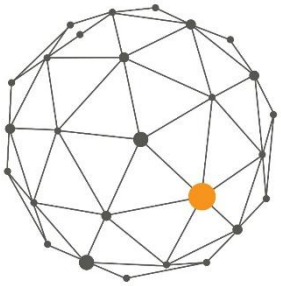

Instituto 17

The role of exports in driving manufacturing pollution in Sub-Saharan Africa and South Asia: towards a better trade-environment governance

Annex 1: Input-output Life Cycle Assessment Methodology

July/2021

Part of the Program Sustainable Manufacturing and Environmental Pollution (SMEP)

UNITED NATIONS
UNCTAD

Note

IO-LCA Methodology

A. LCA Inventory modelling

EXIOBASE was chosen as the supporting database for IO-LCA. EXIOBASE is a global, detailed Multi-regional Environmentally Extended database developed by several research institutes in projects financed by the European research framework programs. It was developed by harmonizing and detailing supply-use tables for many countries, estimating emissions and resource extractions by industry, and linking country supply-use tables via trade.

Version 3.3.16b1 in SimaPro compatible format was used. The database covers 43 countries that respond for 95 per cent of the global GDP and over 150 smaller countries combined in five 'rest of the world' groups by continent. The base year is 2011. It distinguishes over 160 industry sectors and 200 product categories by country. It is a hybrid version so that relations between industries and countries are not only in monetary value but also in physical terms.

EXIOBASE contains the physical layers of energy, water, materials, and land, which can be tracked as resource inputs to the economic production process. Besides, various material extensions provide information on metabolic outputs of production and consumption processes, such as emissions and waste. EXIOBASE covers:

- Greenhouse gas emissions, in kilograms of CO2, CH4, N2O;
- Polluting emissions: SOx, NOx, NH3, CO, Benzenes, Indeno (1,2,3-cd) pyrene, PAHs, PCBs, PCDD_F, HCB, VOCs, PM10, PM2.5, TSP, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn, SF6, HFCs, PFCs);
- Nitrogen and phosphorous emissions to water;
- Domestic material extraction of various types of crops, wood, metal ores, industrial and construction minerals & fossil fuels (differentiated in used and unused extracted materials);
- Withdrawal of blue water, differentiated by the manufacturing, electricity production, and domestic use sector;
- Green and blue water consumption, differentiated by use category, for various types of agriculture, livestock, manufacturing, electricity production, and domestic consumption;

- and land use (by different types of arable land, pastures, and forests).

In EXIOBASE, due to the lack of readily available data for many countries, the approach used to reach global coverage estimates "Rest of the World (RoW)" regions, which typically consist of the remaining countries not explicitly covered in the database. The selected SSA and SA countries are included in two RoW groups by continent (RoW Asia and Pacific and RoW Africa) used in this study.

To build datasets at a country level, and to consider only exports, data on exported quantities for the selected export-oriented manufactured goods in the thirteen target countries were inserted in the system model (see tables bellow) based on trade statistics made available by the International Trade Centre (ITC) (ITC, 2021), which relies on UN Comtrade (United Nations, 2002) and national statistics offices as data sources. Data were downloaded in 4-digit codes, and only quantities registered in "tonnes" were considered.

Table 1 – Exported quantities for the selected manufacturing activities in the thirteen SMEP target countries considered in the modelling - Part 1: division 15

