On behalf of Indorama India Pvt. Ltd.

Report on Comparative Life Cycle Assessment of ECOModa100™ and Conventional Spandex products

Client:	Indorama India Private Limited
Title:	Comparative Life Cycle Assessment of ECOModa100™ and Conventional Spandex Products
Report version:	v1.0
Report date:	02/10/2023

On behalf of Sphera Solutions, Inc., and its subsidiaries

Thinkstep sustainability solutions Pvt Ltd.

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Table of Contents

List of Figures

List of Tables

List of Acronyms

ADP	Abiotic Depletion Potential
AO-245	Antioxidant 245
AP	Acidification Potential
BWC	Blue Water Consumption
CML	Centre of Environmental Science at Leiden, Netherlands
DEA	Diethanolamine
DETA	Diethylenetriamine
DMAC	Dimethylacetamide
EDA	Ethylenediamine
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Cycle Data System
ISO	International Organization for Standardization
IIPL	INDORAMA India Private Limited
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MDI	Methylene diphenyl diisocyanate
MGST	Magnesium Stearate
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone Depletion Potential
PDA	Propylenediamine
PED	Primary Energy Demand
POCP	Photochemical Ozone Creation Potential
PTMEG	Polytetramethylene ether glycol
SFO	Silicone Finishing Oil
SFP	Smog Formation Potential
TETP	Terrestrial Ecotoxicity Potential
TiO_2	Titanium dioxide
VOC	Volatile Organic Compound

Glossary

Life Cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4)

Life Cycle Interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Functional Unit

"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20)

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17)

Closed-loop and Open-loop Allocation of Recycled Material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials."

(ISO 14044:2006, section 4.3.4.3.3)

Foreground System

"Those processes of the system that are specific to it … and/or directly affected by decisions analysed in the study." (JRC, 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background System

"Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good…." (JRC, 2010, pp. 97-98). As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

"Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment" (ISO 14044:2006, section 3.45).

Executive Summary

INDORAMA INDIA Pvt. Ltd. (IIPL) is the Spandex Business of Indorama Corporation established in 2012 at Baddi in Himachal Pradesh and started manufacturing India's first "Made in India" premium spandex fiber. The company has a global presence and supplies quality spandex products to Indian and Global customers across 20+ countries including India, Bangladesh, Sri Lanka, Indonesia, Turkey, Egypt, Latin America, and others. Its products are being used across various applications including Denim, circular/warp knitting, core-spun yarns/air-covered yarns (woven), elastic tapes, narrow-width fabric and in hygiene industry.

As a part of its sustainability agenda, IIPL is interested to conduct comparative life cycle assessment (LCA) of the ECOModa100™ (100% recycled spandex) and conventional spandex products as per ISO 14040 and ISO 14044 standards along with critical review by a panel of 3 experts.

Life Cycle Assessment (LCA) is a recognized tool to measure and quantify the environmental impacts of production systems or products, identifying the "hotspots" with respect to various environment parameters at various stages of product value chain. LCA also aids in discovering further the improvement potentials and enhancing business value.

IIPL has entrusted Sphera Solutions (formerly Thinkstep Sustainability Solutions Pvt. Ltd.) to assess the environmental life cycle information across various life cycle stages for ECOModa100™ and conventional spandex products. The client seeks reliable scientific information to communicate the environmental performance of its products to government, customers or retailers, non-governmental organizations and more generally those requiring such data for environmental labelling purposes.

This is a comparative LCA study of ECOModa100™ and conventional spandex products over cradle to gate system boundary. Subsequent to the collection of data for various products via detailed questionnaires, the data completeness check, harmonization and validation were done. The functional unit considered is 1 Tonne of each of ECOModa100™ and conventional spandex products with packaging. The manufacturing data for conventional spandex correspond to FY 2022-23 whereas the manufacturing data for ECOModa100™ correspond to three months only – January, February and March of 2023. The product system for each product is discussed in detail under Section 2.1. The validated data were utilised to model the various segments of the products using Sphera's GaBi 10.7 LCA software. Once modelled, the environmental impact assessment was evaluated in terms of the impact categories like Acidification Potential (AP), Eutrophication Potential (EP), Global Warming Potential (GWP 100 years), Photochemical Ozone Creation Potential (POCP), Abiotic Depletion Potential (ADP fossil), Primary Energy Demand (PED) and Blue Water Consumption (BWC), etc.

To allow credible communication based on the results of this study, a third-party critical review panel comprising following experts was commissioned to critically review the work and ensure compliance with the ISO 14040 and ISO 14044 standards.

- Dr. Hudai Kara (Panel chair), Managing Director, Metsims Sustainability Consulting, Oxford, UK
- Dr. G. S. Dangayach, Professor, Malaviya National Institute of Technology Jaipur, INDIA
- Prabodha Acharya, Chief Sustainability Officer, JSW Group

The final critical review statement is given in the Annex C: Critical Review Statement.

Results Analysis:

Comparative LCIA results for production of 1 Tonne of each ECOModa100™ and conventional spandex are summarized below in Table 1-1.

Table 1-1: Comparative LCIA Results for 1 Tonne of ECOModa100™ and conventional spandex

Impact Category	Unit	ECOModa100™	Conventional Spandex	% Difference
ADP elements	kg Sb eq.	1.33E-03	0.02	94%
ADP fossil	MJ	20742.96	173571.48	88%
Acidification Potential	kg SO_2 eq.	21.27	37.22	43%
Eutrophication Potential	kg Phosphate eq.	2.49	4.08	39%
Freshwater Aquatic Ecotoxicity Potential	kg DCB eq.	9.87	26.43	63%
GWP 100 years	kg CO_2 eq.	1507.95	8887.56	83%
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	1849.07	9235.74	80%
Human Toxicity Potential	kg DCB eq.	659.41	1077.58	39%
Marine Aquatic Ecotoxicity Potential	kg DCB eq.	4322767.84	5241288.19	18%
Ozone Layer Depletion Potential	kg R11 eq.	3.58E-09	3.08E-08	88%
Photochem. Ozone Creation Potential	kg Ethene eq.	1.62	3.07	47%
Terrestric Ecotoxicity Potential	kg DCB eq.	40.02	201.86	80%
Primary energy demand (net cal. value)	MJ	69937.83	244890.13	71%
Blue water consumption	kg	59806.23	95936.89	38%

- The global warming potential (GWP 100 years) for 1 Tonne of conventional spandex is 8887.56 kg CO_2 eq. Comparing the conventional spandex product, the GWP was reduced by 83% for ECOModa100™ (1507.95 kg CO_2 eq.).
- The abiotic depletion potential (ADP fossil) for 1 Tonne of conventional spandex is 173571.48 MJ. Comparing the conventional spandex, the ADP fossil was reduced by 88% for ECOModa100™ (20742.96 MJ).
- The human toxicity potential (HTP) for 1 Tonne of conventional spandex is 1077.58 kg DCB eq. Comparing the conventional spandex, the HTP was reduced by 39% for ECOModa100™ (659.41 kg DCB eq.).
- The primary energy demand (PED) for 1 Tonne of conventional spandex product is 244890.13 MJ. Comparing the conventional spandex, the PED was reduced by 71% for ECOModa100™ (69937.83 MJ).
- The blue water consumption (BWC) for 1 Tonne of conventional spandex is 95936.89 kg. Comparing the conventional spandex product, the BWC was reduced by 38% for ECOModa100™ (59806.23 kg).

1. Conventional Spandex

Table 1-2 below presents source-wise LCIA results for 1 Tonne of conventional spandex over the cradle to gate system boundary where impacts are classified on the basis of source of impact generation, i.e., raw materials (PTMEG, SFO, TiO_2, MDI, EDA, DMAC, HN150, PDA, n-Butanol, anti-oxidants, and packaging materials), electricity, steam, fuel, hot oil (impact associated with thermal energy required to maintain the temperature of hot oil), transport (transport of raw materials), and waste management.

Table 1-2: Source-wise LCIA Results for 1 Tonne of conventional spandex

Impact Categories	Unit	Total	Raw materials	Transport	Electricity	steam	Fuel	Hot Oil	Process water	Waste management
ADP elements	kg Sb eq.	0.02	0.02	1.89E-06	1.05E-04	2.84E-04	0.00	5.49E-04	1.29E-04	1.58E-05
ADP fossil	MJ	173571	159629	1599.97	5393.01	3696.45	0.00	2800.09	323.22	130.07
Acidification Potential	kg SO_2 eq.	37.22	18.40	1.17	6.40	4.83	0.14	5.95	0.29	0.05
Eutrophication Potential	kg Phosphate eq.	4.08	1.82	0.16	0.27	0.66	0.04	1.09	0.02	0.02
Freshwater Aquatic Ecotoxicity Pot.	kg DCB eq.	26.43	18.77	0.32	0.98	2.29	1.51E-03	3.69	0.13	0.26
GWP 100 years	kg CO_2 eq.	8887.56	7534.84	127.66	543.76	345.94	19.44	246.41	27.89	41.61
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	9235.74	7876.06	125.78	543.97	349.62	18.21	252.99	27.46	41.65
Human Toxicity Potential	kg DCB eq.	1077.58	491.27	12.41	181.91	179.06	0.50	197.88	7.20	7.35
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	5241288	1211062	49174	771401	1316969	0.02	1856241	34197	2241
Ozone Layer Depletion Potential	kg R11 eq.	3.08E-08	2.83E-08	1.22E-10	2.01E-09	1.16E-10	0.00	1.23E-10	8.91E-11	6.87E-11
Photochem. Ozone Creation Potential	kg Ethene eq.	3.07	1.64	0.06	0.30	0.41	0.01	0.64	0.01	2.80E-03
Terrestric Ecotoxicity Potential	kg DCB eq.	201.86	170.89	0.09	1.20	3.40	7.60E-05	5.22	0.11	20.95
Primary energy demand (net cal. value)	MJ	244890	190664	1688	21032	11815	0.00	19052	387	251
Blue water consumption	kg	95936.89	33700.84	134.80	40815.69	2592.49	0.00	3023.90	15889.28	-220.12

The Figure 1.1 shows the graphical representation of the results presented in the Table 1-2.

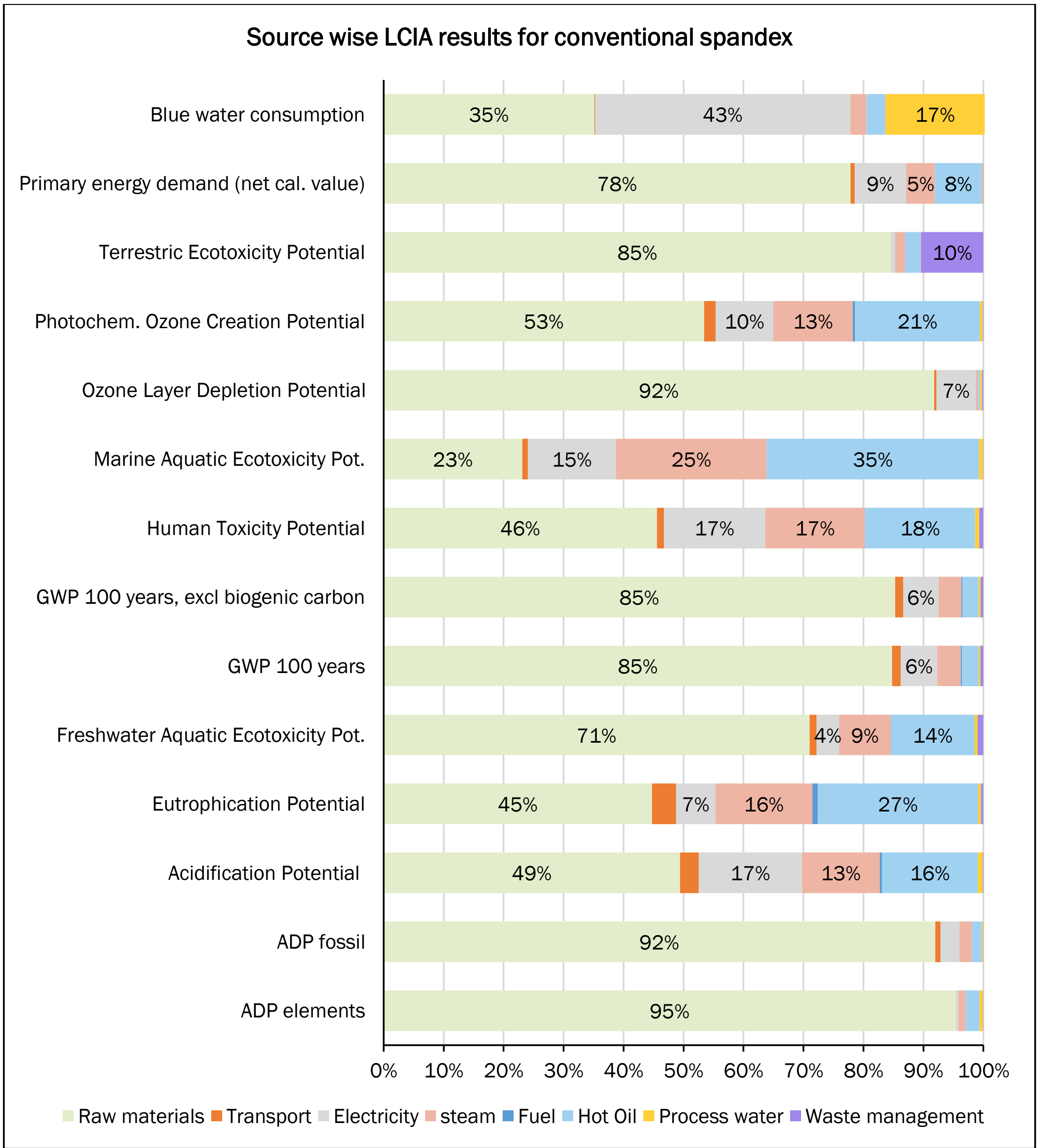

Figure 1.1: Source-wise LCIA results for 1 Tonne of conventional spandex

Hotspot Identification

- Abiotic Depletion Potential (ADP Elements) is 0.02 kg Sb eq. with major contribution from raw materials (~95%).
- Abiotic Depletion Potential (ADP fossil) is 173571.48 MJ with major contribution from raw materials (~92%).
- Acidification Potential (AP) is 37.22 kg SO_2 eq. with major contribution from raw materials (~49%) followed by electricity consumption (~17%), hot oil (~16%) and steam consumption (~13%).
- Eutrophication Potential (EP) is 4.08 kg Phosphate eq. with major contribution from raw materials (~45%) followed by hot oil (~27%), steam consumption (~16%) and electricity consumption (~7%).

- Global Warming Potential (GWP including biogenic carbon) is 8887.56 kg CO_2 eq. with major contribution from raw materials (~85%) followed by electricity consumption (~6%), steam consumption (~4%) and hot oil (~3%).
- Global Warming Potential (GWP excluding biogenic carbon) is 9235.74 kg CO_2 eq. with major contribution from raw materials (~85%) followed by electricity consumption (~6%), steam consumption (~4%) and hot oil (~3%).
- Human Toxicity Potential is 1077.58 kg DCB eq. with major contribution from raw materials (~46%) followed by hot oil (~18%), steam consumption (~17%) and electricity consumption (~17%).
- Ozone Layer Depletion Potential (ODP) is 3.08E-08 kg R11 eq. with major contribution from raw materials (~92%) followed by electricity consumption (~7%)
- Photochemical. Ozone Creation Potential (POCP) is 3.07 kg Ethene eq. with major contribution from raw materials (~53%) followed by Hot Oil (~21%), steam consumption (~13%) and electricity consumption (~10%).
- Primary Energy Demand from renewable and non-renewable Resources (net calorific value) is 244890.13 MJ with major contribution from raw materials (~78%) followed by electricity consumption (~9%), hot oil (~8%) and steam consumption (~5%).
- Blue water consumption is 95936.89 kg with major contribution from electricity consumption (~43%) followed by raw materials (~35%) and process water (~17%).

2. ECOModa100™

Table 1-3 shows the detailed LCIA results for 1 Tonne of ECOModa100™ product over the cradle to gate system boundary where impacts are classified on the basis of source of impact generation, i.e., electricity, steam, fuel (diesel), hot oil (impact associated with thermal energy required to maintain the temperature of hot oil), water, packaging process and waste management.

Table 1-3: Detailed LCIA Results for 1 Tonne of ECOModa100™

Impact Categories	Unit	Total	Electricity	Steam	Hot oil	Process Water	Fuel	Packaging Process	Waste Management
ADP elements	kg Sb eq.	1.33E-03	9.77E-05	2.91E-04	5.44E-04	1.05E-04	0.00	2.74E-04	1.87E-05
ADP fossil	MJ	20742.96	5034.60	3776.53	2753.07	263.38	0.00	8761.38	154.01
Acidification Potential	kg SO_2 eq.	21.27	5.97	4.94	5.88	0.24	0.14	4.05	0.06
Eutrophication Potential	kg Phosphate eq.	2.49	0.25	0.67	1.08	0.02	0.04	0.41	0.02
Freshwater Aquatic Ecotoxicity Pot.	kg DCB eq.	9.87	0.91	2.34	3.65	0.10	1.52E-03	2.55	0.31
GWP 100 years	kg CO_2 eq.	1507.95	507.62	353.44	242.06	22.73	19.52	313.01	49.58
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	1849.07	507.82	357.19	248.58	22.38	18.28	645.21	49.62
Human Toxicity Potential	kg DCB eq.	659.41	169.82	182.94	195.22	5.87	0.50	96.37	8.70
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	4322767.8	720136.2	1345501	1834578	27865.6	0.02	392041	2645.74
Ozone Layer Depletion Potential	kg R11 eq.	3.58E-09	1.88E-09	1.18E-10	1.21E-10	7.26E-11	0.00	1.31E-09	8.18E-11
Photochem. Ozone Creation Potential	kg Ethene eq.	1.62	0.28	0.41	0.63	0.01	0.01	0.27	3.32E-03
Terrestric Ecotoxicity Potential	kg DCB eq.	40.02	1.12	3.47	5.16	0.09	7.63E-05	5.16	25.01
Primary energy demand (net cal. value)	MJ	69937.83	19634.18	12070.80	18847.9	315.32	0.00	18804.9	264.65
Blue water consumption	kg	59806.23	38103.21	2648.66	2994.24	12947.33	0.00	3275.40	-162.60

The Figure 1.2 shows the graphical representation of the results presented in the Table 1-3.

