcia-methodology_101816.pdf)

<sup>7</sup> openLCA modeling software, version 1.5.beta1 By GreenDelta.

<sup>8</sup> Ecoinvent v3.1 Swiss Center for Life Cycle Inventories, 2014. The system model used is based on the recycled content cut-off method. <http://www.ecoinvent.org>

<sup>9</sup> NatureServe Explorer: An Online Encyclopedia of Life. <http://explorer.natureserve.org/>

<sup>10</sup> IUCN Red List Species database; <http://www.iucnredlist.org/>

harvests.<sup>11</sup> Furthermore, it also considers the threatened, endangered, and vulnerable species affected negatively by local land use management practices.

- Ocean acidification, referred to by some as the “evil twin” of Global Climate Change.<sup>12</sup> After emission, roughly 25% of CO<sub>2</sub> is absorbed by the oceans,<sup>13</sup> fundamentally changing the chemistry of seawater in a mechanism parallel to climate change.<sup>14</sup>

While there are a number of impact categories in the scope, this LCA does not use numerical weighting or any other approach to indicate any priority or importance of any impact category over any other.

The relative environmental performance of each scenario is illustrated in Figure 1. The results are provided for the production of 1,000 tons of MMCF, for all ten scenarios, by impact category indicator in the main LCA report.

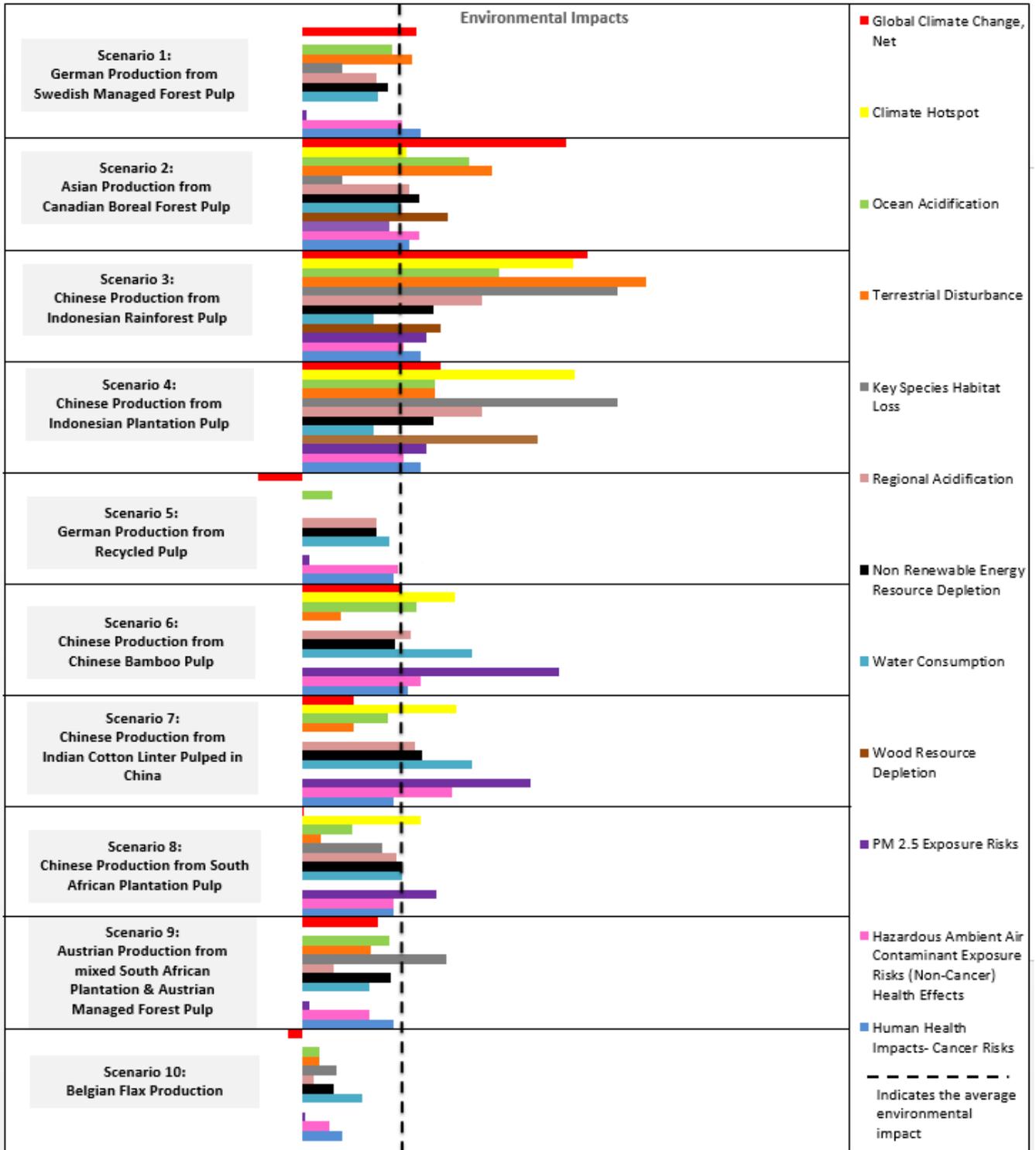
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<sup>11</sup> Across the scenarios, the socio-economic implications of avoiding harvests will be different. For example, the socio-economic implications of regenerating forests in Europe, are very different from forgoing harvesting in forests in Indonesia or Canada’s Boreal. These socio-economic considerations are outside the scope of this LCA.