	EXIOBASE codes											
	I15											
	a	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*K*	*Total*
Correspondence to ISIC rev.3 divisions	*15*											
Bangladesh	-	-	-	-	-	-	-	-	-	-	-	-
Democratic Republic of Congo	3,13E+01	3,13E+01	3,13E+01	3,13E+01	1,03E+04	0,00E+00	9,02E+02	2,80E+01	1,01E+04	6,79E+02	2,60E+01	2,22E+04
Ethiopia	1,33E+02	1,33E+02	1,33E+02	1,33E+02	1,71E+04	3,33E-01	3,51E+03	4,16E+04	2,60E+05	0,00E+00	1,00E+00	3,23E+05
Kenya	6,82E+02	6,82E+02	6,82E+02	6,82E+02	2,27E+05	9,34E+02	5,91E+04	3,69E+03	6,71E+05	1,88E+03	2,40E+01	9,66E+05
Ghana	9,13E+00	9,13E+00	9,13E+00	9,13E+00	2,81E+05	4,33E+02	7,48E+04	2,60E+01	3,17E+05	9,56E+04	3,01E+04	7,99E+05
Nepal	-	-	-	-	-	-	-	-	-	-	-	-
Nigeria	3,25E+00	3,25E+00	3,25E+00	3,25E+00	1,68E+04	7,67E+01	2,09E+04	2,27E+02	5,25E+04	1,01E+05	3,40E+01	1,92E+05
Pakistan	-	-	-	-	-	-	-	-	-	-	-	-
Rwanda	4,90E+02	4,90E+02	4,90E+02	4,90E+02	4,95E+04	1,50E+01	9,21E+04	3,97E+04	1,66E+05	4,03E+03	6,38E+02	3,54E+05
Senegal	1,79E+03	1,79E+03	1,79E+03	1,79E+03	3,40E+01	4,17E+01	8,22E+04	1,79E+03	1,78E+05	1,10E+04	1,77E+04	2,98E+05
Uganda	1,51E+01	1,51E+01	1,51E+01	1,51E+01	1,37E+05	3,25E+02	1,34E+05	1,52E+05	4,88E+05	7,39E+04	9,51E+02	9,86E+05
United Republic of Tanzania	1,68E+03	1,68E+03	1,68E+03	1,68E+03	2,19E+05	3,23E+01	5,49E+02	1,64E+04	7,64E+04	1,40E+01	8,87E+02	3,20E+05
Zambia	3,97E+02	3,97E+02	3,97E+02	3,97E+02	1,45E+05	1,10E+02	2,96E+04	3,11E+05	4,70E+04	1,13E+05	1,74E+03	6,48E+05

Table 2 – Exported quantities for the selected manufacturing activities in the thirteen SMEP target countries considered in the modelling - Part 2: divisions 17, 18, 19 and 24

	EXIOBASE codes								
Correspondence to ISIC rev.3 divisions	*I17*	*I18*	*I19*	*I24*					
				1	*1w*	*2*	*3*	*4*	*Total*
	17	*18*	*19*	*24*					
Bangladesh	7,22E+05	7,00E+00	1,66E+03	5,24E+04	5,24E+04	1,07E+04	1,07E+04	8,35E+04	2,10E+05
Democratic Republic of Congo	5,80E+02	1,04E+02	-	3,64E+03	3,64E+03	1,50E+00	1,50E+00	6,63E+03	1,39E+04
Ethiopia	5,58E+03	1,39E+03	-	2,29E+03	2,29E+03	2,37E+01	2,37E+01	2,51E+03	7,15E+03
Kenya	2,67E+04	6,70E+01	-	1,70E+05	1,70E+05	2,04E+04	2,04E+04	3,60E+05	7,40E+05
Ghana	6,66E+03	1,83E+02	-	6,33E+03	6,33E+03	2,05E+03	2,05E+03	7,08E+04	8,75E+04
Nepal	4,44E+04	1,00E+00	5,65E+02	5,99E+03	5,99E+03	0,00E+00	0,00E+00	8,83E+03	2,08E+04
Nigeria	2,87E+03	6,20E+01	-	3,50E+04	3,50E+04	2,22E+05	2,22E+05	2,96E+05	8,09E+05
Pakistan	1,24E+06	4,60E+01	1,46E+03	2,13E+05	2,13E+05	5,68E+03	5,68E+03	3,00E+05	7,37E+05
Rwanda	4,20E+03	1,26E+02	-	4,26E+02	4,26E+02	1,02E+01	1,02E+01	1,25E+04	1,33E+04
Senegal	5,46E+03	2,41E+02	-	2,29E+05	2,29E+05	3,57E+01	3,57E+01	2,82E+05	7,40E+05
Uganda	4,04E+04	2,07E+03	-	3,93E+03	3,93E+03	1,81E+02	1,81E+02	1,43E+05	1,52E+05
United Republic of Tanzania	1,02E+04	2,77E+03	-	1,29E+04	1,29E+04	5,16E+03	5,16E+03	4,36E+04	7,98E+04
Zambia	1,81E+03	4,00E+01	-	2,70E+05	2,70E+05	8,24E+03	8,24E+03	3,54E+05	9,10E+05

Table 3 – Exported quantities for the selected manufacturing activities in the thirteen SMEP target countries considered in the modelling - Part 3: divisions 26 and 31