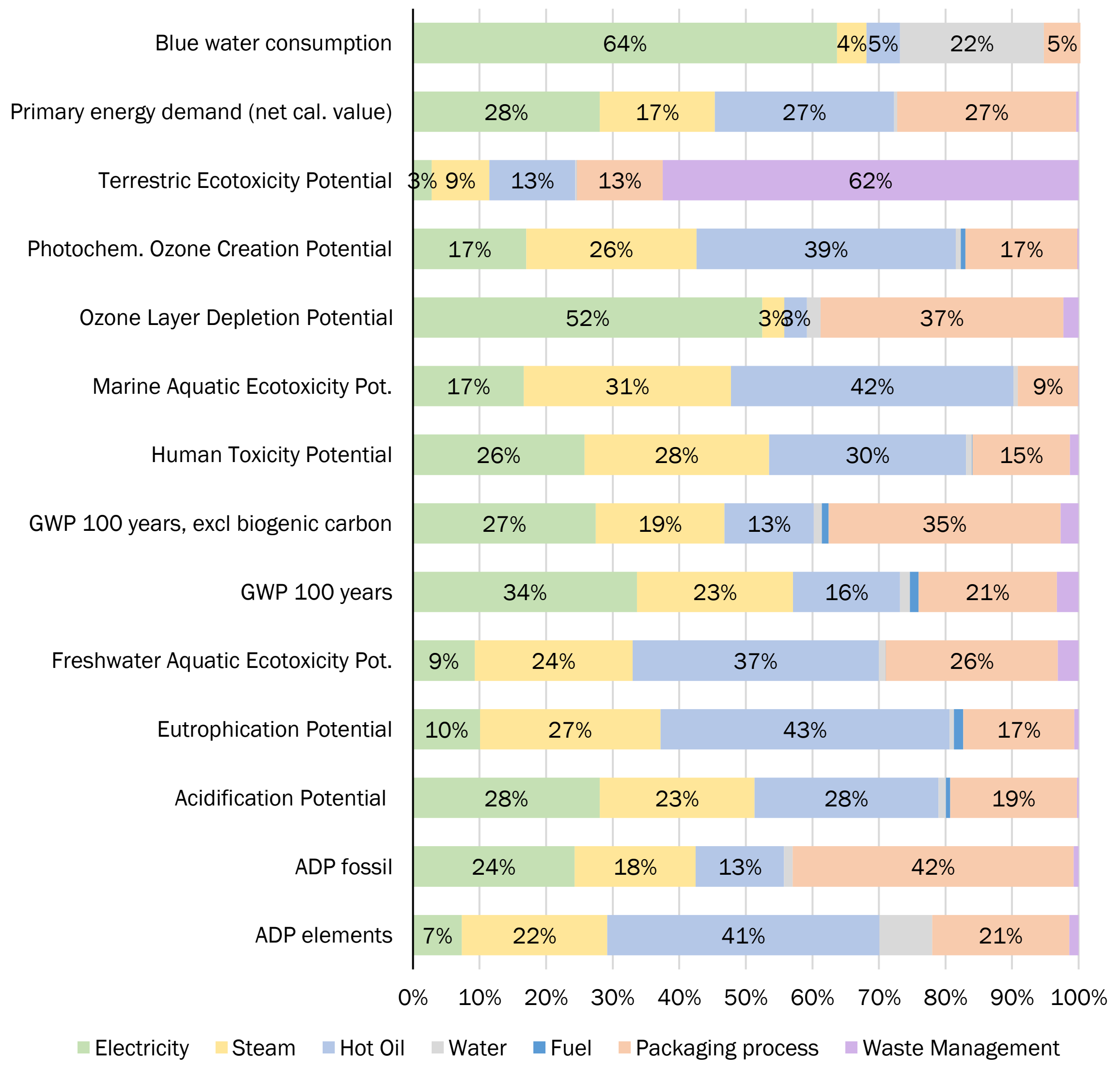

Figure 1.2: Detailed environmental impacts for 1 Tonne of ECOModa100™

Hotspot Identification

- Abiotic Depletion Potential (ADP Elements) is 1.33E-03 kg Sb eq. with major contribution from hot oil (~41%) followed by steam consumption (~22%) and packaging process (~21%).
- Abiotic Depletion (ADP fossil) is 20742.96 MJ with major contribution from packaging process (~42%) followed by electricity consumption (~24%), steam consumption (~18%) and hot oil (~13%).
- Acidification Potential (AP) is 21.27 kg SO_2 eq. with major contribution from hot oil (~28%) followed by electricity consumption (~28%), steam consumption (~23%) and packaging process (~19%).
- Eutrophication Potential (EP) is 2.49 kg Phosphate eq. with major contribution from hot oil (~43%) followed by steam consumption (~27%), packaging process (~17%) and electricity consumption (~10%).
- Global Warming Potential (GWP 100 Years) is 1507.95 kg CO_2 eq. with major contribution from electricity consumption (~34%) followed by steam consumption (~23%), packaging process (~21%) and hot oil (~16%).

- Global Warming Potential (GWP excluding biogenic carbon) is 1849.07 kg CO_2 eq. with major contribution from packaging process (~35%) followed by electricity consumption (~27%), steam consumption (~19%) and hot oil (~13%).
- Human Toxicity Potential is 659.41 kg DCB eq. with major contribution from hot oil (~30%) followed by steam consumption (~28%), electricity consumption (~26%) and packaging process (~15%).
- Ozone Layer Depletion Potential (ODP) is 3.58E-09 kg R11 eq. with major contribution from electricity consumption (~52%) followed by packaging process (~37%).
- Photochemical Ozone Creation Potential (POCP) is 1.62 kg Ethene eq. with major contribution from hot oil (~39%) followed by steam consumption (~26%), electricity consumption (~17%) and packaging process (~17%).
- Primary Energy Demand from renewable and non-renewable Resources (net calorific value) is 69937.83 MJ with major contribution from electricity consumption (~28%), packaging process (~27%), hot oil (~27%) and steam consumption (~17%).
- Blue water consumption is 59806.23 kg with major contribution from electricity consumption (~64%) followed by water (~22%).

Recommendations:

Based on the observations of the present LCA study, a few directional recommendations to reduce GWP across the life cycle stages of ECOModa100™ and conventional spandex production can be summarised as follows:

- ✓ The PTMEG highly influences the overall LCIA results of conventional Spandex, IIPL can consider using biobased PTMEG material instead of PTMEG produced via chemical route.
- ✓ The boilers at IIPL facility consume coal and rice husk as an energy source for steam production, IIPL can consider using natural gas instead of coal.
- ✓ IIPL has easy access to hydroelectricity at Baddi, HP and most of the electricity consumed is from hydel power. IIPL should consider using the electric boiler powered by hydroelectricity.
- ✓ IIPL can also consider recycling its packaging materials such as cardboard boxes, cardboard tubes, and plastic LD liners, which would in turn reduce the demand for virgin packaging materials and lead to GWP impact reduction.
- ✓ IIPL is procuring most of the raw materials from outside the country which is leading to considerable environmental impact because of transportation. IIPL should consider procuring raw materials from the local area.

1. Goal of the Study

The goal of this study is “To carry out comparative life cycle assessment of ECOModa100™ and conventional spandex products manufactured by INDORAMA INDIA Pvt. Ltd. at Baddi in Himachal Pradesh, India”. This will be achieved by conducting the 'Life Cycle Assessment (LCA)' as per the standards ISO 14040:2006 (and its amendment 14040:2006/Amd 1:2020), ISO 14044:2006 (and its amendments 14044:2006/Amd 1:2018 and 14044:2006/Amd 2:2020).

The objectives of this study were:

- Quantifying the environmental impacts of ECOModa100™ and conventional spandex products using LCA approach.
- Identifying the environmental hotspots over a range of environmental impact categories.
- Making strategic business decisions and external communications regarding the environmental benefits of ECOModa100™ in comparison with conventional spandex to various stakeholders.

This assessment is based on credible scientific approach and provides reliable information to various stakeholders. This is a comparative LCA study, and the results of this study can be used in comparative assertions intended to be disclosed to the public. The intended audience for this study includes the internal stakeholders of IIPL such as design, research, marketing, communications, operations etc, while external stakeholders include customers, suppliers, government, environmental practitioners, and non-governmental organizations.

This study provides Life Cycle Inventory (LCI) and Life Cycle Environmental Impact (LCIA) profile over cradle to gate assessment of ECOModa100™ and conventional spandex products. The LCI data consist of the total inputs and outputs of the product system (e.g., carbon dioxide emissions); while the LCIA uses the LCI data to assess impacts such as global warming, etc. Consistent methodology and modelling have been used for this study and are specific to 'ECOModa100™ and conventional spandex products’ manufactured by IIPL.

To allow credible communication based on the results of this study, a third-party critical review panel comprising following experts was commissioned to critically review the work and ensure compliance with the ISO 14040 and ISO 14044 standards.

- Dr. Hudai Kara (Panel chair), Managing Director, Metsims Sustainability Consulting, Oxford, UK
- Dr. G. S. Dangayach, Professor, Malaviya National Institute of Technology Jaipur, INDIA
- Prabodha Acharya, Chief Sustainability Officer, JSW Group

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product System(s)

Spandex (an anagram of the word "expands"), Lycra, or Elastane is a synthetic fiber known for its exceptional elasticity. It is a polyether-polyurea copolymer that was invented in 1958 by chemist Joseph Shivers at DuPont. Brand names for spandex include Lycra (made by The Lycra Company, previously a division of DuPont Textiles and Interiors), Elaspan (The Lycra Company), INVIYA® (INDORAMA INDIA Pvt. Ltd.), ROICA and Dorlastan (Asahi Kasei), ESPA (Toyobo), etc.

The scope includes production of raw materials, their transportation, and the manufacturing of ECOModa100™ and conventional spandex products. Manufacturing data for conventional spandex is obtained from INVIYA® production process at IIPL, Baddi, India and it correspond to FY 2022-23. The manufacturing data for ECOModa100™ correspond to three months only – January, February and March of 2023.

2.1.1. Conventional spandex

The product under this LCA study, conventional spandex is manufactured by IIPL at Baddi in Himachal Pradesh, India and available in markets globally. It is the first new-age spandex fibre produced in India made of advanced polymer, having long-lasting elasticity with robust performance during all textile processes, it exhibits exceptional qualities of stretch and recovery, providing a perfect fit and shape with enhanced comfort and freedom of movement to the wearer.

IIPL uses “Dry spinning” process to manufacture the conventional spandex. Following steps summarize the “Dry spinning” process:

1. Initially the raw materials are dissolved together in presence of a volatile solvent which evaporates when heat is applied to it.
2. The solution produced is then filtered and passed through the vertical spinneret a part of the machine.
3. After the spinneret, the polymer solution travels through the warm air chamber where the volatile solvent is completely evaporated in presence of heated inert gas and the polymer solution solidifies forming fine filaments.
4. The spandex fibres produced are not subjected to an extensional drawing stage which is common in other synthetic filaments but are used in as-spun form.
5. The fibres emerging is twisted, but this twist is later removed when the fibre reaches the first roller, this happens by the tension of the fibre itself.
6. Then oil application is done, and type of oil is dependent on various factors i.e., end application etc. and is done to prevent yarn adhesion on the package.

The Figure 2.1 presents the dry spinning process of spandex production. The major raw materials used for conventional spandex production include PTMEG (sourced from CHINA and TAIWAN), MDI (sourced from CHINA and KOREA), SFO (sourced from USA, GERMANY, CHINA, JAPAN and INDIA), EDA (sourced from SWEDEN and BELGIUM), etc. The electricity required at the manufacturing facility was procured from electricity grid (87% hydel power and 13% Indian grid mix) of Himachal Pradesh, India. Also, the steam required is produced in-house using rice husk and coal as energy sources. Once the spandex is produced, it gets packed using packaging materials like cardboard boxes, cardboard tubes and plastics (LD Liner) and sent for distribution.

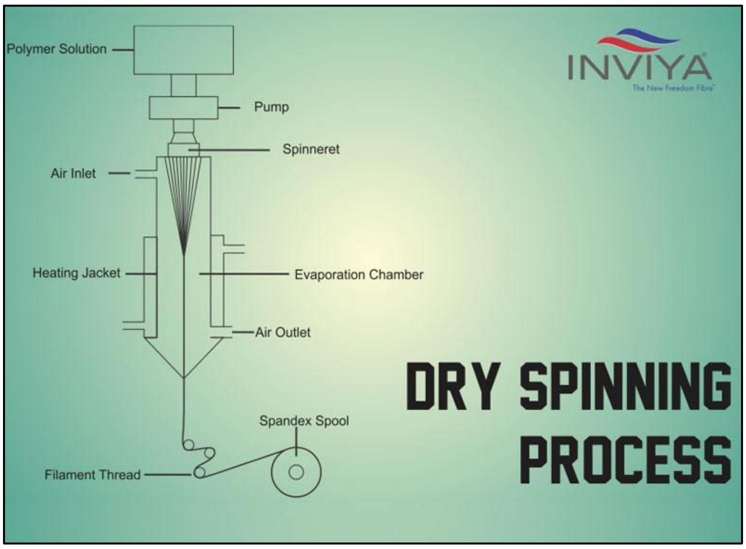

Figure 2.1: Conventional Spandex production method

2.1.2. ECOModa100™

ECOModa100™ is the proprietary spandex product manufactured by IIPL at Baddi in Himachal Pradesh, India. As shown in Figure 2.2, ECOModa100™ is produced by recycling waste spandex as output from conventional spandex production through state-of-the-art technology developed through continuous R&D. ECOModa100™ matches the performance of conventional spandex.

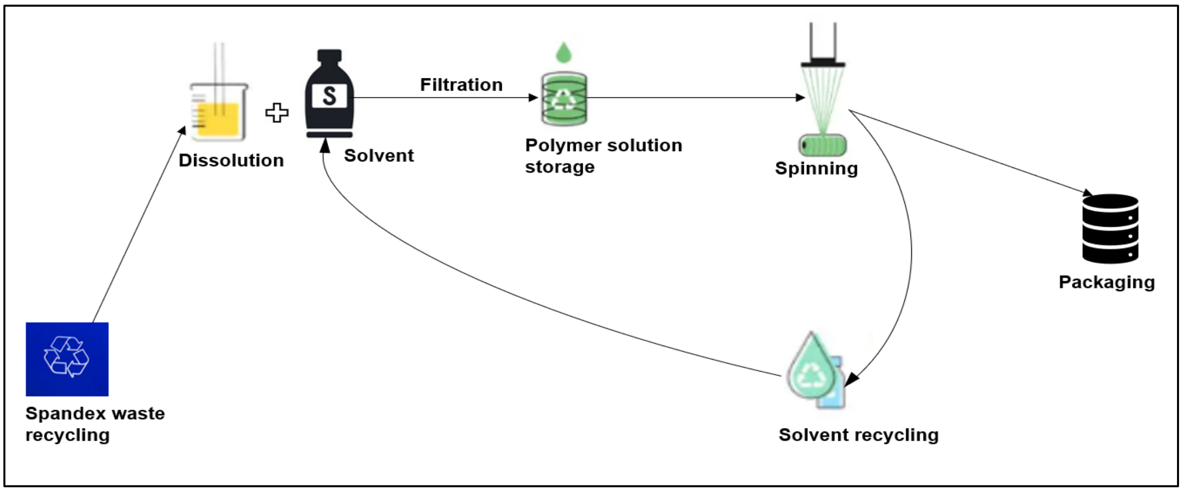

Figure 2.2: ECOModa100™ production process

Product Function and Functional Unit

The functional unit is a reference for the product whose lifecycle impact is being assessed. The functional unit allows quantification of the environmental impacts of the product over cradle-to-gate. These environmental impacts are calculated based on the functional unit wherein each flow related to material consumption, energy consumption, emissions, effluent, and waste is scaled to the reference flow. It is the quantified functional requirements and/or technical requirements for a product to use as a basis for comparison.

The functional unit is 1 Tonne of each of ECOModa100™ and conventional spandex products with packaging.

Therefore, reference flow is 1 Tonne (1000 kg) of each ECOModa100™ and conventional spandex products.

2.2. System Boundary

The LCA model for the study represents a cradle-to-gate approach. It covers various phases in life cycle such as raw materials & packaging materials acquisition, upstream transportation, manufacturing process, and treatment of the waste generated at production facility. The impact associated with the production of the energy (e.g., electricity, natural gas, diesel etc.,) required as utilities is under the scope of this study. The use phase and End of Life (EoL) of products were not included inside the system boundary. The implications of excluding the processes and life cycle stages beyond the factory gate would likely have higher results.

Figure 2.3 shows the cradle to gate system boundary for conventional spandex.

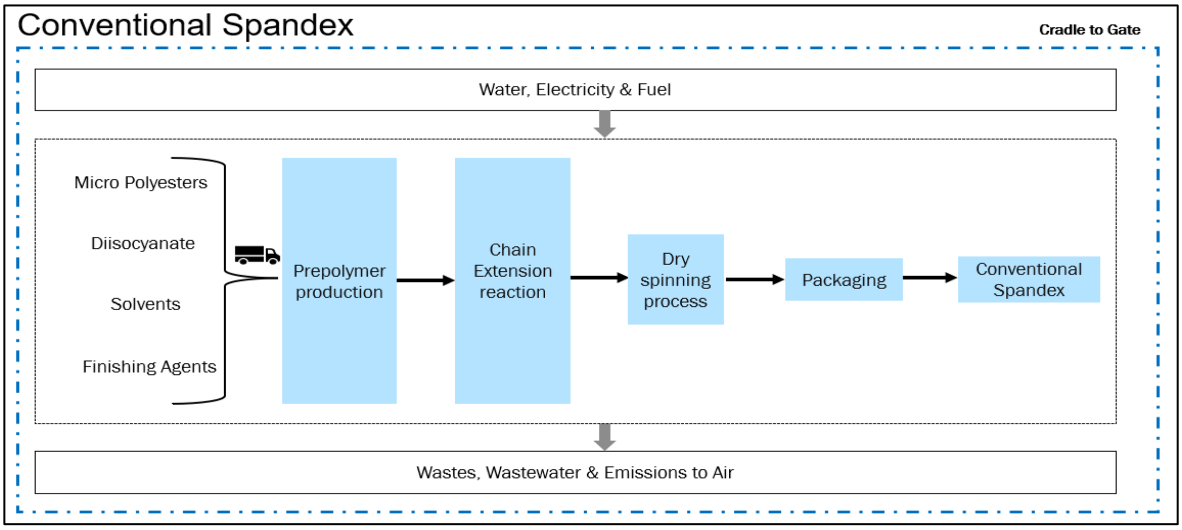

Figure 2.3: Cradle to gate system boundary for conventional spandex

Figure 2.4 shows the cradle to gate system boundary for ECOModa100™.

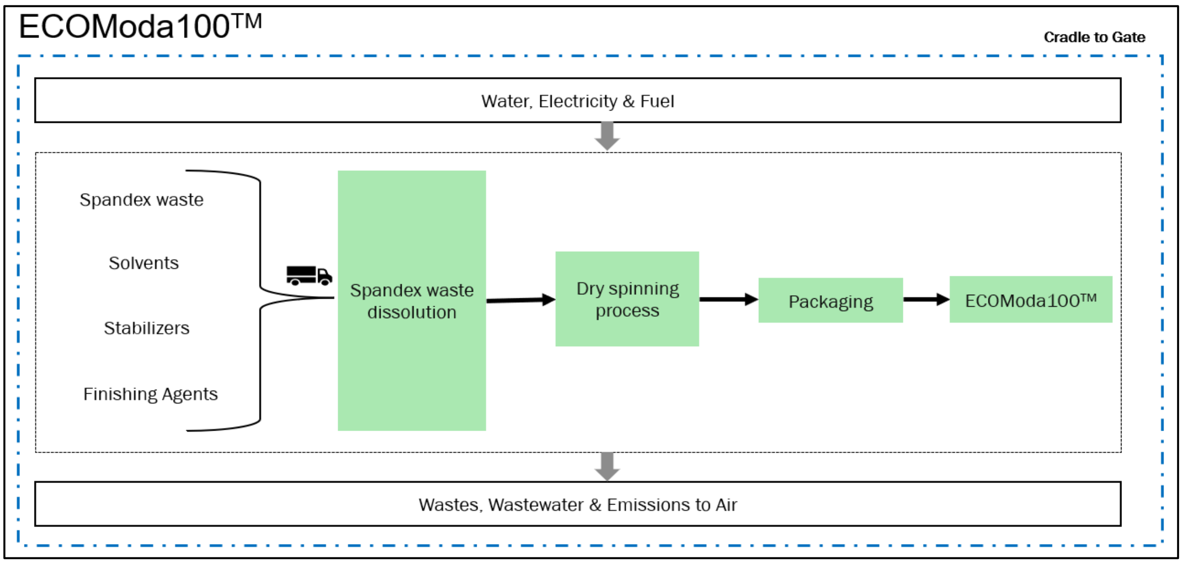

Figure 2.4: Cradle to gate system boundary for ECOModa100™

Table 2-1 enlists various inclusions and exclusions in system boundary for the study.