<sup>12</sup> United Nations University. Climate Change’s ‘Evil Twin’: Ocean Acidification. 2013. See <https://ourworld.unu.edu/en/climate-changes-evil-twin-ocean-acidification>

<sup>13</sup> National Oceanic and Atmospheric Administration. Ocean Acidification: The Other CO<sub>2</sub> Problem. <http://www.pmel.noaa.gov/co2/story/Ocean+Acidification>

<sup>14</sup> The inclusion of ocean acidification anticipates a trend to include this impact category in other LCAs. See Bach, V., et al. Characterization model to assess ocean acidification within life cycle assessment. The International Journal of Life Cycle Assessment. April 2016.



**Figure 1.** Summary chart shows the relative environmental performance, by scenario and by impact category. Results were normalized based on the average environmental impact (indicated as a dash line in the figure). Impact bars which cross the dash line suggest that the scenario has above average impacts, whereas impact bars below the dash line indicate that the scenario has impacts which is below the average.

#### 4. Summary of Key Findings

Based on the results presented above, the following key findings can be derived:

##### **Variation in Impacts of MMCF from Different Sources:**

There is a very wide variability in impacts associated with MMCF sourcing, resulting not only from differences in material feedstocks, but also the region where the fiber inputs originate, the land use management practices involved in raw material feedstock extraction, the location of the supply chain operations and the type of mill technology being used. This LCA makes it clear that it is critical to understand not just the type of material used in MMCF production, but also the source of material.

##### **Key Drivers of Environmental Performance:**

For most scenarios, a few unit processes at similar stages in the life cycle drive most of the resulting impacts. This includes the following processes:

*Land use management, including logging and agriculture.*<sup>15</sup> For Global Climate Change and Ocean Acidification, this accounts for a significant level of impact for all scenarios (due to forest carbon storage losses from harvesting wood/agricultural inputs); and for Terrestrial and Freshwater Ecosystem Impacts, it is the sole driver. The inherently local effects of different land use management regimes on distinct ecosystems in various regions, result in different effects on terrestrial disturbance, key species, and biogenic carbon storage

*Production of dissolving pulp.*<sup>16</sup> The use and purchase of energy leads to air emissions which contribute to multiple impact categories; for Global Climate Change, dissolving pulp production is the first or second most important contributor to results for all scenarios, and is a very significant contributor to PM2.5 Exposure Risks and Regional Acidification as well.