	EXIOBASE codes						
	I26						*I31*
	a	*b*	*c*	*d*	*e*	*Total*	
Correspondence to ISIC rev.3 divisions	*26*						*31*
Bangladesh	2,45E+02	8,17E+03	1,00E+00	1,35E+05	8,66E+03	1,52E+05	-
Democratic Republic of Congo	-	-	-	-	-	-	2,28E+03
Ethiopia	-	-	-	-	-	-	5,00E+02
Kenya	-	-	-	-	-	-	2,01E+03
Ghana	-	-	-	-	-	-	9,74E+03
Nepal	1,97E+04	4,34E+02	0,00E+00	0,00E+00	5,70E+02	2,07E+04	-
Nigeria	-	-	-	-	-	-	6,84E+02
Pakistan	1,94E+04	1,24E+04	1,04E+04	6,66E+06	1,10E+05	6,81E+06	-
Rwanda	-	-	-	-	-	-	1,10E+03
Senegal	-	-	-	-	-	-	4,32E+03
Uganda	-	-	-	-	-	-	1,65E+03
United Republic of Tanzania	-	-	-	-	-	-	1,28E+03
Zambia	-	-	-	-	-	-	1,09E+04

ISIC rev.3 was chosen as a default classification to maintain consistency with the SEI-York study previously published and internally to this study. To convert data to the ISIC rev.3 classification, a concordance table from World Integrated Trade Solution (WITS, 2015) was used. Correlations between ISIC rev.3 and EXIOBASE were based on a concordance table from the Norwegian University of Science and Technology (NTNU, 2018).

When one code from the original classification corresponded to more than one code in the target classification, the value was entirely allocated to the code included in the selected export-oriented goods list in a conservative approach. If more than one code was included in this list, the value was equally distributed to all these codes to avoid double counting.

Table 4 – Concordance table from ISIC 3 to EXIOBASE for Manufacture of food products and beverages sector

ISIC rev.3 code	Description	EXIOBASE code
1511	Production, processing and preserving of meat and meat products	i15.a;i15.b;i15.c;i15.d
1512	Processing and preserving of fish and fish products	i15.k
1513	Processing and preserving of fruit and vegetables	i15.g;i15.i
1514	Manufacture of vegetable and animal oils and fats	i15.e
1520	Manufacture of dairy products	i15.f
1531	Manufacture of grain mill products	i15.g;i15.i
1532	Manufacture of starches and starch products	i15.g;i15.i
1533	Manufacture of prepared animal feeds	i15.g;i15.i
1541	Manufacture of bakery products	i15.g;i15.i
1542	Manufacture of sugar	i15.h
1543	Manufacture of cocoa, chocolate and sugar confectionery	i15.i
1544	Manufacture of macaroni, noodles, couscous and similar farinaceous products	i15.g;i15.i
1549	Manufacture of other food products n.e.c.	i15.i
1551	Distilling, rectifying and blending of spirits; ethyl alcohol production from fermented materials	i15.j
1552	Manufacture of wines	i15.j
1553	Manufacture of malt liquors and malt	i15.j
1554	Manufacture of soft drinks; production of mineral waters	i15.j

Table 5 – Concordance table from ISIC 3 to EXIOBASE for Manufacture of textiles

ISIC rev.3 code	Description	EXIOBASE code
1711	Preparation and spinning of textile fibres; weaving of textiles	i17
1712	Finishing of textiles	i17
1721	Manufacture of made-up textile articles, except apparel	i17
1722	Manufacture of carpets and rugs	i17
1723	Manufacture of cordage, rope, twine and netting	i17
1729	Manufacture of other textiles n.e.c.	i17
1730	Manufacture of knitted and crocheted fabrics and articles	i17

Table 6 – Concordance table from ISIC 3 to EXIOBASE for Manufacture of wearing apparel; dressing and dyeing of fur

ISIC rev.3 code	Description	EXIOBASE code
1810	Manufacture of wearing apparel, except fur apparel	i18
1820	Dressing and dyeing of fur; manufacture of articles of fur	I18

Table 7 – Concordance table from ISIC 3 to EXIOBASE for Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness, and footwear

ISIC rev.3 code	Description	EXIOBASE code
1911	Tanning and dressing of leather	i19
1912	Manufacture of luggage, handbags and the like, saddlery and harness	i19
1920	Manufacture of footwear	i19

Table 8 – Concordance table from ISIC 3 to EXIOBASE for Manufacture of chemicals and chemical products