Table 2-1: Inclusions and exclusions in system boundary

Included	Excluded
✓ Extraction of raw materials and fuel carriers ✓ Inbound transport of raw materials and fuel carriers ✓ Manufacture of ECOModa100™ and conventional spandex products ✓ Packaging of finished product	× Human labour × Construction of equipment × Maintenance and operation of support equipment × Services (Accounting, business, catering, etc.)

2.2.1. Time Coverage

The data collection is related to one year of operation and the year of the data is indicated in the questionnaire for each data point. The manufacturing data for conventional spandex correspond to FY 2022-23 whereas the manufacturing data for ECOModa100™ correspond to three months only – January, February and March of 2023.

2.2.2. Technology Coverage

The exact technological configuration was used for the various process operation of its plants for efficient performance in production and minimizing environmental impacts. It was assumed that secondary data from databases that were used for this assessment, were temporally and technologically comparable to that of primary data and within the temporal coverage already addressed.

The LCI data for production is collected as the average of 12-months data representing FY 2022-23 to compensate the seasonal influence of data. Background data have reference years between 2019 and 2025. The datasets are valid until substantial technological changes in the production chain occurs.

2.2.3. Geographical Coverage

The geographical coverage of this study pertains to the acquisition of various raw materials and packaging materials; and inbound transportations required in production of ECOModa100™ and conventional spandex products by IIPL at Baddi in Himachal Pradesh, India. Country specific datasets were used wherever possible, if no regional datasets were available then Europe [EU] and Germany [DE] specific datasets were chosen.

2.3. Allocation

2.3.1. Multi-output Allocation

Multi-output allocation generally follows the requirements of ISO 14044, section 4.3.4.2. When allocation becomes necessary during the data collection phase, the allocation rule most suitable for the respective process step is applied and documented along with the process in Chapter 3. Allocation of background data (energy and materials) taken from the GaBi 2023 LCI databases is documented online (Sphera Solutions Inc., 2020).

Table 2-2 shows the economic allocation considered in case of conventional spandex production. The impacts are allocated between the conventional spandex product and waste spandex using economic allocation approach.

Table 2-2: Multi-output allocation

Products	Economic allocation factor
Conventional Spandex	99.9%
Waste Spandex	0.062%

2.3.2. End-of-Life Allocation

Not in the scope of this study.

2.4. Cut-off Criteria

In the foreground processes, all relevant flows are considered, with no significant cut-off of material and energy flows. As summarized in section 2.2, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data (see section 3.3) have been applied based on conservative assumptions regarding environmental impacts. The cut-off criteria for the background data have been documented online https://sphera.com/product-sustainability-gabi-data-search/.

In this assessment, construction of capital equipment, maintenance and operation of support equipment, human labour and services were excluded. For upstream system, all relevant raw materials and energy carriers used in manufacturing have been covered in the LCA calculation. The cut-off criteria for the background data have been documented online https://sphera.com/product-sustainability-gabi-data-search/. The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analysed and is discussed in Chapter 0.

2.5. Selection of LCIA Methodology and Impact Categories

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are discussed in this chapter. Various impact assessment methodologies are applicable for use in European and Asian context including e.g., CML, ReCiPe, and selected methods recommended by the ILCD. This assessment is predominantly based on CML2001 – Aug. 2016 impact assessment methodology for the rest of the identified impacts tabulated below. CML 2001 (August 2016) method developed by Institute of Environmental Sciences, Leiden University, Netherlands have been selected for evaluation of environmental impacts. These indicators are scientifically and technically valid.

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project and are given in Table 2-3 and Table 2-4.

Table 2-3: Impact category descriptions

Impact Category	Description	Unit	Reference
Climate change (global warming potential)	A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	(IPCC, 2021)

Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	moles H^+ equivalent	(Seppälä J., 2006; Posch, 2008)
Eutrophication (terrestrial, freshwater, marine)	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	Terrestrial: moles N equivalent Freshwater: kg P equivalent Marine: kg N equivalent	(Seppälä J., 2006; Posch, 2008; Struijs, 2009)
Ozone Depletion	A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants.	kg CFC-11 equivalent	(Guinée, et al., 2002)
Photochemical Ozone Formation	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg C_2H_4 equivalent	(Van Zelm R., 441-453)
Resource use, minerals and metals	The consumption of non-renewable resources leads to a decrease in the future availability of the functions supplied by these resources. Depletion of mineral resources and non-renewable energy resources are reported separately. Depletion of mineral resources is assessed based on ultimate reserves.	kg Sb equivalent	(Guinée, et al., 2002) and (Nassar, et al., 2012)
Resource use, energy carriers	A measure of the total amount of non-renewable primary energy extracted from the earth. Resource use is expressed in energy demand from non-renewable resources including both fossil sources (e.g., petroleum, natural gas, etc.) and uranium for nuclear fuel. Efficiencies in energy conversion (e.g., power, heat, steam, etc.) are taken into account.	MJ	(Guinée, et al., 2002; van Oers, de Koning, Guinée, & Huppes, 2002)

Human toxicity	A measure of toxic emissions which are directly harmful to the health of humans and other species.	Comparative toxic units (CTU_h, CTU_e)	(Rosenbaum, et al., 2008)

Table 2-4: Other environmental indicators

Indicator	Description	Unit	Reference
Primary Energy Demand (PED)	A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g., petroleum, natural gas, etc.) and energy demand from renewable resources (e.g., hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g., power, heat, steam, etc.) are taken into account.	MJ (lower heating value)	(Guinée, et al., 2002)
Water Consumption	A measure of the net intake and release of fresh water across the life of the product system. This is not an indicator of environmental impact without the addition of information about regional water availability.	kg	(Sphera Solutions Inc., 2020) and (Pfister, et al., 2009)

A detailed description of the selected impact categories is given in Annex B: Description of Selected Inventories and Impact Categories.

It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.6. Interpretation to be Used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations and recommendations

Note that in situations where no product outperforms all of its alternatives in each of the impact categories, some form of cross-category evaluation is necessary to draw conclusions regarding the environmental superiority of one product over the other. Since ISO 14044 rules out the use of quantitative weighting factors in comparative assertions to be disclosed to the public, this evaluation will take place qualitatively and the defensibility of the results therefore depend on the authors' expertise and ability to convey the underlying line of reasoning that led to the final conclusion.

2.7. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report.

2.8. Type and Format of the Report

In accordance with the ISO requirements (ISO, 2006) this document aims to report the results and conclusions of the LCA completely, accurately and without bias to the intended audience. The results, data, methods, assumptions and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.9. Software and Database

The LCA model was created using the GaBi 10.7 Software system for life cycle engineering, developed by Sphera Solutions Inc. The GaBi 2023 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.10. Critical Review

As the results of this study are intended to be used to support a comparative assertion disclosed to the public, a critical review must be conducted by a panel of interested, relevant parties, particularly an LCA expert and other stakeholders. The peer review panel is intended to comprise of experts and ISO 14040/44 standard requirements. Table 2-5 enlists the selected critical review committee members.

Table 2-5: Details of Panel Members for Critical Review

Name	Affiliation	Contact detail
Dr Hudai Kara	Managing Director, Metsims Sustainability Consulting, Oxford, UK	hudai.kara@metsims.com
Dr GS Dangayach	Professor, Malaviya National Institute of Technology Jaipur	gsdangayach.mech@mnit.ac.in
Prabodha Acharya	Chief Sustainability Officer, JSW Group	Prabodha.acharya@gmail.com

The objective of the critical review process is to check that the report follows the following criteria:

- The methods used to carry out the LCA are consistent with ISO 14040/44 standards, and scientifically and technically valid.
- The data used are appropriate and reasonable in relation to the goal of the study.
- The interpretations reflect the limitations identified and the goal of the study; and
- The study report is transparent and consistent.

The final critical review statement is given in the Annex C: Critical Review Statement.

3. Life Cycle Inventory Analysis

In this chapter, the software model is described with screenshots and respective explanations. The life cycle impact assessment (LCIA) resulting from the life cycle inventory and the interpretations of the same is displayed in Chapter 4 of this report.

3.1. Data Collection Procedure

Primary data were collected using customised data collection templates, which were sent out by email to the respective data providers in the participating companies. Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera engaged with the data provider to resolve any open issues.

Wherever feasible, the coefficient of variation was established for the different inputs and outputs, either across different data providers or across the reported time period if a breakdown into smaller increments (e.g., 12 months) was available.

The LCI for production of ECOModa100™ and conventional spandex products are reported in Annex A: Life Cycle Inventory.

3.2. Product System(s)

3.2.1. Product Composition

This LCA study compares two spandex products – ECOModa100™ and conventional spandex. Manufacturing data of conventional spandex is obtained from INVIYA® production process at IIPL. Both the spandex products were manufactured by IIPL at Baddi in Himachal Pradesh, India. Raw materials consumption for production of ECOModa100™ and conventional spandex products under this study are summarised in the Annex A: Life Cycle Inventory.

3.2.2. Overview of Product System

For the considered products, GaBi models were prepared and explained in following sub-sections. Cradle to gate models were created in GaBi 10.7 LCA software tool to generate results by feeding the production data for ECOModa100™ and conventional spandex. The background datasets for raw materials, energy, and transportation are listed in Section 3.3.

Figure 3.1 shows snapshot of the GaBi plan for 1 Tonne of conventional spandex production.

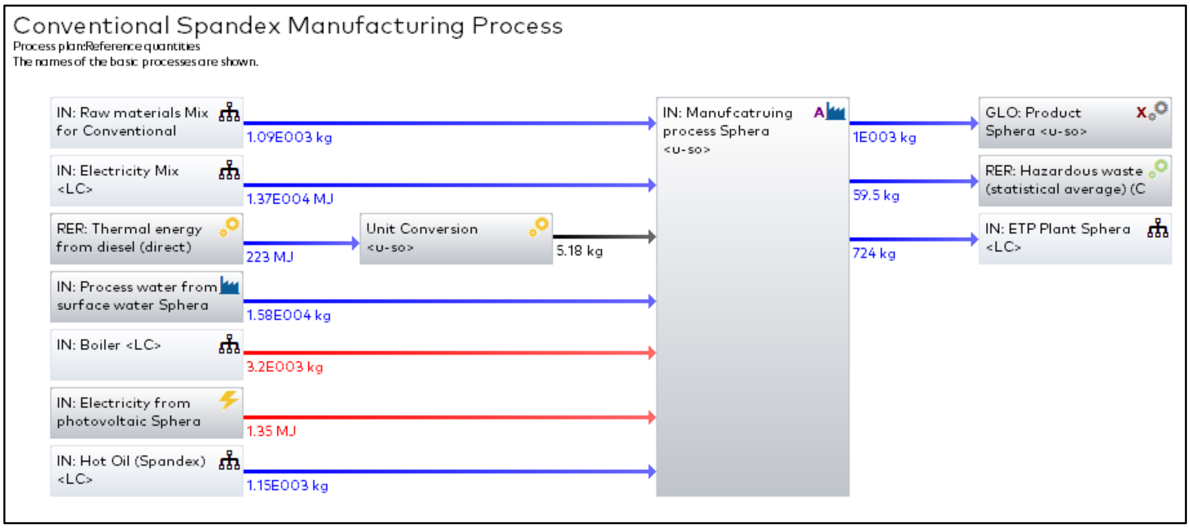

Figure 3.1: GaBi plan for production process of 1 Tonne of conventional spandex

Figure 3.2 shows the GaBi plan of raw materials mix for conventional spandex.

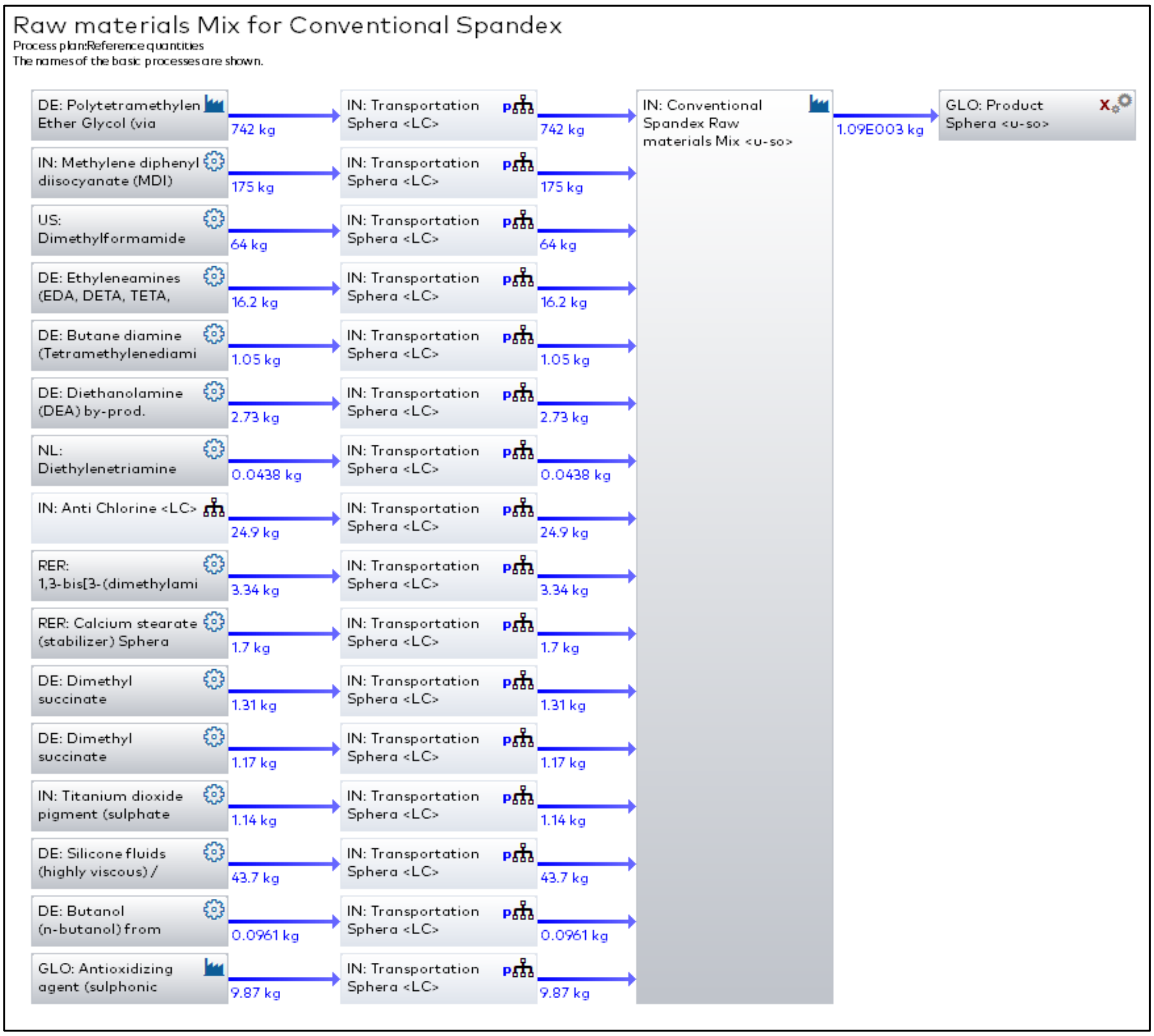

Figure 3.2: Cradle-to-gate GaBi plan of raw materials mix for conventional spandex

Figure 3.3 shows the overall cradle to gate GaBi plan for 1 Tonne of ECOModa100™ manufacturing. The waste spandex output from conventional spandex production was used as the starting raw material for ECOModa100™ manufacturing. Waste spandex is considered to be an environmentally burden free while modelling the ECOModa100™ manufacturing process in GaBi software.

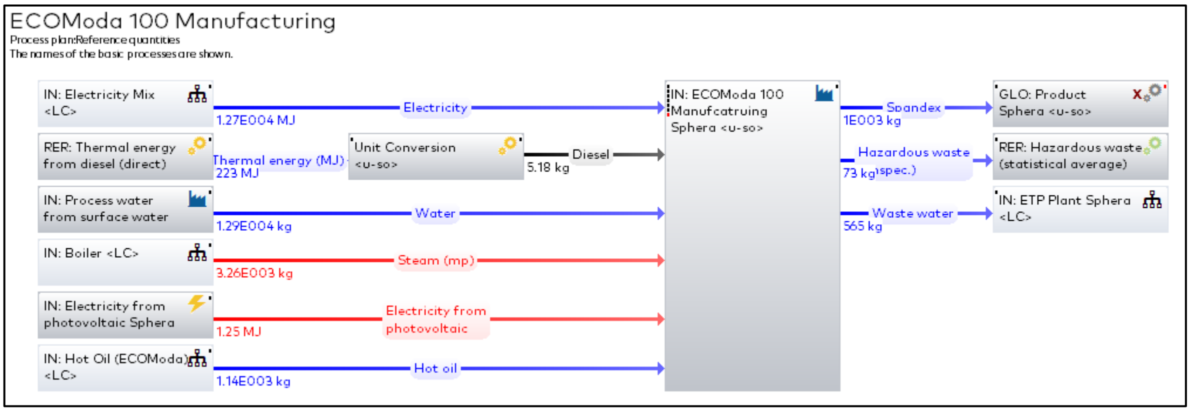

Figure 3.3: Cradle-to-gate GaBi plan for 1 Tonne of ECOModa100™ manufacturing

3.2.3. Manufacturing

The manufacturing phase includes the consumption of electricity and steam during the manufacturing of ECOModa100™ and conventional spandex products as well as the waste management at manufacturing site. Manufacturing data of conventional spandex is from INVIYA® production process at IIPL. Both the spandex products are manufactured at Baddi in Himachal Pradesh, India. The manufacturing data for conventional spandex corresponds to FY 2022-23 whereas the manufacturing data for ECOModa100™ corresponds to three months only – January, February and March of 2023.

The production of 1 Tonne of conventional spandex consumes about 3801 kWh of grid electricity and 0.375 kWh of solar electricity, 5.18 kg of diesel and 15833.25 kg of water whereas the production of 1 Tonne of ECOModa100™ consumes about 3527 kWh of grid electricity and 0.347 kWh of solar electricity, 5.18 kg of diesel and 12870.71 kg of water. The waste spandex output from conventional spandex production was used as the starting raw material for ECOModa100™ manufacturing.

3.2.4. Electricity mix

Figure 3.4 shows the GaBi plan for electricity mix. The electricity mix constituted of 87% contribution from hydroelectricity and 13% contribution from grid electricity (Himachal Pradesh, India).

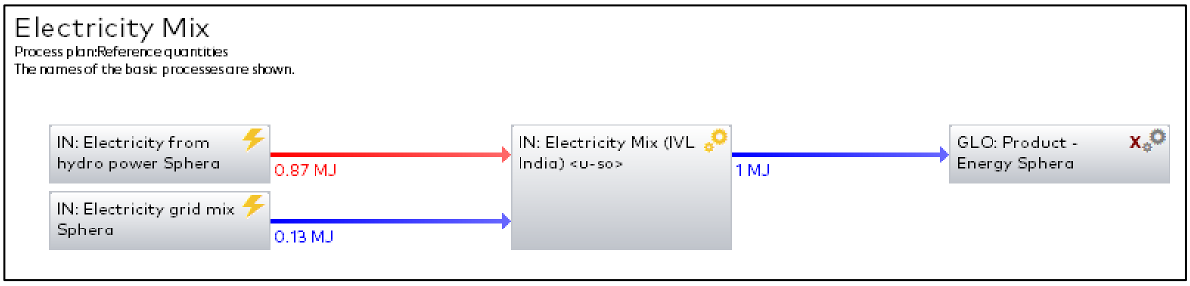

Figure 3.4: GaBi plan for electricity mix

3.2.5. Product Packaging

Figure 3.5 represents the GaBi snapshot of the plan for conventional spandex packaging. Packaging materials include cardboard boxes, cardboard tubes and plastics (LD Liner). Packaging materials amount to 224 kg per tonne of Conventional Spandex product.