*Operations at MMCF mills.* The use and purchase of energy leads to air emissions which contribute to multiple impact categories; for Global Climate Change, it contributes between 9-37%. It is the dominant contributor (accounting for over 50% of results) to Regional Acidification in nearly all scenarios, and contributes to at least 25% of total impacts across all scenarios.

*Sodium hydroxide production and sulfuric acid production.* These processes, including the upstream production of these materials used at MMCF mills, make up important contributions to several impact categories in selected scenarios, including Global Climate change (for Scenario 5: German Production from Recycled Pulp and Scenario 10: Belgian Flax Production), Climate Hot Spots (for all scenarios where this impact is relevant), Non-renewable energy resource depletion, Regional Acidification, and PM2.5 Exposure Risks.

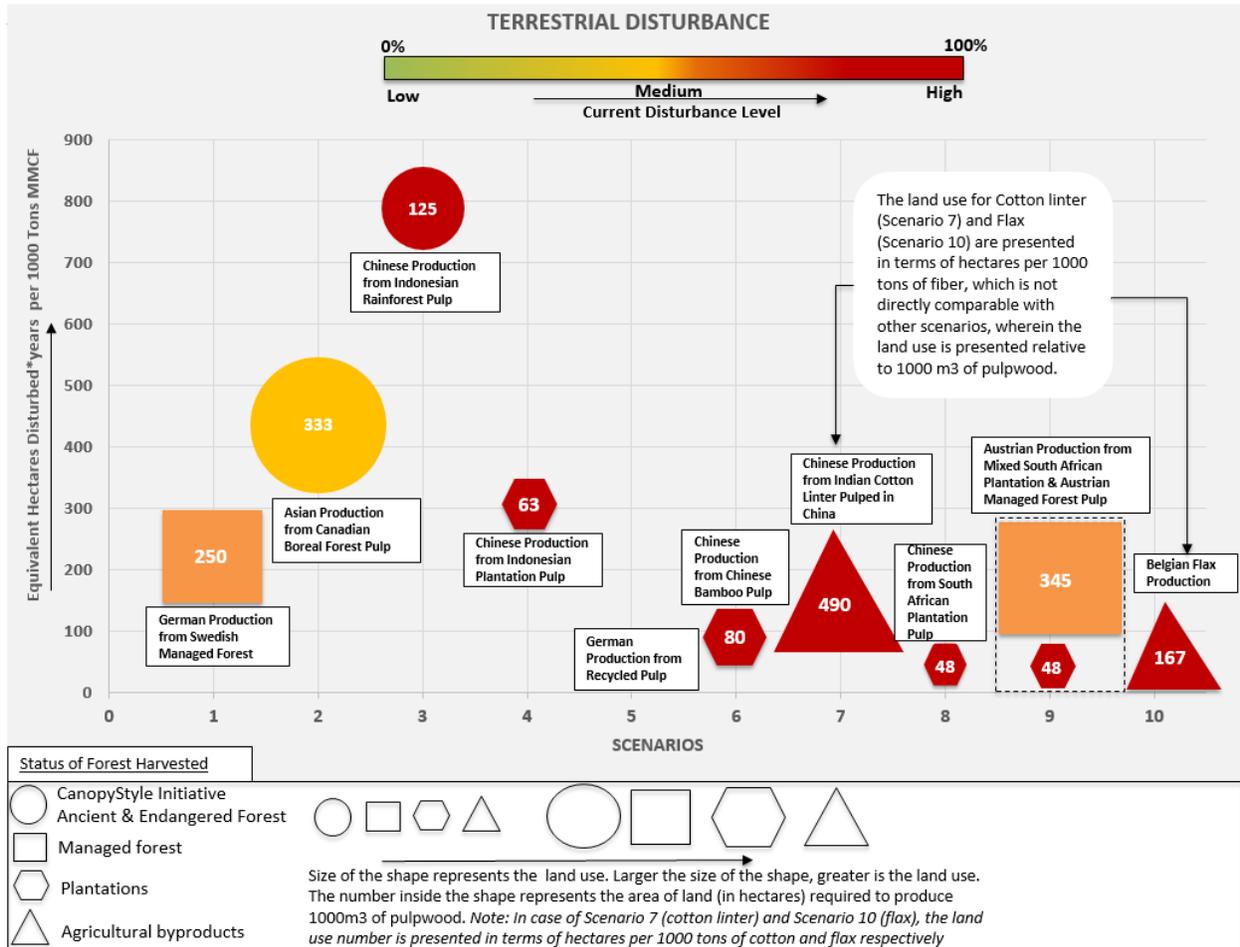
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<sup>15</sup> Not relevant for Scenario 5: German Production from Recycled Pulp.