ISIC rev.3 code	Description	EXIOBASE code
2411	Manufacture of basic chemicals, except fertilizers and nitrogen compounds	i24.1;i24.1.w;i24.4
2412	Manufacture of fertilizers and nitrogen compounds	i24.2;i24.3;i24.4
2413	Manufacture of plastics in primary forms and of synthetic rubber	i24.1;i24.1.w;i24.4
2421	Manufacture of pesticides and other agrochemical products	i24.4
2422	Manufacture of paints, varnishes, and similar coatings, printing ink and mastics	i24.4
2423	Manufacture of pharmaceuticals, medicinal chemicals, and botanical products	i24.4
2424	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes, and toilet preparations	i24.4
2429	Manufacture of other chemical products n.e.c.	i24.4
2430	Manufacture of man-made fibres	i24.4

Table 9 – Concordance table from ISIC 3 to EXIOBASE for Manufacture of other non-metallic mineral products

ISIC rev.3 code	Description	EXIOBASE code
2610	Manufacture of glass and glass products	i26.a;i26.w.1
2691	Manufacture of non-structural non-refractory ceramic ware	i26.b
2692	Manufacture of refractory ceramic products	i26.b
2693	Manufacture of structural non-refractory clay and ceramic products	i26.c
2694	Manufacture of cement, lime and plaster	i26.d
2695	Manufacture of articles of concrete, cement, and plaster	i26.e
2696	Cutting, shaping, and finishing of stone	i26.e
2699	Manufacture of other non-metallic mineral products n.e.c.	i26.e

Table 10 – Concordance table from ISIC 3 to EXIOBASE for Manufacture of electrical machinery and apparatus n.e.c.

ISIC rev.3 code	Description	EXIOBASE code
3110	Manufacture of electric motors, generators, and transformers	i31
3120	Manufacture of electricity distribution and control apparatus	i31
3130	Manufacture of insulated wire and cable	i31
3140	Manufacture of accumulators, primary cells, and primary batteries	i31
3150	Manufacture of electric lamps and lighting equipment	I31
3190	Manufacture of other electrical equipment n.e.c.	I31

In EXIOBASE, the processes included in the system model were the 'Producing industries' in the 'Linked database', which relates to inventories of production of goods and services that allow detailed supply chain interpretation. Therefore, a "cradle to gate" system boundary was assumed, including upstream processes from the supply chain. System boundary then goes from the beginning of raw materials extraction to the end of the manufacturing phase. Before including export data in the database, quantities were transformed to dry matter, using the same factors described for creating EXIOBASE inventories.

B. Life Cycle Impact Assessment

Life Cycle Impact Assessment is performed using a set of indicators considered to be representative of the total environmental impact embedded in EXIOBASE and Ecoinvent database (Steinmann et al., 2018). This set includes headline indicators proposed by Eurostat (European Commission, 2020) consisting of the material, land, water, and carbon footprint and five additional indicators (marine eco-toxicity, terrestrial eco-toxicity, photochemical oxidation, terrestrial acidification, and eutrophication) which are needed to cover 95 per cent of the variance in product-region rankings. Additionally, human health indicators are added to the set to include this impact dimension, fitting the study goals. Ozone depletion is an exception (it is indicated by the authors but is not included in the method). Ozone depletion is not included in the method, even if it is indicated for LCAs using the Ecoinvent database. However, ozone depletion is becoming less relevant due to successful emission reduction policies (WMO, 2011), which justifies its exclusion.

Characterization factors[1] are taken from midpoint (problem-oriented) impact categories, hierarchical perspectives in ReCiPe 2016[2] method. All the impact categories included in the method are presented in Table 2. Infrastructure datasets and long-term emissions (considered to happen beyond 100 years) are excluded, to avoid uncertainty.

C. IO-LCA results

The tables below (Table 11, Table 12, Table 13, Table 14, Table 15 and Table 16) show the impact results for the selected indicators in SA and SSA SMEP target countries and the four case study countries, namely Bangladesh, Pakistan, Kenya, and the United Republic of Tanzania.