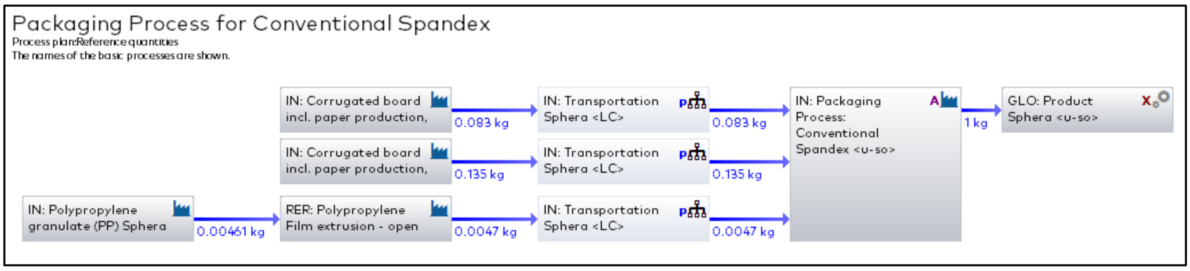

Figure 3.5: GaBi plan for conventional spandex packaging

Figure 3.6 represents the GaBi snapshot of the plan for ECOModa100™ packaging. Packaging materials include cardboard boxes, cardboard tubes and plastics (LD Liner). Packaging materials amount to 211 kg per tonne of ECOModa100™ product.

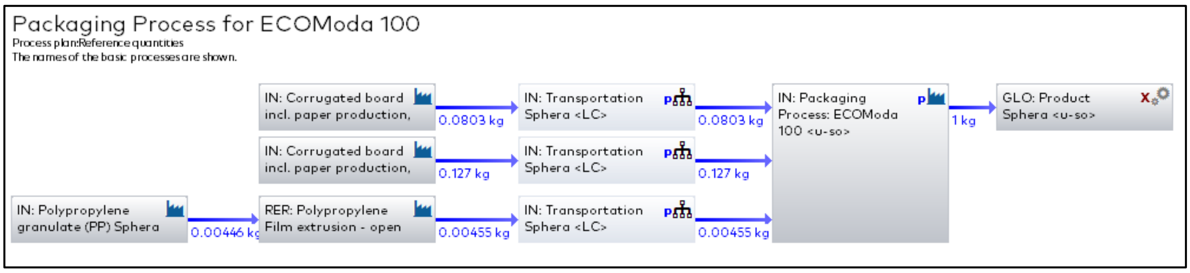

Figure 3.6: GaBi plan for ECOModa100™ packaging

3.2.6. Transportation

Figure 3.7 represents the GaBi plan for inbound transport of raw materials and packaging materials used in the manufacture of ECOModa100™ and conventional spandex products.

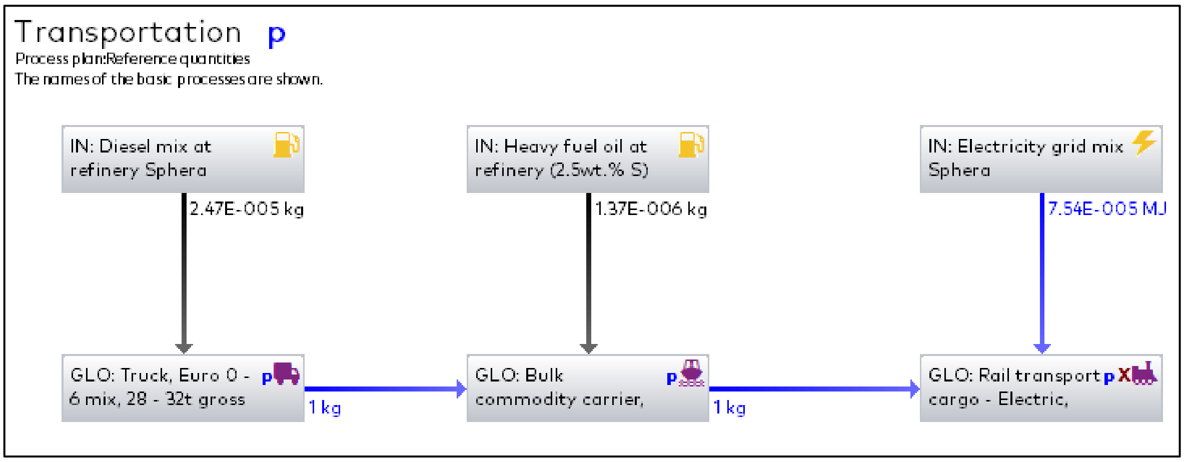

Figure 3.7: GaBi plan for transportation

Table 3-1 shows the transportation distances of raw materials and the packaging materials from their origin to the manufacturing facility at Baddi in Himachal Pradesh, India.

Table 3-1: Transportation Distances of the Major Materials

Material	Transportation Distance (km)			
	Truck	Rail	Ship	Origin (Country)
PTMEG	110	1745	8758	TAIWAN
	110	1745	9708	CHINA
	110	1745	10456	CHINA
	110	1745	9802	CHINA
MDI	1655	---	9708	CHINA
	1655	---	10758	KOREA
DMAC	1655	---	10890	CHINA
	1655	---	---	INDIA
	1655	---	8527	TURKEY
EDA	110	1745	14292	SWEDEN
	1655	---	---	INDIA
	110	1745	13116	BELGIUM
PDA	1655	---	---	INDIA
DEA	1655	---	---	INDIA
DETA	1655	---	---	INDIA
DHT800	110	1745	10758	KOREA
HN-150	110	1745	10456	CHINA
IRGANOX	110	1745	13116	BELGIUM
AO-245	110	1745	10456	CHINA
SONGNOX	110	1745	10758	KOREA
HW245	110	1745	10456	CHINA
MGST	110	1745	11140	JAPAN
OT-100	1655	---	---	INDIA
XHOT100	110	1745	10456	CHINA
TIO_2	1655	---	---	INDIA
SFO	110	1745	17401	USA
	110	1745	13738	GERMANY
	1655	---	---	INDIA
	110	1745	9802	CHINA
	110	1745	11140	JAPAN
n-BUTANOL	1655	---	---	INDIA

3.2.7. Use

Not in the scope of this study.

3.2.8. End-of-Life

Not in the scope of this study.

3.3. Background Data

Documentation for all GaBi datasets can be found online (Sphera Solutions Inc., 2022). Every effort has been made to implement the most credible, representative, and up-to-date information available. The data of materials, fuels, water consumption and energy for all the models have been entered in GaBi 10.7 LCA software. The most relevant LCI datasets used in modelling the product systems with relevant attributes were obtained from the GaBi 2023 LCI database.

3.3.1. Fuel and Energy

National averages for fuel inputs and electricity grid mixes were obtained from the GaBi 2023 LCI database. Table 3-2 shows the most relevant LCI datasets used in modelling the product systems. Electricity consumption was modelled using national grid mixes. The datasets are valid from 2019 to 2025.

Table 3-2: Fuel and energy datasets

Energy/Fuel	Dataset	Owner of the dataset	Reference year	Data Quality[1]		
				Tech	Time	Geo
Hydroelectricity	IN: Electricity from hydro power	Sphera Solutions GmbH	2019	vg	vg	vg
Grid Electricity	IN: Electricity grid mix	Sphera Solutions GmbH	2019	vg	vg	vg
Solar Electricity	IN: Electricity from photovoltaic	Sphera Solutions GmbH	2019	vg	vg	vg
Diesel	RER: Thermal energy from diesel	Sphera Solutions GmbH	2019	vg	vg	g
Biomass	IN: Thermal energy from biomass (solid)	Sphera Solutions GmbH	2019	vg	vg	vg
Deionised water	IN: Deionised water	Sphera Solutions GmbH	2022	vg	vg	vg
Hard coal	IN: Thermal energy from hard coal	Sphera Solutions GmbH	2019	vg	vg	vg

3.3.2. Raw Materials and Processes

Table 3-3 shows the most relevant LCI datasets for raw materials and unit processes used in modelling the product systems.

Table 3-3: Raw materials datasets used in inventory analysis

Material/Process	Dataset	Owner of the dataset	Reference year	Data Quality		
				Tech	Time	Geo
PTMEG	DE: Polytetramethylene Ether Glycol (via Tetrahydroflourethane) (PTMEG)	Sphera Solutions GmbH	2022	vg	vg	g

[1] Information on data quality - p= poor; f = fair; g = good; vg = very good

Ethylenediamine (EDA)	DE: Ethyleneamines (EDA, DETA, TETA, TEPA, PEHA)	Sphera Solutions GmbH	2022	vg	vg	g
DHT800	Mix of DE: Aluminium Hydroxide from Bauxite and IN: Magnesium carbonate ($MgCO3$, fine, washed for filler)	Sphera Solutions GmbH	2022	vg	vg	g
MGST	RER: Calcium stearate (stabilizer)	Sphera Solutions GmbH	2022	g	vg	g
Plastic (LD Liner)	RER: Polypropylene Film extrusion - open input polypropylene granulate	Sphera Solutions GmbH	2022	g	vg	g
n-Butanol	DE: Butanol (n-butanol) from propylene with rhodium catalyst	Sphera Solutions GmbH	2022	g	vg	g
Process water	IN: Process water from surface water	Sphera Solutions GmbH	2022	g	vg	vg
Titanium dioxide	IN: Titanium dioxide pigment (sulphate process)	Sphera Solutions GmbH	2022	g	vg	vg
Corrugated boxes	IN: Corrugated board incl. paper production, average composition	Sphera Solutions GmbH	2022	g	vg	vg
Antioxidizing agent	GLO: Antioxidizing agent (sulphonic derivatives based compound)	Sphera Solutions GmbH	2022	g	g	vg
Landfilling	RER: Inert matter (Unspecific construction waste) on landfill	Sphera Solutions GmbH	2022	g	vg	vg
Propylene diamine (PDA)	DE: Butane diamine (Tetramethylenediamine TMDA)	Sphera Solutions GmbH	2022	g	vg	g
Diethanolamine (DEA)	DE: Diethanolamine (DEA) by-prod. ethanolamines	Sphera Solutions GmbH	2022	g	g	g
Plastic (LD Liner)	IN: Polypropylene granulate (PP)	Sphera Solutions GmbH	2022	g	vg	vg
OT 100, XHOT 100	DE: Dimethyl succinate (approximation)	Sphera Solutions GmbH	2022	vg	g	g
Dimethylacetamide (DMAC)	US: Dimethylformamide (DMF) (approximation)	Sphera Solutions GmbH	2022	vg	g	g
Urea	IN: Urea (agrarian)	Sphera Solutions GmbH	2022	g	vg	vg

SFO	DE: Silicone fluids (highly viscous) / polydimethylsiloxanes (from organosilanes)	Sphera Solutions GmbH	2022	g	vg	vg
HN 150	RER: 1,3-bis[3-(dimethylamino)propyl]urea	Sphera Solutions GmbH	2022	g	vg	g
Diethylenetriamine (DETA)	NL: Diethylenetriamine (DETA)	Sphera Solutions GmbH	2022	g	vg	vg
Deionised water	IN: Deionised water (approximation)	Sphera Solutions GmbH	2022	g	vg	vg
Methylene diphenyl diisocyanate (MDI)	IN: Methylene diphenyl diisocyanate (MDI) by-product hydrochloric acid, methanol	Sphera Solutions GmbH	2022	vg	vg	vg

3.3.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities. The GaBi 2023 LCI database was used to model transportation. Transportation was modelled using the GaBi global transportation datasets. Fuels were modelled using the geographically appropriate datasets (Table 3-4).

Table 3-4: Transportation dataset

Mode/Fuel	Dataset	Owner of the dataset	Reference year	Data Quality		
				Tech	Time	Geo
Ship	GLO: Bulk commodity carrier, 1.000 to 250.000 dwt payload capacity, deep sea	Sphera Solutions GmbH	2022	vg	vg	vg
Electricity	IN: Electricity grid mix	Sphera Solutions GmbH	2019	vg	vg	vg
Truck	GLO: Truck, Euro 0 - 6 mix, 28 - 32t gross weight / 22t payload capacity	Sphera Solutions GmbH	2022	vg	vg	vg
HFO	IN: Heavy fuel oil at refinery (2.5wt.% S)	Sphera Solutions GmbH	2019	vg	vg	vg
Diesel	IN: Diesel mix at refinery	Sphera Solutions GmbH	2019	vg	vg	vg
Rail	GLO: Rail transport cargo - Electric, extra-large train, gross tonne weight 2,000t /1,452t payload cap.	Sphera Solutions GmbH	2022	vg	vg	vg

4. LCIA Results

This chapter contains the results for the impact categories and additional metrics defined in section 2.5. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Comparative LCIA Results: ECOModa100™ and Conventional Spandex products

Comparative LCIA results for production of 1 Tonne of each ECOModa100™ and conventional spandex are summarized below in Table 4-1. The table below represents the absolute LCIA results for both the products along with the relative change in the results for the ECOModa100™ with respect to conventional spandex.

Table 4-1: Comparative LCIA results for 1 Tonne of ECOModa100™ and conventional spandex

Impact Category	Unit	ECOModa100™	Conventional Spandex	% Difference
ADP elements	kg Sb eq.	1.33E-03	0.02	94%
ADP fossil	MJ	20742.96	173571.48	88%
Acidification Potential	kg SO_2 eq.	21.27	37.22	43%
Eutrophication Potential	kg Phosphate eq.	2.49	4.08	39%
Freshwater Aquatic Ecotoxicity Potential	kg DCB eq.	9.87	26.43	63%
GWP 100 years	kg CO_2 eq.	1507.95	8887.56	83%
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	1849.07	9235.74	80%
Human Toxicity Potential	kg DCB eq.	659.41	1077.58	39%
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	4322767.84	5241288.19	18%
Ozone Layer Depletion Potential	kg R11 eq.	3.58E-09	3.08E-08	88%
Photochem. Ozone Creation Potential	kg Ethene eq.	1.62	3.07	47%
Terrestric Ecotoxicity Potential	kg DCB eq.	40.02	201.86	80%
Primary energy demand (net cal. value)	MJ	69937.83	244890.13	71%
Blue water consumption	kg	59806.23	95936.89	38%

Figure 4.1 shows the GWP (100 years) impacts including and excluding biogenic carbon over cradle to gate are reduced by 83% and 80% respectively for production of 1 Tonne of ECOModa100™ as compared to conventional spandex. In other impact categories also substantial reduction in impact has been observed for ECOModa100™ compared to conventional spandex since it is produced by recycling the waste spandex.

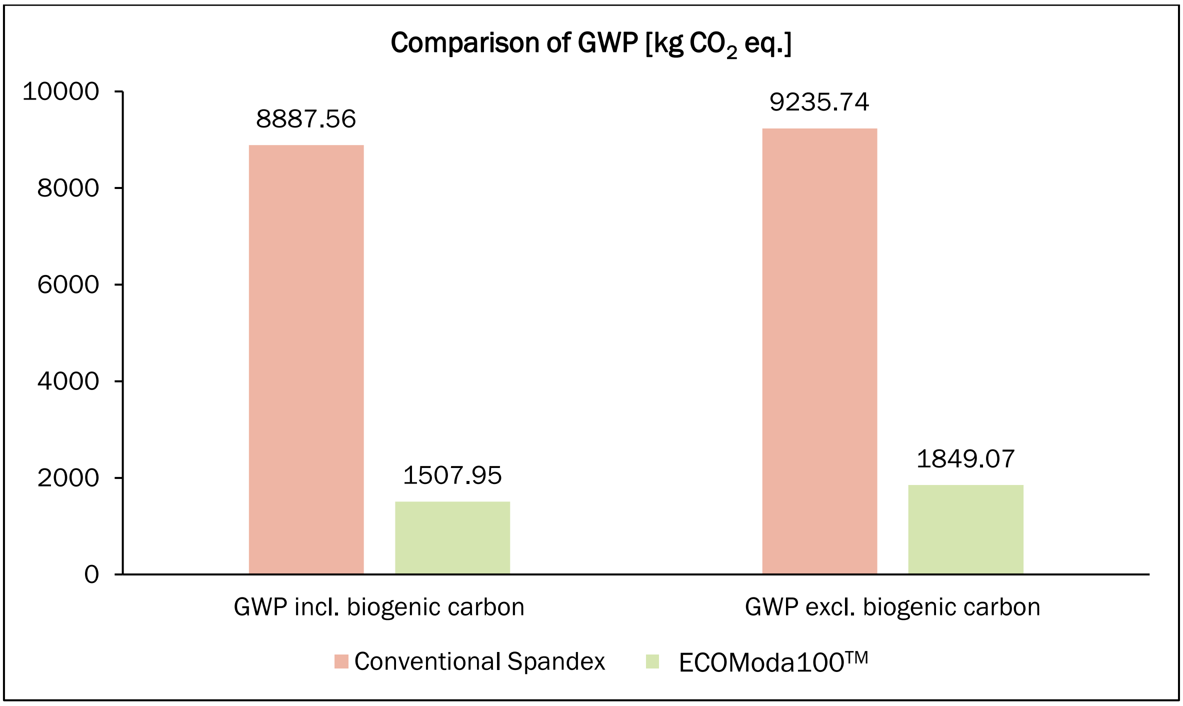

Figure 4.1: Comparison of GWP for ECOModa100™ and conventional spandex

Figure 4.2 represents the comparison of environmental impacts for the two spandex products – ECO-Moda100™ and conventional spandex in ADP Fossil, AP, EP, ODP, POCP impact categories. A similar trend is seen in these impact categories as that of GWP (100 years) i.e., impacts are lower for ECOModa100™ than conventional spandex over cradle to gate system boundary. The ADP (fossil) for 1 Tonne of conventional spandex product is 173571.48 MJ. Comparing the conventional spandex product, the ADP fossil was reduced by 88% for ECOModa100™ product (20742.96 MJ). In AP, EP and POCP the impacts are reduced by 43%, 39% and 47% respectively for ECOModa100™ as compared to conventional spandex.

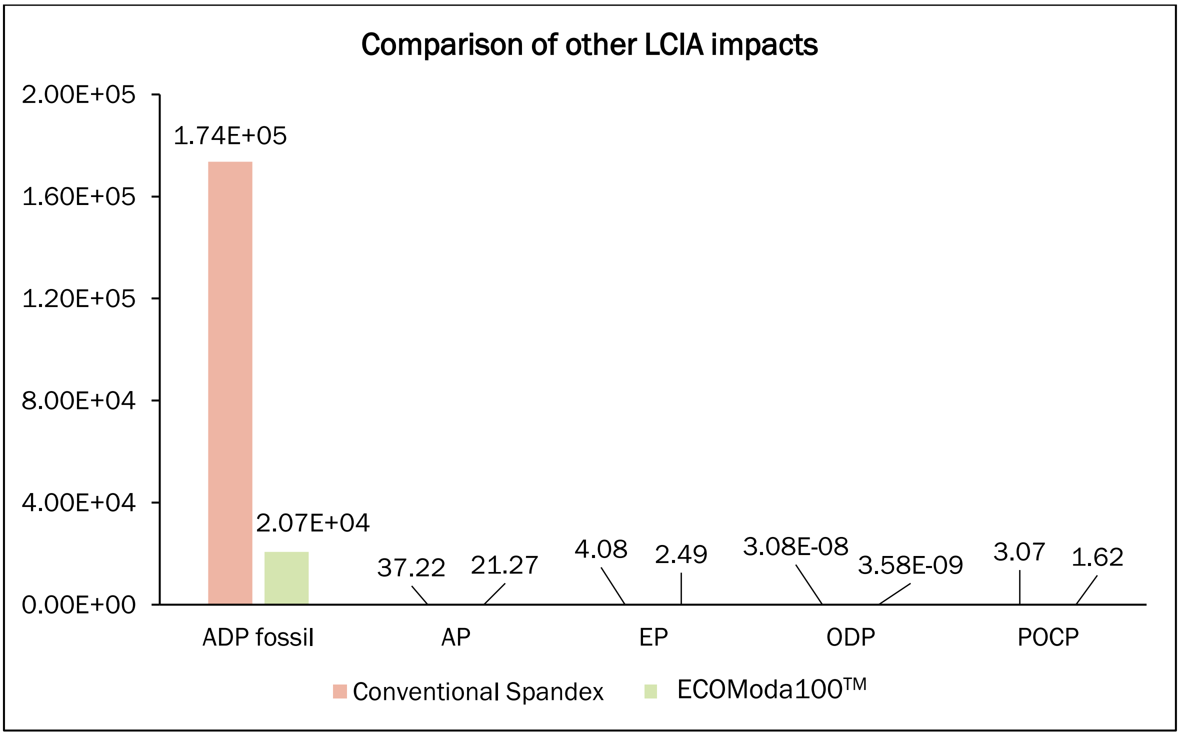

Figure 4.2: Comparison of other LCIA impacts for ECOModa100™ and conventional spandex

Figure 4.3 shows that the primary energy demand (PED) and blue water consumption (BWC) for production of 1 Tonne of conventional spandex are 244890.13 MJ and 95936.89 kg respectively. Comparing the conventional spandex product, the PED and BWC values were reduced by 71% and 38% respectively for ECOModa100™ product.