<sup>16</sup> Not relevant for Scenario 10: Belgian Flax Production.

## Variations in Terrestrial and Freshwater Ecosystem Impacts

The Terrestrial and Freshwater Ecosystem Impacts vary widely (as illustrated in the chart below) and are mainly driven by logging and agriculture (depending on the raw material from which the fiber is manufactured).



**Figure 2.** Terrestrial disturbance chart portraying the following information for each source of MMCF: (i) number of hectares disturbed to produce MMCF; (ii) the status of forest harvested by scenario (i.e. plantations or agricultural byproducts); (iii) land use is the area required to produce 1,000m<sup>3</sup> pulpwood or 1,000 tons of agricultural by-product (applicable to cotton linter and Scenario 10: Belgian Flax Production); and (iv) the color of the shape indicates the current terrestrial disturbance level (i.e. green color indicates low disturbance, orange indicates medium disturbance and red indicates high disturbance). Refer to the main LCA for detailed interpretation of results. See Section 1.2.1 in the main LCA report for the definition of “ancient and endangered” forest as used in the CanopyStyle initiative.

The terrestrial disturbance impacts are dependent on the site productivity in a given region; the volume of fiber which can be extracted from a given area over an extended period of time. Although some forests, such as those in Scenario 3: Chinese production from Indonesian Rainforest Pulp, Scenario 4: Chinese Production from Indonesian plantation pulp, and Scenario 8: Chinese production from South African plantation pulp, are in a very high state of disturbance because of transition from native forests or grasslands to exotic plantations, forests in these regions are extremely productive. Conversely,

Sweden, Canada and Austria do not experience the high state of disturbance, however require significantly more area to be managed for harvest to produce the same amount of material.

In Indonesia, forest conversion has been extremely rapid, with forests being converted from a largely undisturbed state 20 years ago to a fully disturbed state today. At the current trend, there will be essentially no undisturbed forest remaining in the Indonesian region in 10-20 years. This LCA finding is consistent with independent evaluations completed for Indonesian forests by organizations such as WWF.<sup>17</sup> These trends in forest disturbance are factored into the analysis and is one of the reasons for the relatively high result of terrestrial disturbance for dissolving pulp sourced from Indonesia.

In addition to physical alterations resulting in terrestrial disturbance, wood extraction, intensive agriculture and land transformation activities, can also have a negative influence on the species habitat, causing a decline in species population.

## **5. Conclusions**

It can be concluded that the choice of the MMCF raw material input is a critical one with overarching effects on life cycle analysis of impacts. While there is no source of MMCF which is unambiguously environmentally preferable across all impact categories, Scenario 10: Belgian Flax Production seems favorable across majority of the impact categories, followed by Scenario 5: German Production from Recycled Pulp. Table 2 below provides a relative comparison of the ten scenarios across each impact category and identifies the best, worst and mid-range performer(s) in the same.