[1] Factors derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the commun unit of the category indicator (ISO, 2006)

[2] ReCiPe 2016 (Huijbregts et al., 2016) is an improvement on ReCiPe 2008 (Goedkoop et al., 2009), and its predecessors CML 2000 and Eco-indicator 99. It was developed through collaboration between the Dutch National Institute for Public Health and the Environment (RIVM), Radboud University Nijmegen, Norwegian University of Science and Technology, and PRé Sustainability. The primary objective of the ReCiPe method is to transform the long list of life cycle inventory results into a limited number of indicator scores, which express the relative severity on an environmental impact category. Where possible, it uses impact mechanisms that have global scope. The method uses two mainstream ways of deriving characterization factors: at midpoint or endpoint. Characterization factors at the midpoint level are located somewhere along the impact pathway, typically at the point after which the environmental mechanism is identical for all environmental flows assigned to that impact category. Characterization factors at the endpoint level correspond to three areas of protection, i.e. human health, ecosystem quality and resource scarcity. Following the same strategy as in ReCiPe2008, different sources of uncertainty and different choices were grouped into a limited number of perspectives or scenarios, according to the "Cultural Theory" (Thompson et al., 1990). These perspectives do not claim to represent archetypes of human behavior, they are merely used to group similar types of assumptions and choices. Three perspectives were included in ReCiPe2016:1. The individualistic perspective is based on the short-term interest, impact types that are undisputed, and technological optimism with regard to human adaptation;2. The hierarchist perspective is based on scientific consensus with regard to the time frame and plausibility of impact mechanisms;3. The egalitarian perspective is the most precautionary perspective, taking into account the longest time frame and all impact pathways for which data is available.

Table 11 – Impact results for SA SMEP target countries exports (absolute contribution)

		Textiles		Wearing apparel, fur		Leather, leather products, and footwear		Chemicals & chemical products /pharmaceuticals		Non-metallic mineral products	
Impact category	Unit	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate
Global warming	kg CO_2 eq	1,55E+10	3,08E+09	1,80E+05	6,90E+04	4,29E+07	6,61E+06	1,14E+09	6,74E+08	1,09E+09	5,32E+09
Terrestrial acidification	kg SO_2 eq	1,11E+08	1,19E+07	1,98E+03	2,83E+02	5,68E+05	2,87E+04	8,38E+06	4,80E+06	3,81E+06	2,07E+07
Freshwater eutrophication	kg P eq	5,43E+06	0,00E+00	1,08E+02	0,00E+00	2,68E+04	0,00E+00	2,50E+05	0,00E+00	2,86E+04	0,00E+00
Marine eutrophication	kg N eq	2,07E+07	0,00E+00	5,04E+02	0,00E+00	5,29E+04	0,00E+00	9,68E+05	0,00E+00	8,19E+04	0,00E+00
Terrestrial ecotoxicity	kg 1,4-DCB	5,53E+09	2,32E+09	7,34E+04	4,70E+04	5,84E+06	3,50E+06	1,17E+09	3,74E+08	4,42E+08	1,45E+09
Marine ecotoxicity	kg 1,4-DCB	2,95E+06	1,10E+06	3,96E+01	2,27E+01	3,11E+03	1,75E+03	6,64E+05	1,86E+05	2,34E+05	7,00E+05
Land use	m^2a crop eq	8,11E+10	0,00E+00	5,46E+05	0,00E+00	2,08E+08	0,00E+00	2,74E+09	0,00E+00	2,58E+08	0,00E+00
Water consumption	m^3	1,07E+10	8,85E+07	3,99E+05	2,01E+03	2,74E+07	1,96E+05	5,28E+08	2,15E+07	5,63E+07	5,61E+07
Ozone formation, Human health	kg NO_x eq	3,81E+07	8,03E+06	3,48E+02	1,71E+02	1,25E+05	5,23E+05	2,07E+06	4,57E+06	2,07E+06	2,25E+07
Human carcinogenic toxicity	kg 1,4-DCB	3,91E+06	6,33E+05	5,98E+01	1,52E+01	4,35E+03	1,58E+03	1,10E+06	1,43E+05	3,71E+05	3,98E+05
Human non-carcinogenic toxicity	kg 1,4-DCB	5,55E+08	5,75E+07	6,96E+03	1,32E+03	5,19E+05	1,28E+05	1,43E+08	1,27E+07	4,46E+07	4,35E+07
Fossil resource scarcity	kg oil eq	2,05E+09	0,00E+00	3,92E+04	0,00E+00	3,56E+06	0,00E+00	2,49E+08	0,00E+00	5,40E+08	0,00E+00

Table 12 – Impact results for SSA SMEP target countries exports (absolute contribution)