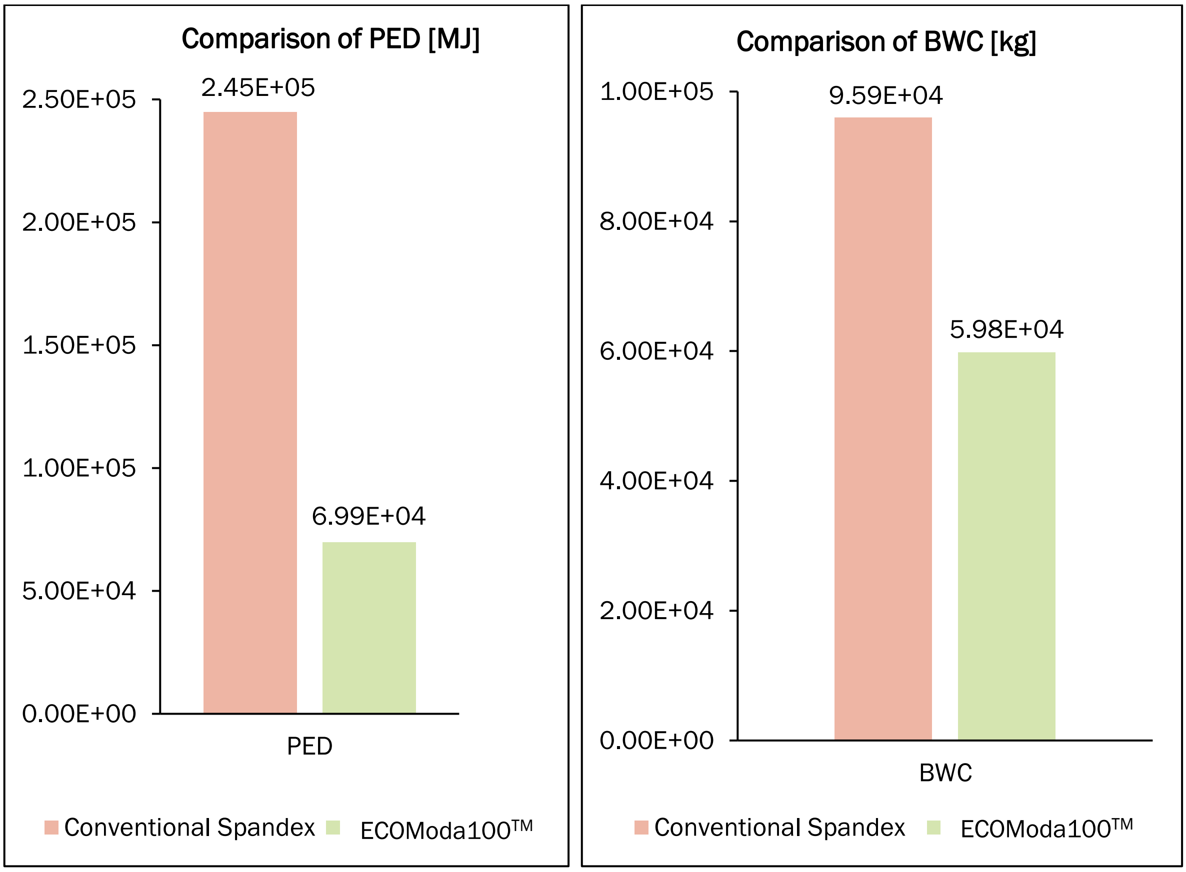

Figure 4.3: Comparison of PED and BWC impacts for ECOModa100™ and conventional spandex

Figure 4.4 shows source-wise comparison of GWP (100 years) including biogenic carbon impact for production of 1 Tonne of each of ECOModa100™ and conventional spandex products. The GWP (100 years) for 1 Tonne of conventional spandex is 8887.56 kg CO_2 equivalent wherein the raw materials (85%) are the major contributors. PTMEG comprises 68% (%wt.) of all the raw materials and impact contribution is 66% to the total GWP impact among all the raw materials. Electricity (6%) and steam (4%) consumption at manufacturing site are next major contributors to the overall GWP (100 years) impact for conventional spandex. As ECOModa100™ is produced from the waste spandex, which is burden free, therefore major contributors to the total GWP (100 years) impact for ECOModa100™ are utilities (electricity and steam) and packaging materials. The GWP (100 years) impact including biogenic carbon for 1 Tonne of ECOModa100™ is 1507.95 kg CO_2 equivalent with major contribution from electricity consumption (~34%) followed by steam consumption (~23%), raw material (packaging materials) (~21%) and hot oil (~16%) (impact associated with thermal energy required for maintaining temperature of hot oil).

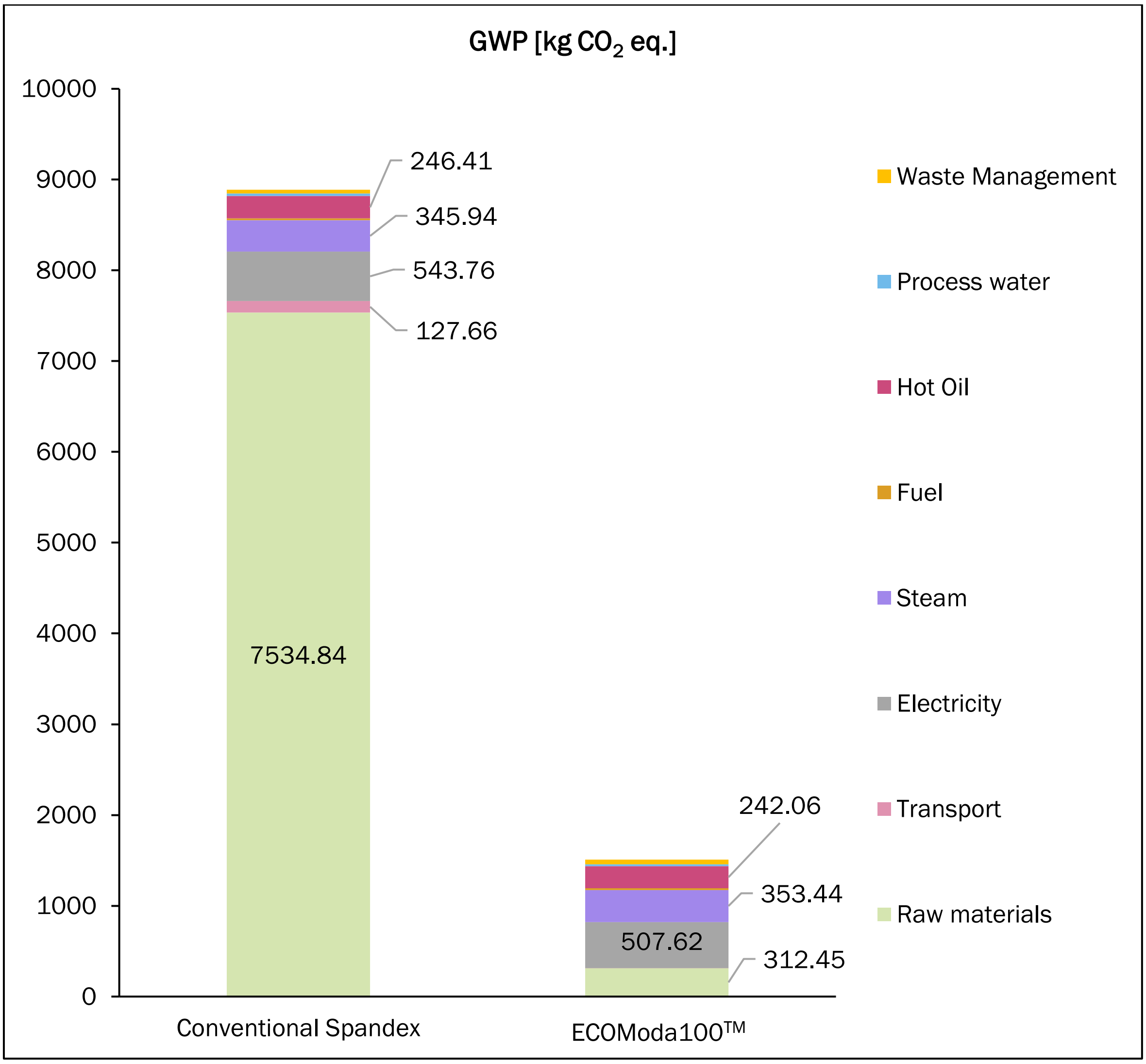

Figure 4.4: Source-wise comparison of GWP for ECOModa100™ and conventional spandex

Figure 4.5 shows source-wise comparison of PED values for production of 1 Tonne of each of ECO-Moda100™ and conventional spandex products. PED for 1 Tonne of conventional spandex is 244890.13 MJ with major contribution from raw materials (~78%) followed by electricity consumption (~9%), hot oil (~8%) and steam consumption (~5%). Among raw materials, major contributors to PED impact are PTMEG (~65%) followed by SFO (~11%), packaging process (~10%) and MDI (~9%). PED for 1 Tonne of ECO-Moda100™ is 69937.83 MJ with major contribution from electricity consumption (~28%) followed by raw materials (packaging materials) (~27%), hot oil (~27%) and steam consumption (~17%).

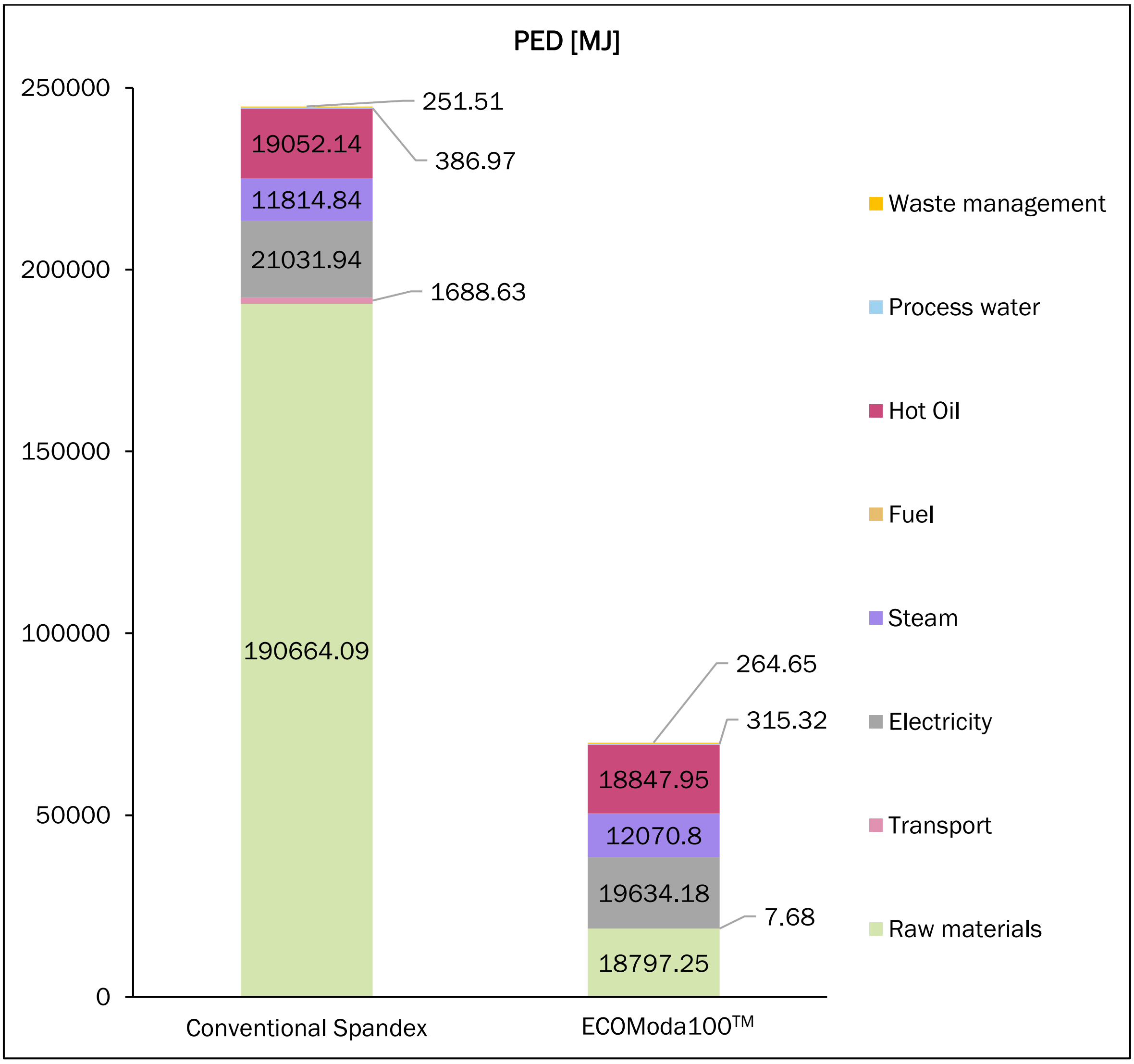

Figure 4.5: Source-wise comparison of PED for ECOModa100™ and conventional spandex

Figure 4.6 shows source-wise comparison of BWC values for production of 1 Tonne of each of ECO-Moda100™ and conventional spandex products. BWC for 1 Tonne of conventional spandex is 95936.89 kg with major contribution from electricity consumption (~43%) followed by raw materials (~35%) and process water (~17%). The maximum contribution to BWC comes from electricity consumption because 87% of electricity supplied to manufacturing site is from hydroelectricity. Among raw materials, major contributors to BWC impact are PTMEG (~43%) followed by SFO (~28%), MDI (~14%), and packaging process (~10%). BWC for 1 Tonne of ECOModa100™ is 59806.23 kg with major contribution from electricity consumption (~64%) followed by process water (~22%), raw materials (packaging materials) (~5.5%) and steam consumption (~4%).

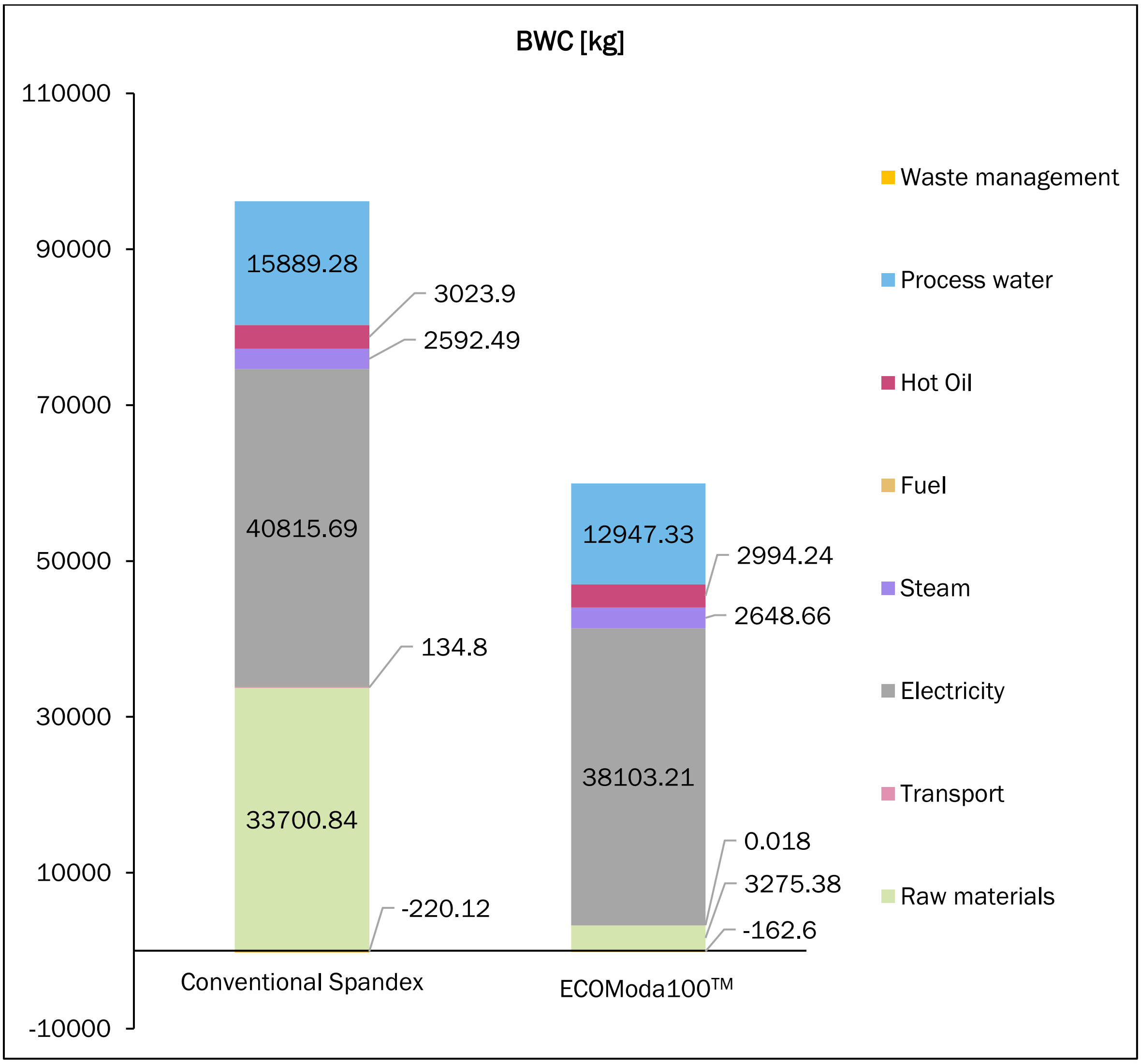

Figure 4.6: Source-wise comparison of BWC for ECOModa100™ and conventional spandex

4.2. Overall Results – Conventional Spandex

The Table 4-2 presents the cradle to gate LCIA results for 1 Tonne conventional spandex production with packaging.