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<sup>17</sup> Terrdaily, 2005. WWF Warns that Borneo's Forests Could be Destroyed within a Decade.  
<http://www.terraily.com/news/terraily-05f.html>

**Table 2.** Color coded matrix to distinguish the best and worst performers amongst the ten scenarios, by impact category, on the basis of LCA results presented in Section 1.3. Refer to the legend provided in the table below.

Impact Categories by Group		1. German Production from Swedish Managed Forest Pulp	2. Asian Production from Canadian Boreal Forest Pulp	3. Chinese Production from Indonesian Rainforest Pulp	4. Chinese Production from Indonesian Plantation Pulp	5. German Production from Recycled Pulp	6. Chinese Production from Chinese Bamboo	7. Chinese Production from Indian Cotton Linter Pulped in China	8. Chinese Production from South African Plantation Pulp	9. Austrian Production from mixed South African Plantation & Austrian Managed Forest Pulp	10. Belgian Flax Production
<b>Biotic/Abiotic Resource Depletion Impacts</b>											
Nonrenewable Energy Resource Depletion										*	
Net Freshwater Consumption			*	*	*		*	*	*	*	
Wood Resource Depletion							*				
<b>Global and Regional Climate System Impacts</b>											
Global Climate Change, Net										*	
Regional Climate Impacts			*	*	*		*	*	*		
<b>Ocean Ecosystem Impacts</b>											
Ocean Acidification				*	*		*	*	*	*	
Ocean Warming											
<b>Terrestrial &amp; Freshwater Ecosystem Impacts (from Emissions)</b>											
Regional Acidification							*	*		*	
Freshwater Eutrophication											
<b>Terrestrial &amp; Freshwater Ecosystem Impacts (from Land Use and Conversion)</b>											
Terrestrial Disturbance							*	*	*		
Freshwater Disturbance											
Wetland Disturbance											
Threatened species Habitat Disturbance											
<b>Human Health Impacts (from Chronic Exposure to Hazardous Chemicals)</b>											
PM 2.5 Exposure Risks							*	*		*	
Hazardous Ambient Air Contaminant Exposure Risks – Respiratory (Non-Cancer) Health Effects		*	*	*	*	*	*	*	*	*	*
Human Health Impacts- Cancer Risks		*	*	*	*	*	*	*	*	*	*
Ground Level Ozone Exposure Risks											
Legend		*	Indicates Low Data Quality								
			Impact category is relevant but could not be evaluated due to lack of consistent data across all scenarios								
		Best performer(s) amongst the ten scenarios <sup>18</sup>									
		Worst performer(s) amongst the ten scenarios									
		Mid-range performer (better than some scenarios, worse than others)									

<sup>18</sup> Impact category indicator results for the best and worst performers which are within ~±15% are denoted in the same color. This is within a reasonable margin of error. As a result, some scenarios have multiple best and worst performers, indicating there was not sufficient accuracy in results to differentiate these scenarios.

All raw material inputs of MMCF have benefits and disadvantages environmentally. However, some sources of fiber have more benefits, and fewer disadvantages, than others. The following can be noted from the relative comparison of the ten different scenarios across each impact category:

- MMCF from Scenario 5: German Production from Recycled Pulp and Scenario 10: Belgian Flax Production have lowest impacts and Scenario 2: Asian Production from Canadian Boreal Forest Pulp, Scenario 3: Chinese Production from Indonesian Rainforest Pulp, Scenario 4: Chinese Production from Indonesian Plantation Pulp and Scenario 7: Chinese Production from Indian Cotton Linter Pulped in China should be avoided. These findings should be reconciled with existing corporate policies and commitments related to forests while making procurement decisions.
- Scenario 3: Chinese Production from Indonesian Rainforest Pulp, Scenario 4: Chinese Production from Indonesian Plantation Pulp are the worst performers in multiple categories, including Global Climate Change, Climate Hotspot, Ocean Acidification (applies to Scenario 3 only), Terrestrial Disturbance (applies to Scenario 3 only), Regional acidification, Non-renewable resource depletion and Human Health impacts. These two scenarios are also the worst performers in terms of number of species affected by habitat loss. This is due to the rapid and large scale conversion of forests in this region, as well as the highly diverse nature of local ecosystems.
- Impacts to Terrestrial and Freshwater Ecosystem are a major driver for many impact categories, with the exception of Scenario 5: German Production from Recycled Pulp. There is wide variation in the level of impacts on forest ecosystems as described below.
  - Wood resource depletion impacts are only relevant for Scenario 2: Asian Production from Canadian Boreal Forest Pulp, and Scenario 3: Chinese Production from Indonesian Rainforest Pulp. These are the only regions where a depletion in valuable wood resources is occurring.
  - Scenario 3: Chinese Production from Indonesian Rainforest Pulp, exhibits the highest terrestrial disturbance, followed by Scenario 2: Asian Production from Canadian Boreal Forest Pulp. Of note, Scenario 2 is the 2<sup>nd</sup> worst performer for Global Climate Change, faring better only than Scenario 3, where carbon loss is very high. These are the worst performing options across all potential sources of MMCF by a wide margin.

The main LCA report provides more depth on the results and key findings described above, as well as the methodology and data sources used to derive the results.

## PEER PREVIEW PANEL FINDINGS

This critical review panel reviewed 4 drafts of the Life Cycle Assessment Comparing Ten Sources of Manmade Cellulose Fiber, conducted by SCS Global Services. Based on expertise that covers the range of investigations included in this LCA, the panel paid particular attention to ensuring that the LCA:

- Evaluated the life cycle impact profile of manmade cellulose fibers from ten different sources, conforming methodologically to the international LCA standard (ISO 14040 and 14044).
- Compares the life cycle footprint of the 10 fiber sources included in the study, using primary data whenever available, public data as specific as possible, and local data when needed.
- Inventory data for DP and MMCF plants was based on a mix of specific data provided by the plant operators, supplemented for several mills using site-level databases that were reasonable and considered to be of appropriate data quality, similar to the data quality of primary data collected from manufacturers.
- Recognizes and acknowledges limitations of the data when necessary, while advocating for further research to further improve future analyses.
- Some indicators used in the impact assessment phase have not been used in an LCA for viscose fiber (eg. climate change indicator incorporating indirect impacts of SO<sub>2</sub> and NO<sub>x</sub> emissions) before. A sensitivity analysis was performed showing that the relative results between scenarios were rather consistent with relative results between scenarios obtained with the CML impact assessment coefficients and indicators (eg for climate change and acidification), which is a positive feature of the study.
- Provides transparency to the greatest extent possible.
- Assures accessibility to the information and process as completely as possible, including to non-technical readers.

The review panel held a series of discussions after the 2<sup>nd</sup> draft, to explore critical issues. It submitted nearly 700 comments during the first 3 rounds of review, all of which were addressed and incorporated in substantive ways. The panel then provided more than 48 comments focusing on ever finer points on the last draft, all of which were addressed and incorporated.

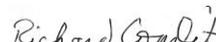
As a result of this intensive review, we consider that this LCA provides an extensive report on the environmental impacts of manmade cellulose fibers, In addition, the report's transparency and accessibility has been an essential priority to us. We are satisfied that this LCA meets ISO 14040 and ISO 14044 standards.



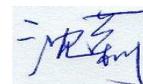
**Neva Murtha (Chair)**  
Senior Campaign Manager  
Canopy



**Olivier Muller**  
PwC Stratégie,  
Développement Durable,  
PricewaterhouseCoopers Advisory



**Dr. Richard Condit**  
Smithsonian Tropical  
Institute



**Dr. Li Shen**  
Assistant Professor,  
Energy & Resources,  
Copernicus Institute of  
Sustainable Development,  
Utrecht University