		Textiles		Wearing apparel, fur		Leather, leather products, and footwear		Chemicals & chemical products /pharmaceuticals		Non-metallic mineral products	
Impact category	Unit	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate
Global warming	kg CO_2 eq	3,61E+09	2,66E+08	4,91E+08	5,07E+07	7,31E+07	3,32E+06	8,42E+08	1,59E+09	2,66E+08	6,14E+06
Terrestrial acidification	kg SO_2 eq	3,99E+07	9,69E+05	3,77E+06	1,80E+05	4,76E+05	1,13E+04	5,49E+06	1,99E+07	1,34E+07	1,13E+04
Freshwater eutrophication	kg P eq	1,18E+06	0,00E+00	2,13E+05	0,00E+00	1,27E+04	0,00E+00	7,19E+04	0,00E+00	1,01E+04	0,00E+00
Marine eutrophication	kg N eq	5,79E+06	0,00E+00	7,45E+05	0,00E+00	4,20E+04	0,00E+00	2,46E+05	0,00E+00	2,34E+04	0,00E+00
Terrestrial ecotoxicity	kg 1,4-DCB	8,68E+08	3,06E+08	1,79E+08	5,78E+07	5,83E+07	4,12E+06	8,24E+08	1,88E+09	9,39E+08	9,47E+06
Marine ecotoxicity	kg 1,4-DCB	4,44E+05	1,41E+05	8,93E+04	2,66E+04	2,98E+04	1,88E+03	4,33E+05	8,58E+05	5,39E+05	4,21E+03
Land use	m^2a crop eq	3,58E+10	0,00E+00	4,28E+09	0,00E+00	2,55E+08	0,00E+00	4,31E+09	0,00E+00	2,54E+08	0,00E+00
Water consumption	m^3	1,66E+09	3,56E+06	1,76E+08	6,60E+05	1,06E+07	4,31E+04	5,44E+07	2,06E+07	8,02E+06	7,85E+04
Ozone formation, Human health	kg NO_x eq	1,01E+07	9,47E+06	1,31E+06	1,88E+05	2,15E+05	1,31E+04	-1,76E+06	1,44E+07	7,23E+05	2,02E+04
Human carcinogenic toxicity	kg 1,4-DCB	6,89E+05	1,10E+05	1,47E+05	2,03E+04	4,12E+04	1,25E+03	3,21E+06	4,95E+05	6,84E+05	9,95E+02
Human non-carcinogenic toxicity	kg 1,4-DCB	4,99E+07	3,09E+06	1,11E+07	5,77E+05	4,73E+06	3,90E+04	5,14E+07	1,96E+07	1,42E+08	6,67E+04
Fossil resource scarcity	kg oil eq	3,49E+08	0,00E+00	7,11E+07	0,00E+00	1,43E+07	0,00E+00	1,02E+09	0,00E+00	5,04E+07	0,00E+00

Table 13 – Impact results for Bangladesh's exports (absolute contribution)

		Textiles		Wearing apparel, fur		Leather, leather products, and footwear		Chemicals & chemical products /pharmaceuticals		Non-metallic mineral products	
Impact category	Unit	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate
Global warming	kg CO_2 eq	5,57E+09	1,11E+09	2,33E+04	8,94E+03	1,93E+07	2,97E+06	2,50E+08	1,45E+08	3,02E+07	1,14E+08
Terrestrial acidification	kg SO_2 eq	3,98E+07	4,28E+06	2,56E+02	3,66E+01	2,55E+05	1,29E+04	1,81E+06	1,15E+06	1,14E+05	4,46E+05
Freshwater eutrophication	kg P eq	1,95E+06	0,00E+00	1,39E+01	0,00E+00	1,20E+04	0,00E+00	5,33E+04	0,00E+00	8,69E+02	0,00E+00
Marine eutrophication	kg N eq	7,47E+06	0,00E+00	6,53E+01	0,00E+00	2,38E+04	0,00E+00	2,06E+05	0,00E+00	2,39E+03	0,00E+00
Terrestrial ecotoxicity	kg 1,4-DCB	2,83E+09	0,00E+00	1,56E+04	0,00E+00	4,20E+06	0,00E+00	3,31E+08	0,00E+00	4,71E+07	0,00E+00
Marine ecotoxicity	kg 1,4-DCB	1,46E+06	0,00E+00	8,07E+00	0,00E+00	2,18E+03	0,00E+00	1,83E+05	0,00E+00	2,35E+04	0,00E+00
Land use	m^2a crop eq	2,92E+10	0,00E+00	7,07E+04	0,00E+00	9,35E+07	0,00E+00	5,80E+08	0,00E+00	9,01E+06	0,00E+00
Water consumption	m^3	3,85E+09	3,19E+07	5,17E+04	2,60E+02	1,23E+07	8,80E+04	1,13E+08	4,59E+06	1,57E+06	1,36E+06
Ozone formation, Human health	kg NO_x eq	1,37E+07	2,89E+06	4,51E+01	2,21E+01	5,64E+04	2,35E+05	4,94E+05	9,20E+05	6,05E+04	4,65E+05
Human carcinogenic toxicity	kg 1,4-DCB	1,41E+06	2,28E+05	7,75E+00	1,97E+00	1,96E+03	7,11E+02	2,36E+05	3,08E+04	1,15E+04	9,82E+03
Human non-carcinogenic toxicity	kg 1,4-DCB	2,00E+08	2,07E+07	9,02E+02	1,71E+02	2,33E+05	5,75E+04	3,05E+07	2,70E+06	1,48E+06	1,02E+06
Fossil resource scarcity	kg oil eq	7,39E+08	0,00E+00	5,08E+03	0,00E+00	1,60E+06	0,00E+00	5,51E+07	0,00E+00	1,38E+07	0,00E+00