Table 4-2: Overall LCIA Results for 1 Tonne of conventional spandex production with packaging

Impact Category	Unit	Total
ADP elements	kg Sb eq.	0.02
ADP fossil	MJ	173571.48
Acidification Potential	kg SO_2 eq.	37.22
Eutrophication Potential	kg Phosphate eq.	4.08
Freshwater Aquatic Ecotoxicity Pot.	kg DCB eq.	26.43
GWP 100 years	kg CO_2 eq.	8887.56
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	9235.74
Human Toxicity Potential	kg DCB eq.	1077.58
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	5241288.19
Ozone Layer Depletion Potential	kg R11 eq.	3.08E-08
Photochem. Ozone Creation Potential	kg Ethene eq.	3.07
Terrestric Ecotoxicity Potential	kg DCB eq.	201.86
Primary energy demand (net cal. value)	MJ	244890.13
Blue water consumption	kg	95936.89

The Global Warming Potential (GWP 100 years), excluding biogenic carbon for 1 Tonne of conventional spandex production is 9235.74 kg CO_2 eq. and Global Warming Potential (GWP 100 years), including biogenic carbon is 8887.56 kg CO_2 eq.

The detailed LCIA results and hotspots are discussed in the below section:

4.2.1. Process wise LCIA Results for 1 Tonne kg of conventional spandex

The Table 4-3 presents the process wise LCIA results for 1 Tonne of conventional spandex production with packaging. The Production process includes the impact associated with raw materials production, their transportation to the manufacturing facility, energy consumption and waste management whereas, the Packaging process includes the impact associated with production of packaging materials and their transport.

Table 4-3: Process wise LCIA results for 1 Tonne of conventional spandex

Impact Categories	Unit	Total	Production	Packaging
ADP elements	kg Sb eq.	0.02	0.02	2.88E-04
ADP fossil	MJ	173571.48	164362.59	9208.89
Acidification Potential	kg SO_2 eq.	37.22	32.96	4.26
Eutrophication Potential	kg Phosphate eq.	4.08	3.64	0.44
Freshwater Aquatic Ecotoxicity Pot.	kg DCB eq.	26.43	23.75	2.68
GWP 100 years	kg CO_2 eq.	8887.56	8558.47	329.10
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	9235.74	8557.33	678.41
Human Toxicity Potential	kg DCB eq.	1077.58	976.26	101.31
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	5241288.19	4829111.08	412177.10
Ozone Layer Depletion Potential	kg R11 eq.	3.08E-08	2.95E-08	1.37E-09
Photochem. Ozone Creation Potential	kg Ethene eq.	3.07	2.78	0.29
Terrestric Ecotoxicity Potential	kg DCB eq.	201.86	196.43	5.43
Primary energy demand (net cal. value)	MJ	244890.13	225120.45	19769.69
Blue water consumption	kg	95936.89	92493.57	3443.32

The Figure 4.7 presents the graphical representation of the results shown in Table 4-3 above.

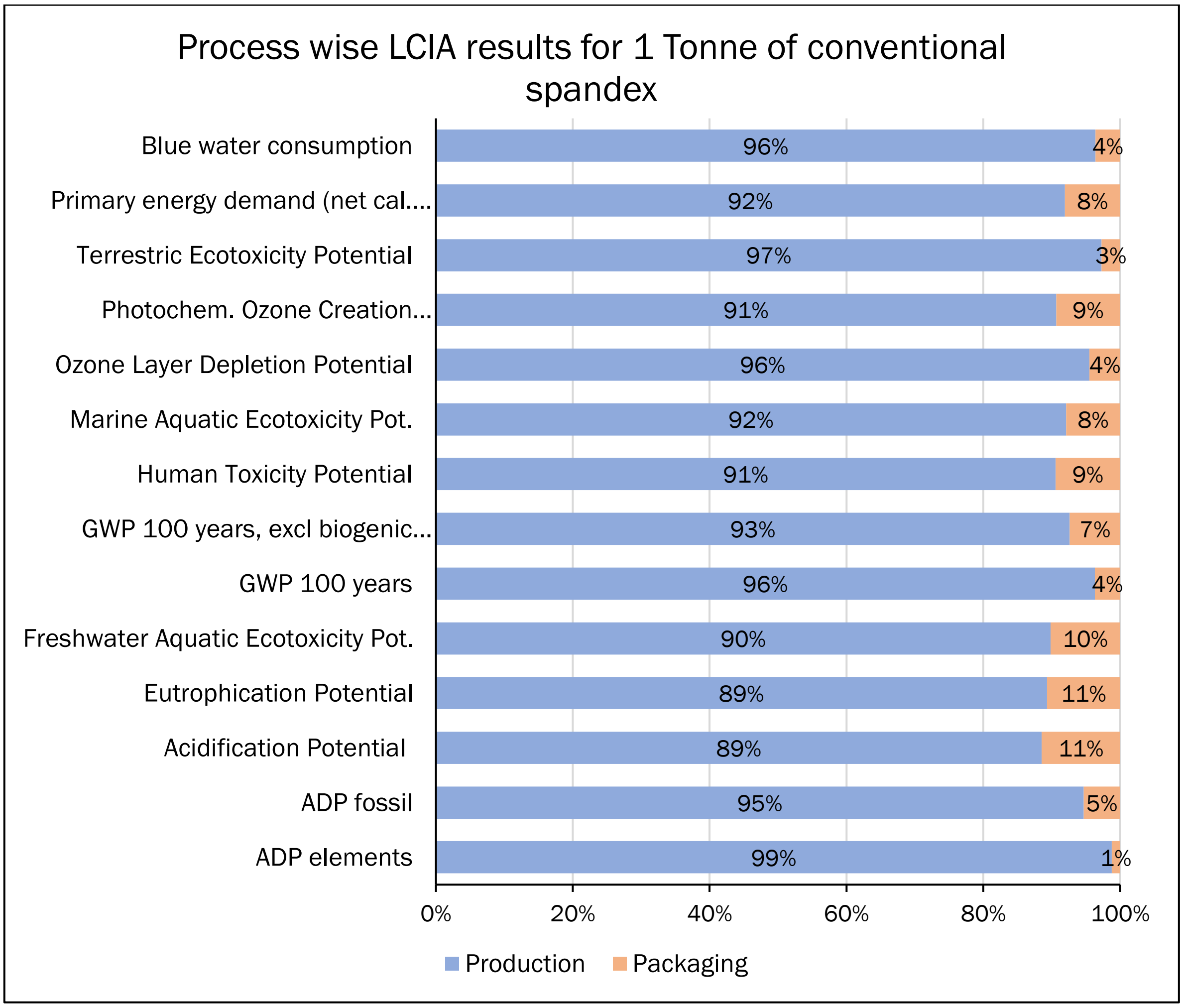

Figure 4.7: Process wise LCIA results for 1 Tonne of conventional spandex

The global warming potential (excluding biogenic Carbon) (GWP) for producing 1 Tonne of conventional spandex is 9235.74 kg CO_2-Equiv. with major contribution from production process (~93%). In other impact categories also, the production process contributes more than 90% in almost all impact categories.

4.2.2. Source-wise LCIA Results for 1 Tonne of conventional spandex

Table 4-4 below presents source-wise LCIA results for 1 Tonne of conventional spandex over the cradle to gate system boundary where impacts are classified on the basis of source of impact generation, i.e., raw materials (PTMEG, SFO, TiO_2, MDI, EDA, DMAC, HN150, PDA, n-Butanol, anti-oxidants, etc. and packaging materials), electricity, steam, hot oil (impact associated with thermal energy required for maintaining temperature of hot oil), transport (inbound transport of raw materials), waste management.

Table 4-4: Source-wise LCIA Results for 1 Tonne of conventional spandex

Impact Categories	Unit	Total	Raw materi-als	Electricity	steam	Fuel	Hot Oil	Process water	Transport	Waste manage-ment
ADP elements	kg Sb eq.	0.02	0.02	1.05E-04	2.84E-04	0.00	5.49E-04	1.29E-04	1.89E-06	1.58E-05
ADP fossil	MJ	173571.48	159628.67	5393.01	3696.45	0.00	2800.09	323.22	1599.97	130.07
Acidification Potential	kg SO_2 eq.	37.22	18.40	6.40	4.83	0.14	5.95	0.29	1.17	0.05
Eutrophication Potential	kg Phos-phate eq.	4.08	1.82	0.27	0.66	0.04	1.09	0.02	0.16	0.02
Freshwater Aquatic Ecotoxi-city Pot.	kg DCB eq.	26.43	18.77	0.98	2.29	1.51E-03	3.69	0.13	0.32	0.26
GWP 100 years	kg CO_2 eq.	8887.56	7534.84	543.76	345.94	19.44	246.41	27.89	127.66	41.61
GWP 100 years, excl bio-genic carbon	kg CO_2 eq.	9235.74	7876.06	543.97	349.62	18.21	252.99	27.46	125.78	41.65
Human Toxicity Potential	kg DCB eq.	1077.58	491.27	181.91	179.06	0.50	197.88	7.20	12.41	7.35
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	5241288.19	1211062.82	771401	1316969	0.02	1856241	34197.36	49174.2	2241.54
Ozone Layer Depletion Po-tential	kg R11 eq.	3.08E-08	2.83E-08	2.01E-09	1.16E-10	0.00	1.23E-10	8.91E-11	1.22E-10	6.87E-11
Photochem. Ozone Creation Potential	kg Ethene eq.	3.07	1.64	0.30	0.41	0.01	0.64	0.01	0.06	2.80E-03
Terrestric Ecotoxicity Poten-tial	kg DCB eq.	201.86	170.89	1.20	3.40	7.60E-05	5.22	0.11	0.09	20.95
Primary energy demand (net cal. value)	MJ	244890.13	190664.09	21031.9	11814.8	0.00	19052.1	386.97	1688.63	251.51
Blue water consumption	kg	95936.89	33700.84	40815.7	2592.49	0.00	3023.90	15889.28	134.80	-220.12

The Figure 4.8 shows the graphical representation of the results shown in the Table 4-4.

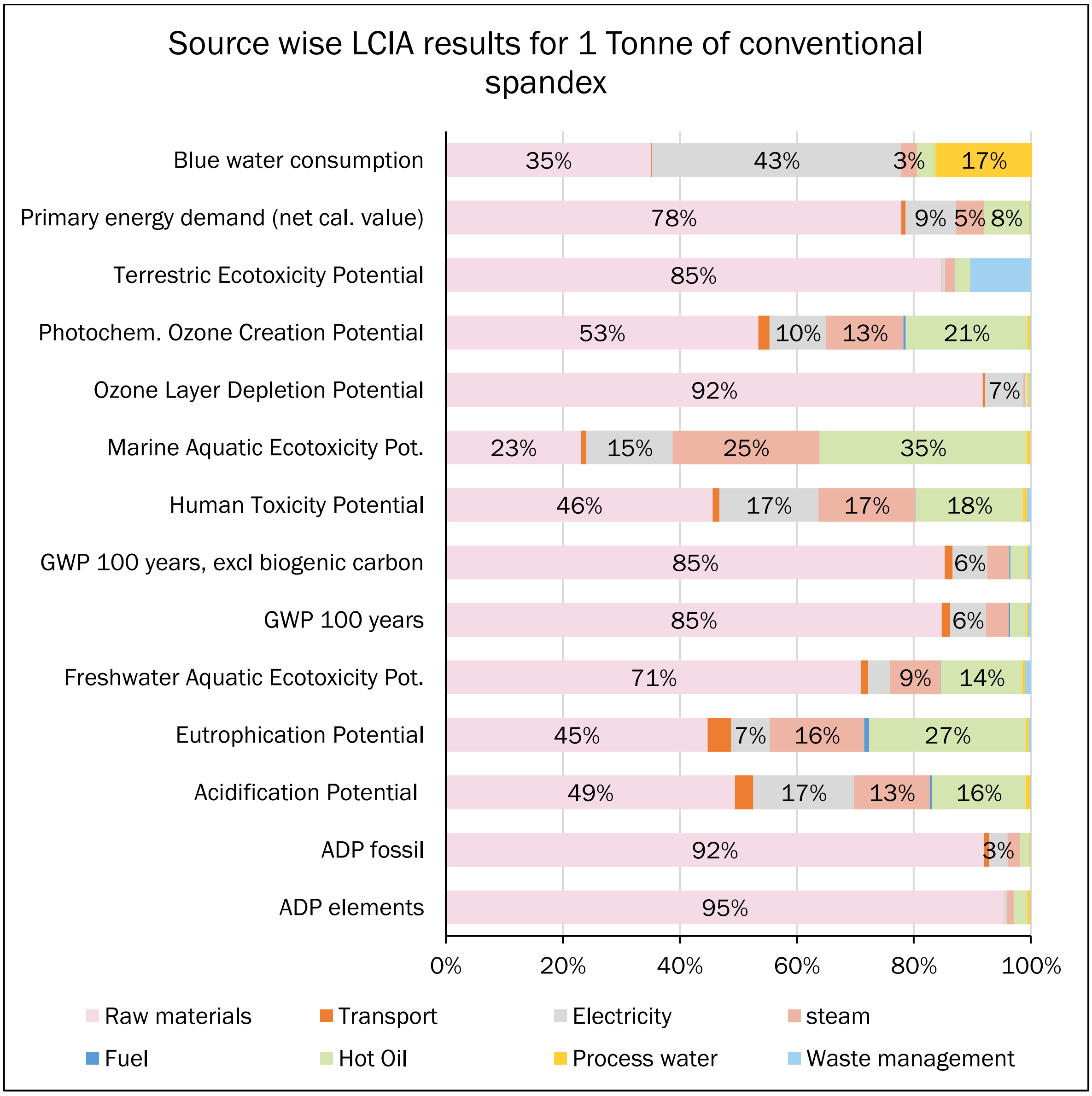

Figure 4.8: Source-wise LCIA results for 1 Tonne of conventional spandex

Hotspot Identification

- Abiotic Depletion Potential (ADP Elements) is 0.02 kg Sb eq. with major contribution from raw materials (~95%).
- Abiotic Depletion Potential (ADP fossil) is 173571.48 MJ with major contribution from raw materials (~92%).
- Acidification Potential (AP) is 37.22 kg SO_2 eq. with major contribution from raw materials (~49%) followed by electricity consumption (~17%), hot oil (~16%) and steam consumption (~13%).
- Eutrophication Potential (EP) is 4.08 kg Phosphate eq. with major contribution from raw materials (~45%) followed by hot oil (~27%), steam consumption (~16%) and electricity consumption (~7%).
- Global Warming Potential (GWP including biogenic carbon) is 8887.56 kg CO_2 eq. with major contribution from raw materials (~85%) followed by electricity consumption (~6%), steam consumption (~4%) and hot oil (~3%).

- Global Warming Potential (GWP excluding biogenic carbon) is 9235.74 kg CO_2 eq. with major contribution from raw materials (~85%) followed by electricity consumption (~6%), steam consumption (~4%) and hot oil (~3%).
- Human Toxicity Potential is 1077.58 kg DCB eq. with major contribution from raw materials (~46%) followed by hot oil (~18%), steam consumption (~17%) and electricity consumption (~17%).
- Ozone Layer Depletion Potential (ODP) is 3.08E-08 kg R11 eq. with major contribution from raw materials (~92%) followed by electricity consumption (~7%).
- Photochem. Ozone Creation Potential (POCP) is 3.07 kg Ethene eq. with major contribution from raw materials (~53%) followed by hot oil (~21%), steam consumption (~13%) and electricity consumption (~10%).
- Primary Energy Demand from renewable and non-renewable Resources (net calorific value) is 244890.13 MJ with major contribution from raw materials (~78%) followed by electricity consumption (~9%), hot Oil (~8%) and steam consumption (~5%).
- Blue water consumption is 95936.89 kg with major contribution from electricity consumption (~43%) followed by raw materials (~35%) and process water (~17%).

4.2.3. Raw materials LCIA results for 1 Tonne of conventional spandex

The Table 4-5 gives break-up of LCIA results for Raw Materials used in production of conventional spandex. Other Raw Materials include DHT100, PDA, n-butanol, DEA, XHOT100, OT100, TiO_2, DETA, HN150, magnesium stearate (MGST) and anti-oxidizing agent; packaging materials include cardboard boxes, cardboard tubes and plastics (LD Liner).

Table 4-5: Raw materials LCIA results for 1 Tonne of conventional spandex

Impact Categories	Unit	Total	EDA	PTMEG	SFO	MDI	DMAC	Other Raw Materials	Packaging Materials
ADP elements	[kg Sb eq.]	0.02	6.36E-04	3.89E-04	0.02	2.02E-03	2.51E-05	0.00	2.88E-04
ADP fossil	[MJ]	159628.67	2574.80	114279.96	12555.52	1611358	3660.57	1245.74	9198.48
Acidification Potential	[kg SO2 eq.]	18.40	0.12	6.21	2.31	5.25	0.05	0.19	4.26
Eutrophication Potential	[kg Phos-phate eq.]	1.82	0.03	0.61	0.26	0.43	0.02	0.04	0.44
Freshwater Aquatic Ecotoxicity Pot.	[kg DCB eq.]	18.77	0.27	5.35	3.54	2.39	0.21	4.34	2.68
GWP 100 years	[kg CO2 eq.]	7534.84	145.38	5002.60	887.26	978.66	141.01	51.60	328.34
GWP 100 years, excl biogenic carbon	[kg CO2 eq.]	7876.06	145.33	5000.37	877.97	977.95	140.99	55.77	677.68
Human Toxicity Potential	[kg DCB eq.]	491.27	3.62	116.22	124.18	137.21	2.43	6.31	101.30
Marine Aquatic Ecotoxicity Pot.	[kg DCB eq.]	1211062.8	5126.70	109017.54	102191.50	570668.22	1990.98	9901.03	4.12E+05
Ozone Layer Depletion Poten-tial	[kg R11 eq.]	2.81E-08	1.07E-09	1.70E-08	7.13E-09	1.43E-09	9.00E-11	0.00	1.37E-09
Photochem. Ozone Creation Potential	[kg Ethene eq.]	1.64	0.01	0.55	0.28	0.47	0.02	0.02	0.29
Terrestric Ecotoxicity Potential	[kg DCB eq.]	170.89	0.21	8.71	115.53	37.71	0.11	3.19	5.43
Primary energy demand (net cal. value)	[MJ]	190664.09	3157.35	123591.06	21792.43	17118.48	3796.68	1448.83	19759.25
Blue water consumption	[kg]	33700.84	359.52	14459.00	9544.74	4835.39	752.88	306.01	3443.29

The Figure 4.9 show the graphical representation of the results presented in the Table 4-5.

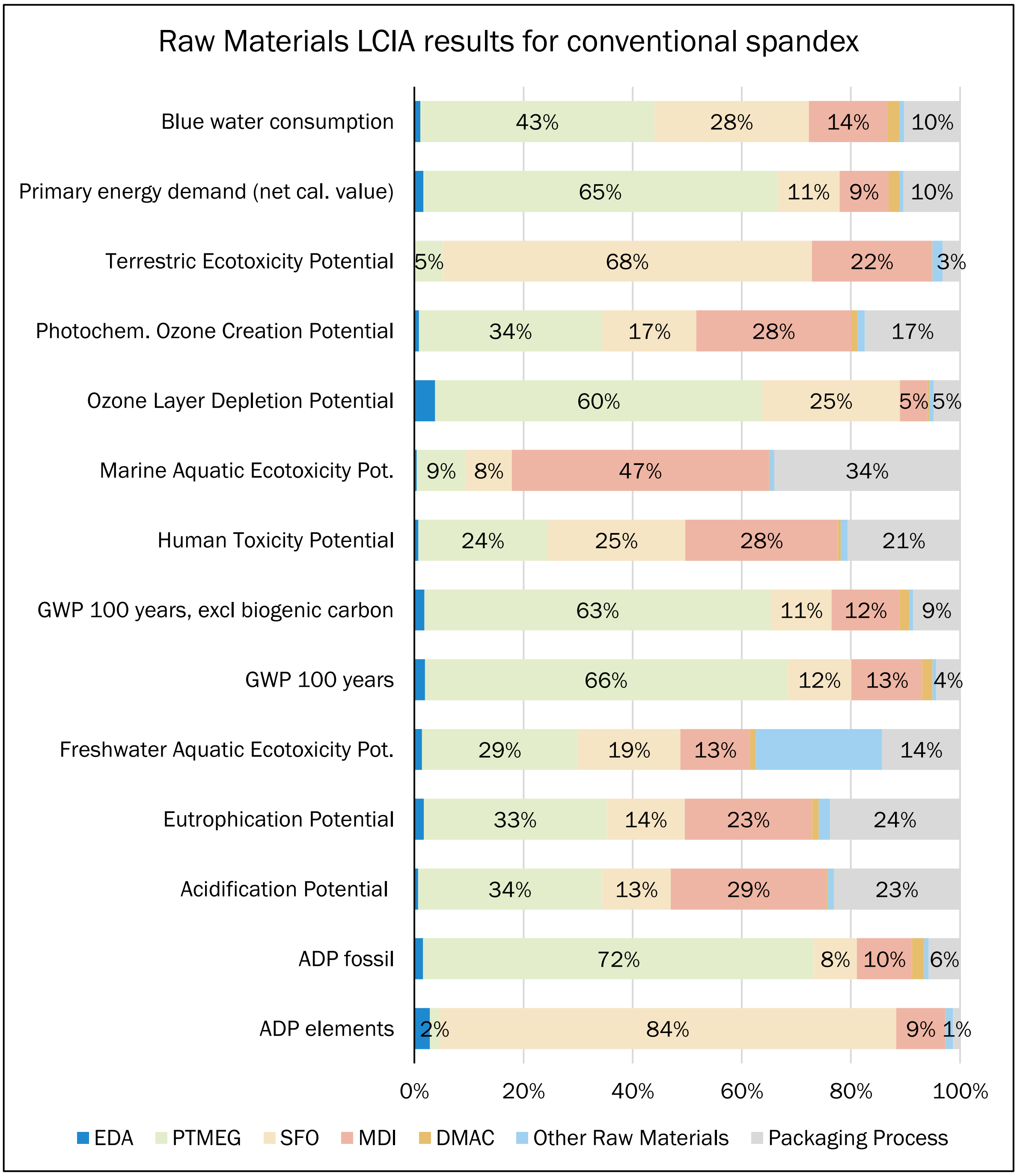

Figure 4.9: Raw Materials LCIA results for conventional spandex

Hotspot Identification

- Abiotic Depletion Potential (ADP Elements) is 0.02 kg Sb eq. with major contribution from SFO (~84%) followed by MDI (~9%).
- Abiotic Depletion Potential (ADP fossil) is 159628.67 MJ with major contribution from PTMEG (~72%) followed by MDI (~10%), SFO (~8%) and packaging process (~6%).
- Acidification Potential (AP) is 18.40 kg SO_2 eq. with major contribution from PTMEG (~34%) followed by MDI (~29%), packaging process (~23%) and SFO (~13%).

- Eutrophication Potential (EP) is 1.82 kg Phosphate eq. with major contribution from PTMEG (~33%) followed by packaging process (~24%), MDI (~23%) and SFO (~14%).
- Global Warming Potential (GWP 100 Years) is 7534.84 kg CO_2 eq. with major contribution from PTMEG (~66%) followed by MDI (~13%), SFO (~12%) and packaging process (~4%).
- Global Warming Potential (GWP excluding biogenic carbon) is 7876.06 kg CO_2 eq. with major contribution from PTMEG (~63%) followed by MDI (~12%), SFO (~11%) and packaging process (~9%).
- Human Toxicity Potential is 491.27 kg DCB eq. with major contribution from MDI (~28%) followed by SFO (~25%), PTMEG (~24%) and packaging process (~21%).
- Ozone Layer Depletion Potential (ODP) is 2.81E-08 kg R11 eq. with major contribution from PTMEG (~60%) followed by SFO (~25%), MDI (~5%) and packaging process (~5%).
- Photochemical Ozone Creation Potential (POCP) is 1.64 kg Ethene eq. with major contribution from PTMEG (~34%) followed by MDI (~28%), SFO (~17%) and packaging process (~17%).
- Primary Energy Demand from renewable and non-renewable Resources (net calorific value) is 190664.09 MJ with major contribution from PTMEG (~65%) followed by SFO (~11%), packaging process (~10%) and MDI (~9%).
- Blue water consumption is 33700.84 kg with major contribution from PTMEG (~43%) followed by SFO (~28%), MDI (~14%), and packaging process (~10%).

4.3. Overall Results – ECOModa100™

The Table 4-6 presents the cradle to gate LCIA results for 1 Tonne of ECOModa100™ production with packaging.

Table 4-6: Overall LCIA Results for 1 Tonne of ECOModa100™

Impact Categories	Unit	Total
ADP elements	kg Sb eq.	1.33E-03
ADP fossil	MJ	20742.96
Acidification Potential	kg SO_2 eq.	21.27
Eutrophication Potential	kg Phosphate eq.	2.49
Freshwater Aquatic Ecotoxicity Pot.	kg DCB eq.	9.87
GWP 100 years	kg CO_2 eq.	1507.95
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	1849.07
Human Toxicity Potential	kg DCB eq.	659.41
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	4.32E+06
Ozone Layer Depletion Potential	kg R11 eq.	3.58E-09
Photochem. Ozone Creation Potential	kg Ethene eq.	1.62
Terrestric Ecotoxicity Potential	kg DCB eq.	40.02
Primary energy demand (net cal. value)	MJ	69937.83
Blue water consumption	kg	59806.23

Global warming (GWP 100 years), excluding biogenic carbon for 1 Tonne of ECOModa100™ production is 1849.07 kg CO_2 eq. and Global warming (GWP 100 years), including biogenic carbon is 1507.95 kg CO_2 eq. The waste spandex is considered to be environmentally burden-free while calculating the overall impacts of the ECOModa100™ product.

The detailed LCIA results and hotspots are discussed in the below section:

4.3.1. Process wise LCIA Results for 1 Tonne of ECOModa100™

The Table 4-7 presents the process wise LCIA results for 1 Tonne of ECOModa100™ production with packaging. The Production process includes the impact associated with energy consumption and waste management whereas, the packaging process includes the impact associated with production of packaging materials and their transport to manufacturing facility.

Table 4-7: Process wise LCIA results for 1 Tonne of ECOModa100™

Impact Categories	Unit	Total	Production	Packaging
ADP elements	kg Sb eq.	1.33E-03	1.06E-03	2.74E-04
ADP fossil	MJ	20742.96	11981.58	8761.38
Acidification Potential	kg SO_2 eq.	21.27	17.22	4.05
Eutrophication Potential	kg Phosphate eq.	2.49	2.07	0.41
Freshwater Aquatic Ecotoxicity Pot.	kg DCB eq.	9.87	7.32	2.55
GWP 100 years	kg CO_2 eq.	1507.95	1194.94	313.01
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	1849.07	1203.86	645.21
Human Toxicity Potential	kg DCB eq.	659.41	563.05	96.37
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	4322767.84	3930727.13	392040.70
Ozone Layer Depletion Potential	kg R11 eq.	3.58E-09	2.27E-09	1.31E-09
Photochem. Ozone Creation Potential	kg Ethene eq.	1.62	1.35	0.27
Terrestric Ecotoxicity Potential	kg DCB eq.	40.02	34.85	5.16
Primary energy demand (net cal. value)	MJ	69937.83	51132.90	18804.93
Blue water consumption	kg	59806.23	56530.83	3275.40

The Figure 4.10 shows the graphical representation of the results presented in the Table 4-7.

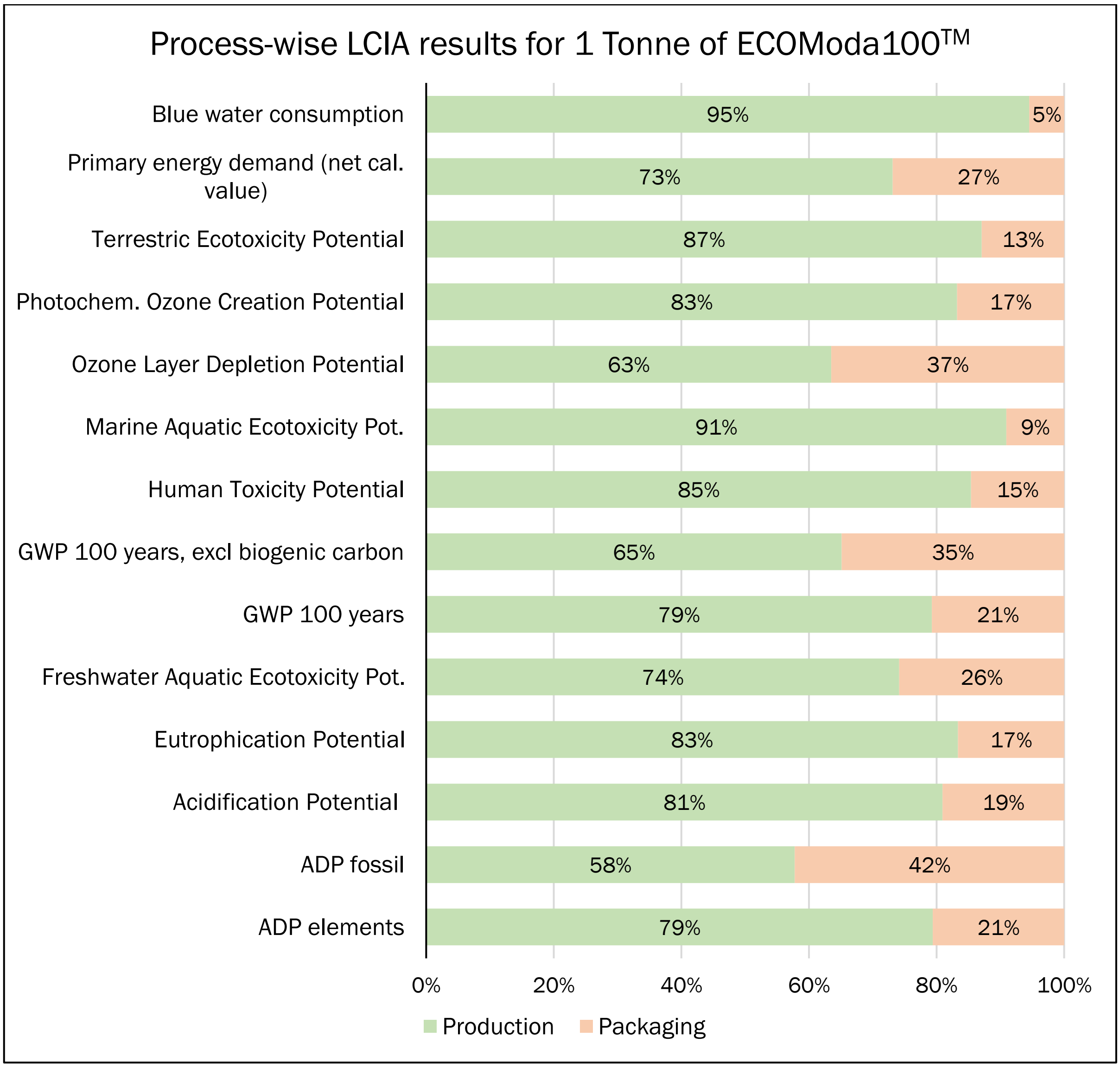

Figure 4.10: Process wise LCIA results for 1 Tonne of ECOModa100™

The Global Warming Potential (excluding biogenic Carbon) (GWP) for producing 1 Tonne of ECOModa100™ is 1849.07 kg CO_2 eq. with major contributions from production process (~65%) and packaging process (~35%). In all the other impact categories also, the production process is the major environmental hotspot.

4.3.2. Detailed LCIA Results for 1 Tonne of ECOModa100™

Table 4-8 below shows the detailed LCIA results for 1 Tonne of ECOModa100™ product over the cradle to gate system boundary where impacts are classified on the basis of source of impact generation, i.e., electricity, steam, fuel (diesel), hot oil (impact associated with thermal energy required to maintain the temperature of hot oil), water, packaging process (impact associated with packaging materials production and their transport to manufacturing facility) and waste management.

Table 4-8: Detailed LCIA Results for 1 Tonne of ECOModa100™

Impact Categories	Unit	Total	Electricity	Steam	Hot oil	Water	Fuel	Packaging Process	Waste Management
ADP elements	kg Sb eq.	1.33E-03	9.77E-05	2.91E-04	5.44E-04	1.05E-04	0.00	2.74E-04	1.87E-05
ADP fossil	MJ	20742.96	5034.60	3776.53	2753.07	263.38	0.00	8761.38	154.01
Acidification Potential	kg SO_2 eq.	21.27	5.97	4.94	5.88	0.24	0.14	4.05	0.06
Eutrophication Potential	kg Phosphate eq.	2.49	0.25	0.67	1.08	0.02	0.04	0.41	0.02
Freshwater Aquatic Ecotoxicity Pot.	kg DCB eq.	9.87	0.91	2.34	3.65	0.10	1.52E-03	2.55	0.31
GWP 100 years	kg CO_2 eq.	1507.95	507.62	353.44	242.06	22.73	19.52	313.01	49.58
GWP 100 years, excl biogenic carbon	kg CO_2 eq.	1849.07	507.82	357.19	248.58	22.38	18.28	645.21	49.62
Human Toxicity Potential	kg DCB eq.	659.41	169.82	182.94	195.22	5.87	0.50	96.37	8.70
Marine Aquatic Ecotoxicity Pot.	kg DCB eq.	4322767.8	720136.2	1345501	1834578	27865.6	0.02	392041	2645.74
Ozone Layer Depletion Potential	kg R11 eq.	3.58E-09	1.88E-09	1.18E-10	1.21E-10	7.26E-11	0.00	1.31E-09	8.18E-11
Photochem. Ozone Creation Potential	kg Ethene eq.	1.62	0.28	0.41	0.63	0.01	0.01	0.27	3.32E-03
Terrestric Ecotoxicity Potential	kg DCB eq.	40.02	1.12	3.47	5.16	0.09	7.63E-05	5.16	25.01
Primary energy demand (net cal. value)	MJ	69937.83	19634.18	12070.80	18847.9	315.32	0.00	18804.9	264.65
Blue water consumption	kg	59806.23	38103.21	2648.66	2994.24	12947.33	0.00	3275.40	-162.60

The Figure 4.11 shows the graphical representation of the results presented in the Table 4-8.

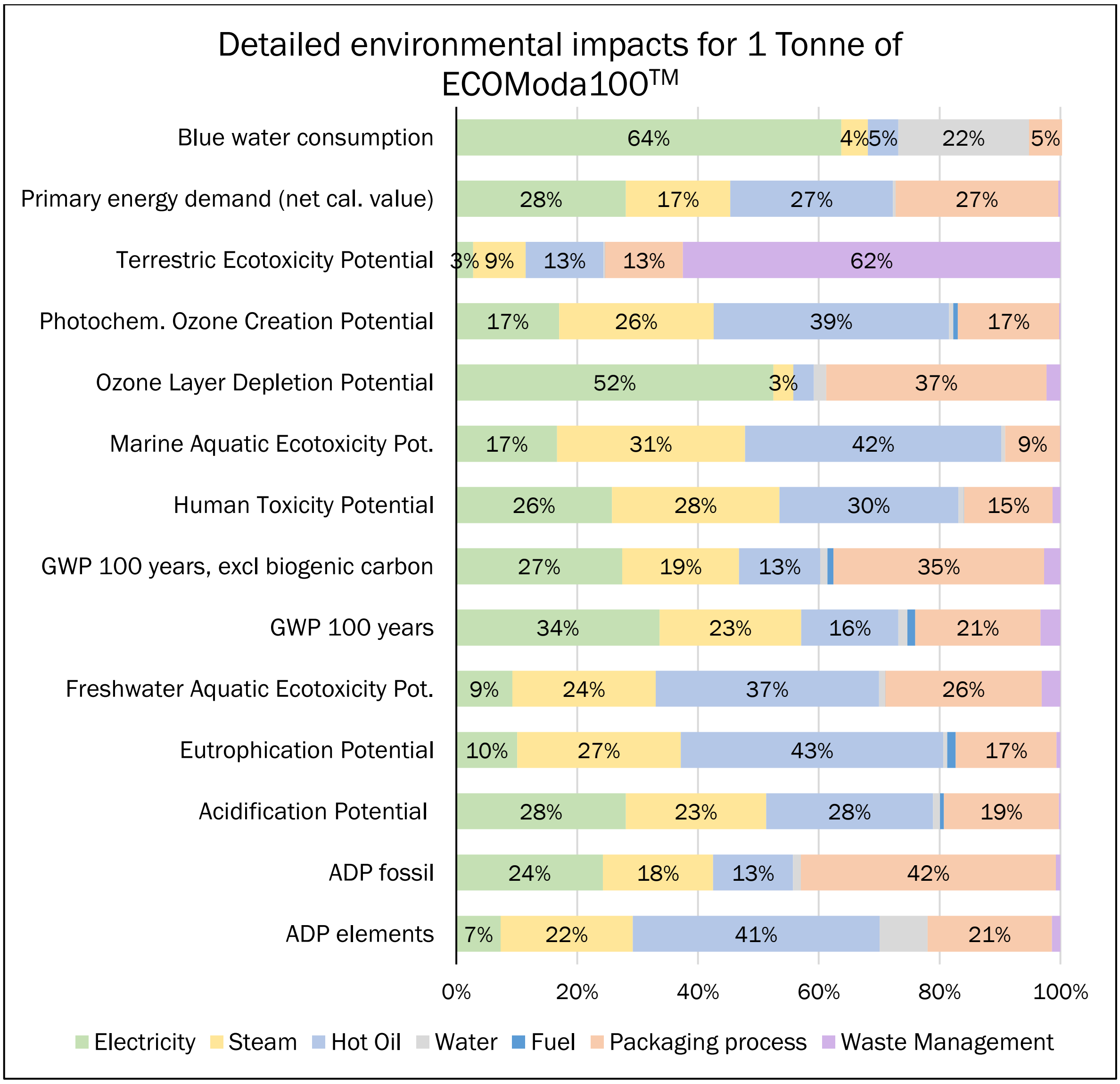

Figure 4.11: Detailed environmental impacts for 1 Tonne of ECOModa100™

Hotspot Identification

- Abiotic Depletion Potential (ADP Elements) is 1.33E-03 kg Sb eq. with major contribution from hot oil (~41%) followed by steam consumption (~22%) and packaging process (~21%).
- Abiotic Depletion (ADP fossil) is 20742.96 MJ with major contribution from packaging process (~42%) followed by electricity consumption (~24%), steam consumption (~18%) and hot oil (~13%).
- Acidification Potential (AP) is 21.27 kg SO_2 eq. with major contribution from hot oil (~28%) followed by electricity consumption (~28%), steam consumption (~23%) and packaging process (~19%).
- Eutrophication Potential (EP) is 2.49 kg Phosphate eq. with major contribution from hot oil (~43%) followed by steam consumption (~27%), packaging process (~17%) and electricity consumption (~10%).
- Global Warming Potential (GWP 100 Years) is 1507.95 kg CO_2 eq. with major contribution from electricity consumption (~34%) followed by steam consumption (~23%), packaging process (~21%) and hot oil (~16%).

- Global Warming Potential (GWP excluding biogenic carbon) is 1849.07 kg CO_2 eq. with major contribution from packaging process (~35%) followed by electricity consumption (~27%), steam consumption (~19%) and hot oil (~13%).
- Human Toxicity Potential is 659.41 kg DCB eq. with major contribution from hot oil (~30%) followed by steam consumption (~28%), electricity consumption (~26%) and packaging process (~15%).
- Ozone Layer Depletion Potential (ODP) is 3.58E-09 kg R11 eq. with major contribution from electricity consumption (~52%) followed by packaging process (~37%).
- Photochemical Ozone Creation Potential (POCP) is 1.62 kg Ethene eq. with major contribution from hot oil (~39%) followed by steam consumption (~26%), electricity consumption (~17%) and packaging process (~17%).
- Primary Energy Demand from renewable and non-renewable Resources (net calorific value) is 69937.83 MJ with major contribution from electricity consumption (~28%), packaging process (~27%), hot oil (~27%) and steam consumption (~17%).
- Blue water consumption is 59806.23 kg with major contribution from electricity consumption (~64%) followed by water (~22%).