Table 14 – Impact results for Pakistan's exports (absolute contribution)

		Textiles		Wearing apparel, fur		Leather, leather products, and footwear		Chemicals & chemical products /pharmaceuticals		Non-metallic mineral products	
Impact category	Unit	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate
Global warming	kg CO_2 eq	9,56E+09	1,90E+09	1,53E+05	5,87E+04	1,70E+07	2,62E+06	8,63E+08	5,14E+08	1,04E+09	5,19E+09
Terrestrial acidification	kg SO_2 eq	6,82E+07	7,35E+06	1,68E+03	2,41E+02	2,25E+05	1,14E+04	6,38E+06	3,55E+06	3,62E+06	2,02E+07
Freshwater eutrophication	kg P eq	3,35E+06	0,00E+00	9,16E+01	0,00E+00	1,06E+04	0,00E+00	1,91E+05	0,00E+00	2,66E+04	0,00E+00
Marine eutrophication	kg N eq	1,28E+07	0,00E+00	4,29E+02	0,00E+00	2,10E+04	0,00E+00	7,39E+05	0,00E+00	7,58E+04	0,00E+00
Terrestrial ecotoxicity	kg 1,4-DCB	3,42E+09	1,43E+09	6,25E+04	4,00E+04	2,32E+06	1,39E+06	8,90E+08	2,85E+08	4,16E+08	1,41E+09
Marine ecotoxicity	kg 1,4-DCB	1,82E+06	6,82E+05	3,37E+01	1,93E+01	1,23E+03	6,95E+02	5,06E+05	1,42E+05	2,20E+05	6,80E+05
Land use	m^2a crop eq	5,01E+10	0,00E+00	4,64E+05	0,00E+00	8,24E+07	0,00E+00	2,10E+09	0,00E+00	2,38E+08	0,00E+00
Water consumption	m^3	6,61E+09	5,47E+07	3,39E+05	1,71E+03	1,09E+07	7,75E+04	4,03E+08	1,64E+07	5,23E+07	5,43E+07
Ozone formation, Human health	kg NO_x eq	2,35E+07	4,96E+06	2,96E+02	1,45E+02	4,97E+04	2,07E+05	1,53E+06	3,55E+06	1,97E+06	2,20E+07
Human carcinogenic toxicity	kg 1,4-DCB	2,41E+06	3,91E+05	5,09E+01	1,30E+01	1,73E+03	6,27E+02	8,43E+05	1,09E+05	3,50E+05	3,85E+05
Human non-carcinogenic toxicity	kg 1,4-DCB	3,43E+08	3,55E+07	5,92E+03	1,12E+03	2,06E+05	5,07E+04	1,09E+08	9,73E+06	4,17E+07	4,22E+07
Fossil resource scarcity	kg oil eq	1,27E+09	0,00E+00	3,34E+04	0,00E+00	1,41E+06	0,00E+00	1,88E+08	0,00E+00	5,21E+08	0,00E+00

Table 15 – Impact results for Kenya's exports (absolute contribution)