5. Interpretation

5.1. Identification of Relevant Findings

5.1.1. Conventional Spandex

- Abiotic Depletion Potential (ADP fossil) is 173571.48 MJ with major contribution from raw materials (~92%). Among the Raw Materials, the major contribution is from PTMEG (~72%) followed by MDI (~10%), SFO (~8%) and packaging process (~6%).
- Acidification Potential (AP) is 37.22 kg SO_2 eq. with major contribution from raw materials (~49%) followed by electricity consumption (~17%), hot oil (~16%) and steam consumption (~13%). Among the Raw Materials, the major contribution is from PTMEG (~34%) followed by MDI (~29%), packaging process (~23%) and SFO (~13%).
- GWP impact for 1 Tonne of conventional spandex production is 8887.56 kg CO_2 eq. with major contribution from raw materials (~85%) followed by electricity consumption (~6%), steam consumption (~4%) and hot oil (~3%). Among the Raw Materials, the major contribution to GWP is from PTMEG (~66%) followed by MDI (~13%), SFO (~12%) and packaging process (~4%).
- Primary Energy Demand (PED) from renewable and non-renewable Resources (net calorific value) is 244890.13 MJ with major contribution from raw materials (~78%) followed by electricity consumption (~9%), hot oil (~8%) and steam consumption (~5%). Among the Raw Materials, the major contribution to PED is from PTMEG (~34%) followed by MDI (~28%), SFO (~17%) and packaging process (~17%).
- Blue water consumption is 95936.89 kg with major contribution from electricity consumption (~43%) followed by raw materials (~35%) and process water (~17%). Among the Raw Materials, the major contribution is from PTMEG (~43%) followed by SFO (~28%), MDI (~14%), and packaging process (~10%).

5.1.2. ECOModa100™

- Abiotic Depletion (ADP fossil) is 20742.96 MJ with major contribution from packaging process (~42%) followed by electricity consumption (~24%), steam consumption (~18%) and hot oil (~13%).
- Acidification Potential (AP) is 21.27 kg SO2 eq. with major contribution from hot oil (~28%) followed by electricity consumption (~28%), steam consumption (~23%) and packaging process (~19%).
- Global Warming Potential (GWP 100 Years) is 1507.95 kg CO2 eq. with major contribution from electricity consumption (~34%) followed by steam consumption (~23%), packaging process (~21%) and hot oil (~16%).
- Primary Energy Demand from renewable and non-renewable Resources (net calorific value) is 69937.83 MJ with major contribution from electricity consumption (~28%), packaging process (~27%), hot oil (~27%) and steam consumption (~17%).
- Blue water consumption is 59806.23 kg with major contribution from electricity consumption (~64%) followed by water (~22%).

5.2. Assumptions and Limitations

As per the data provided by IIPL for FY 2022-23, the assumptions and limitations made during the evaluation of life cycle information for the products under study are summarised below.

- Transport of materials through truck and ship are analysed by using GaBi datasets.
- There were very few cases where proxy datasets had to be used in the LCA models. This occurred when no LCI data was available for an intermediate chemical/material.
- Likewise, there were few cases where data had to be used from a different region or technology. These instances were uncommon and noted in the Data Quality section of the LCA report.
- GaBi datasets provide a completely aggregated, cradle-to-gate process inventory. The use of this type of datasets had two main consequences, on the modelling exercise: (i) predefined methodological choices had to be used (e.g., regarding multifunctionality), making it difficult to ensure consistency within the same product life cycle and across the different analysed scenarios; and (ii) the level of granularity of the contribution analysis was bound to the level of aggregation of the used datasets, which is particularly high for processes in the upstream part of the supply chain.
- Services (Accounting, business, catering, etc) inputs are excluded from the study.

5.3. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi 2023 database were used. The LCI datasets from the GaBi 2023 LCI database are widely distributed and used with the GaBi 10.7 LCA software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.3.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. Seasonal variations/variations across different manufacturers were balanced out by using yearly averages/weighted averages. All background data are sourced from GaBi databases with the documented precision.

- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

5.3.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases.

- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modelling approaches.

5.3.3. Representativeness

- ✓ **Temporal:** All primary data were collected for FY 2022-23. All secondary data come from the GaBi 2023 LCI database and are representative of the years 2019-2025. As the study intended to compare the product systems for the reference year 2022, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.4. Model Completeness and Consistency

5.4.1. Completeness

All relevant process steps for each product system were considered and modelled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.

5.4.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimised by exclusively/predominantly using LCI data from the GaBi 2023 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.5. Recommendations

Based on the observations of the present LCA study, a few directional recommendations to reduce GWP across the life cycle stages of ECOModa100™ and conventional spandex production can be summarised as follows:

- ✓ The PTMEG highly influences the overall LCIA results of conventional spandex, IIPL can consider using biobased PTMEG material instead of PTMEG produced via chemical route.
- ✓ The boilers at IIPL facility consume coal and rice husk as an energy source for steam production, IIPL can consider using natural gas or biofuels instead of coal.
- ✓ IIPL has easy access to hydroelectricity at Baddi, HP and most of the electricity consumed at manufacturing facility comes from hydel power. IIPL can consider using the electric boiler powered by hydroelectricity.
- ✓ IIPL can also consider recycling its packaging materials such as cardboard boxes, cardboard tubes, and plastic LD liners, which would in turn reduce the demand for virgin packaging materials and lead to GWP (100 years) impact reduction.
- ✓ IIPL is procuring most of the raw materials from outside the country which is leading to considerable environmental impact because of transportation. IIPL should consider procuring raw materials from the local area.

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Annex A: Life Cycle Inventory

The input-output inventory for conventional spandex and ECOModa100™ are summarised in Table A-1 and Table A-2 respectively.

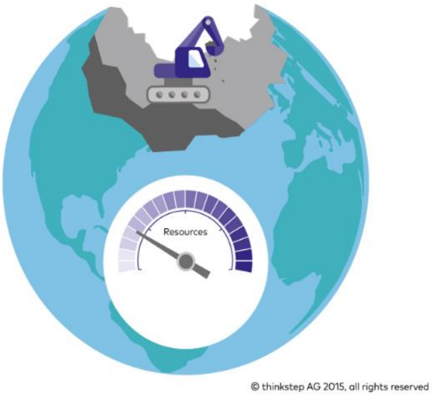
Table A-1: Life Cycle Inventory of raw materials, energy and emissions for conventional spandex

Conventional Spandex (Utility Data)		
Input	**Unit**	**Value**
Diesel	litre	76677.28
Electricity	kWh	46847161.04
Electricity from photovoltaics	kWh	4633.98
Steam	Tonne	39398.84
Water	m^3	195141.52
Output	**Unit**	**Value**
Conventional Spandex	Tonne	12317.39
Solid waste	Tonne	135.218
Chemical waste	Tonne	733.14
Wastewater	Tonne	8925.73
Raw materials mix for conventional spandex		
Input	**Unit**	**Quantity for 2022-23**
Antioxidizing agent	kg	121673.69
Butane diamine	kg	12959.32
Butanol (n-Butanol)	kg	1184.93
DHT800	kg	307184.07
Diethanolamine (DEA)	kg	33598.25
Diethylenetriamine (DETA)	kg	539.97
Dimethylacetamide	kg	788509.12
Ethylenediamine	kg	199249.67
Finishing Agent	kg	538473.08
HN-150	kg	41197.86
Methylene diphenyl diisocyanate	kg	2154838.28
MGST	kg	20998.91
OT-100	kg	16098.16
Polytetramethylene Ether Glycol (PTMEG)	kg	9140096.12
Titanium dioxide	kg	13999.27
XHOT100	kg	14399.25
Output	**Unit**	**Quantity for 2022-23**
Raw materials mix for conventional spandex	kg	13405000

Table A-2: Life Cycle Inventory of raw materials, energy and emissions for ECOModa100™

ECOModa100™		
Input	**Unit**	**Value**
Waste Spandex from conventional spandex	Tonne	75.588
Waste Polymer	Tonne	1.003
Diesel	litre	410.86
Electricity	kWh	233638.96
Electricity from photovoltaics	kWh	22.98
Steam	Tonne	215.04
Water	m^3	849.48
Output	**Unit**	**Value**
ECOModa100™	Tonne	66.001
Chemical Waste	Tonne	4.82
Wastewater	Tonne	0.56

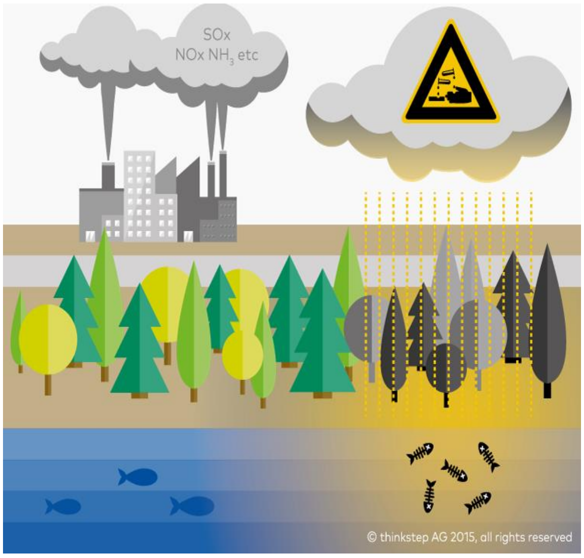
Annex B: Description of Selected Inventories and Impact Categories



Abiotic depletion

This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of de-accumulation. The geographic scope of this indicator is at global scale. [2]

Acidification Potential



The acidification of soils and waters occurs predominantly through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 and below. Sulphur dioxide and nitrogen oxide and their respective acids (H_2SO_4 und HNO_3) produce relevant contributions. This damages ecosystems, whereby forest dieback is the most well-known impact.

Acidification has direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones which are corroded or disintegrated at an increased rate. When analysing acidification, it should be considered that although it is a global problem, the regional effects of acidification can vary.

The acidification potential is given in sulphur dioxide equivalents (SO_2-Eq.). The acidification potential is described as the ability of certain substances to build and release H+ - ions. Certain emissions can also be considered to have an acidification potential, if the given S-, N- and halogen atoms are set in proportion to the molecular mass of the emission. The reference substance is sulphur dioxide.

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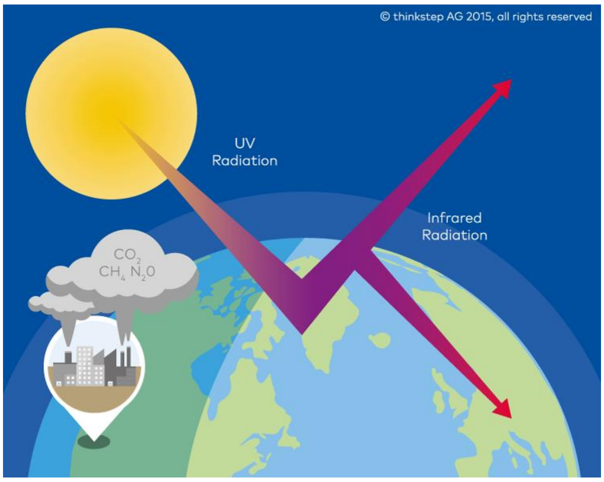
[2] CML (Centrum voor Milieukunde Leiden).

Global Warming Potential



The mechanism of the greenhouse effect can be observed on a small scale, as the name suggests, in a greenhouse. These effects are also occurring on a global scale. The occurring short-wave radiation from the sun comes into contact with the earth's surface and is partly absorbed (leading to direct warming) and partly reflected as infrared radiation. The reflected part is absorbed by so-called greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect at the earth's surface.

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases that are considered to be caused, or increased, anthropogenically are, for example, carbon dioxide, methane and CFCs. An analysis of the greenhouse effect should consider the possible long term global effects.

The global warming potential is calculated in carbon dioxide equivalents (CO_2-Eq.). This means that the greenhouse potential of an emission is given in relation to CO_2. Since the residence time of the gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A period of 100 years is customary.

Primary energy demand

Primary energy demand is often difficult to determine due to the various types of energy source. Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere or geosphere or energy source without any anthropogenic change. For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e., the energy content of the raw material). For renewable resources, the energy-characterised amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e., from the height difference). As aggregated values, the following primary energies are designated:

The total **"Primary energy from non-renewable resources"**, given in MJ, essentially characterises the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents e.g., in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations.

The total **"Primary energy from renewable resources"**, given in MJ, is generally accounted separately and comprises hydropower, wind power, solar energy and biomass.

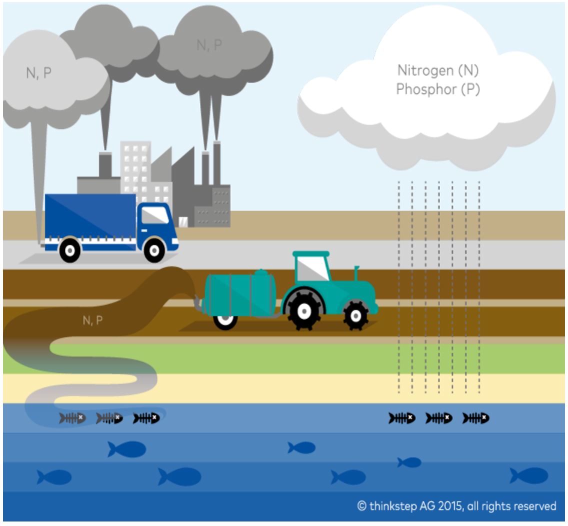
It is important that the end energy (e.g., 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end energy will not be accounted for.

The energy content of the manufactured products will be considered as feedstock energy content. It will be characterized by the net calorific value of the product. It represents the still usable energy content.

Aquatic Eutrophication

Aquatic Eutrophication occurs when excessive amounts of nutrients reach freshwater systems or oceans. Algae bloom may result, and fish may disappear. Whereas phosphorous is mainly responsible for eutrophication in freshwater systems, nitrogen is mainly responsible for eutrophication in ocean water bodies.

The Aquatic Eutrophication indicator based on the potential impact relative to the reference substance phosphorous, i.e. [kg P eq / FU] is recommended for freshwater eutrophication and mass of nitrogen equivalents [kg N eq) / FU] is recommended for marine eutrophication.



Photochemical Ozone Creation Potential (POCP)

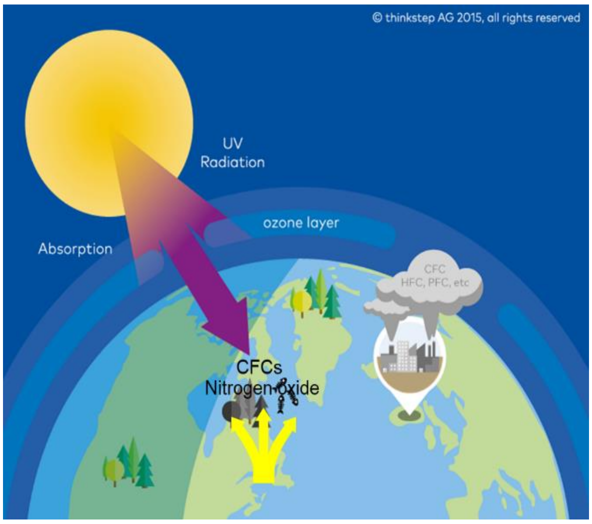
Photochemical Ozone Creation Potential (POCP) is the potential of ozone creation at ground level (i.e. tropospheric ozone) through photochemical transformation of ozone precursor emissions. The main ozone precursor compounds are nitrogen oxides (NOx) and non-methane volatile organic compounds

(NMVOC). Mass of non-methane volatile organic compound equivalents, e.g. [kg NMVOC eq / FU] calculated using the "photochemical oxidant formation potential" indicator at a midpoint level, as described in the ReCiPe impact assessment methodology.

Ozone Depletion potential

The "ozone depletion" refers to the thinning of the stratospheric ozone layer, which protects the earth from harmful ultraviolet radiation. The major causes of ozone depletion are emissions of chlorofluorocarbons and hydrofluorocarbons, which were commonly used in refrigerants, propellants, solvents, and insulating foam. Fortunately,

nearly every country in the world has agreed to phase out the production and use of these and other ozone-depleting substances. However, because some of these chemicals are still being phased out, they can still be found in many products and production chains.



Water Scarcity Potential

A measure of the stress on a region due to water consumption addressed by applying the relative Available Water Remaining (AWARE) per area in a watershed. AWARE is to be used as a water use midpoint indicator representing the relative Available Water Remaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. Based on the water consumption, i.e., the calculation logic inputs – degradative outputs. The flows are multiplied with the country specific characterization factors. The "AWARE 1.2C, global average" refers to the average Water Scarcity Potential at globally.

Human toxicity Potential (HTP)

The Human toxicity Potential (HTP), a calculated index that reflects the potential harm of a unit of chemical released into the environment, is based on both the inherent toxicity of a compound and its potential dose. It is used to weight emissions inventoried as part of a life-cycle assessment (LCA) or in the toxics release inventory (TRI) and to aggregate emissions in terms of a reference compound. Total emissions can be evaluated in terms of benzene equivalence (carcinogens) and toluene equivalents (non-carcinogens).

Annex C: Critical Review Statement

INDEPENDENT VERIFICATION REPORT

COMPARATIVE LIFE CYCLE ASSESSMENT

OF

CONVENTIONAL SPANDEX AND ECOMODA100TM PRODUCTS

01 OCTOBER 2023

Sphera Solutions commissioned Dr Hudai Kara (Chair), Dr GS Dangayach and Prabodha Acharya to perform an external independent verification of the report:

Report on Comparative Life Cycle Assessment of Conventional Spandex and ECOModa100TM products.

Ramjee Chaudhary of Sphera Solutions completed the Life Cycle Assessment (LCA) study on behalf of the commissioning organization, Indorama India Private Limited.

The review of the study was performed to demonstrate conformance with the following standards:

- International Organization for Standardization. (2006). Environmental management -- Life cycle assessment – Principles and framework (ISO 14040:2006);
- International Organization for Standardization. (2006). Environmental management -- Life cycle assessment -- Requirements and guidelines (ISO 14044:2006);
- International Organization for Standardization. (2014). Environmental management -- Life cycle assessment -- Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 1404 4:2006. (ISO/TS 14071:2014).

The independent third-party verification was conducted by a panel of external experts per ISO 14044:2006 Section 6.3: Critical review by panel of interested parties.

Dr Hudai Kara (Panel Chair), Managing Director, Metsims Sustainability Consulting

Dr GS Dangayach, Professor, Malaviya National Institute of Technology Jaipur (Panelist)

Prabodha Acharya, Chief Sustainability Officer, JSW Group (Panelist)

REVIEW SCOPE

The intent of this review was to provide an independent third-party external verification of a completed LCA study report for a comparative life cycle assessment of Conventional Spandex and ECOModa100TM products.

REVIEW PROCESS

The review involved the verification of the LCA report as submitted based on the requirements set forth by the applicable ISO standards.

VERIFICATION STATEMENT

Based on the independent verification objectives, **Comparative Life Cycle Assessment of Conventional Spandex and ECOModa100TM products**, was verified to be ***in conformance*** with the applicable ISO standards referenced above. The plausibility, quality, and accuracy of the LCA-based data and supporting information are confirmed.

As the External Independent Third-Party Review Panel, we confirm that we have sufficient knowledge and experience of textile products, the ISO standards and the geographical areas intended to carry out this verification.

Sincerely,

Dr Hudai Kara (Chair) **Dr GS Dangayach** **Prabodha Acharya**