		Textiles		Wearing apparel, fur		Leather, leather products, and footwear		Chemicals & chemical products /pharmaceuticals		Non-metallic mineral products	
Impact category	Unit	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate
Global warming	kg CO_2 eq	6,35E+10	3,69E+09	1,26E+10	1,30E+09	6,97E+07	3,17E+06	1,78E+10	3,51E+10	1,56E+09	3,60E+07
Terrestrial acidification	kg SO_2 eq	8,64E+08	1,31E+07	9,67E+07	4,62E+06	4,54E+05	1,08E+04	1,20E+08	3,84E+08	7,84E+07	6,60E+04
Freshwater eutrophication	kg P eq	2,64E+07	0,00E+00	5,46E+06	0,00E+00	1,21E+04	0,00E+00	1,64E+06	0,00E+00	5,93E+04	0,00E+00
Marine eutrophication	kg N eq	1,31E+08	0,00E+00	1,91E+07	0,00E+00	4,01E+04	0,00E+00	5,65E+06	0,00E+00	1,37E+05	0,00E+00
Terrestrial ecotoxicity	kg 1,4-DCB	1,51E+10	4,12E+09	4,60E+09	1,49E+09	5,56E+07	3,93E+06	1,83E+10	4,13E+10	5,50E+09	5,55E+07
Marine ecotoxicity	kg 1,4-DCB	7,71E+06	1,90E+06	2,29E+06	6,84E+05	2,85E+04	1,80E+03	9,59E+06	1,88E+07	3,16E+06	2,47E+04
Land use	m^2a crop eq	7,48E+11	0,00E+00	1,10E+11	0,00E+00	2,43E+08	0,00E+00	9,88E+10	0,00E+00	1,49E+09	0,00E+00
Water consumption	m^3	3,00E+10	5,07E+07	4,53E+09	1,69E+07	1,01E+07	4,11E+04	1,22E+09	4,55E+08	4,70E+07	4,60E+05
Ozone formation, Human health	kg NO_x eq	2,07E+08	1,27E+08	3,37E+07	4,83E+06	2,05E+05	1,25E+04	-4,47E+07	3,28E+08	4,24E+06	1,19E+05
Human carcinogenic toxicity	kg 1,4-DCB	1,25E+07	1,49E+06	3,76E+06	5,22E+05	3,93E+04	1,19E+03	7,37E+07	1,09E+07	4,01E+06	5,83E+03
Human non-carcinogenic toxicity	kg 1,4-DCB	8,56E+08	4,17E+07	2,84E+08	1,48E+07	4,51E+06	3,72E+04	1,12E+09	4,33E+08	8,34E+08	3,91E+05
Fossil resource scarcity	kg oil eq	5,76E+09	0,00E+00	1,83E+09	0,00E+00	1,37E+07	0,00E+00	2,28E+10	0,00E+00	2,95E+08	0,00E+00

Table 16 – Impact results for United Republic of Tanzania's exports (absolute contribution)

		Textiles		Wearing apparel, fur		Leather, leather products, and footwear		Chemicals & chemical products /pharmaceuticals		Non-metallic mineral products	
Impact category	Unit	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate	Supply chain	Gate-to-gate
Global warming	kg CO_2 eq	2,66E+08	1,14E+07	4,79E+07	4,95E+06	2,87E+07	1,30E+06	2,34E+07	3,30E+07	9,87E+06	2,27E+05
Terrestrial acidification	kg SO_2 eq	4,90E+06	4,23E+04	3,67E+05	1,76E+04	1,87E+05	4,46E+03	1,32E+05	4,78E+05	4,95E+05	4,17E+02
Freshwater eutrophication	kg P eq	1,62E+05	0,00E+00	2,07E+04	0,00E+00	4,99E+03	0,00E+00	1,51E+03	0,00E+00	3,75E+02	0,00E+00
Marine eutrophication	kg N eq	4,80E+05	0,00E+00	7,27E+04	0,00E+00	1,65E+04	0,00E+00	4,97E+03	0,00E+00	8,66E+02	0,00E+00
Terrestrial ecotoxicity	kg 1,4-DCB	6,71E+07	1,31E+07	1,75E+07	5,64E+06	2,29E+07	1,62E+06	1,78E+07	3,91E+07	3,48E+07	3,51E+05
Marine ecotoxicity	kg 1,4-DCB	3,44E+04	6,02E+03	8,71E+03	2,60E+03	1,17E+04	7,40E+02	9,49E+03	1,78E+04	2,00E+04	1,56E+02
Land use	m^2a crop eq	3,76E+09	0,00E+00	4,17E+08	0,00E+00	1,00E+08	0,00E+00	9,44E+07	0,00E+00	9,43E+06	0,00E+00
Water consumption	m^3	8,07E+07	1,52E+05	1,72E+07	6,43E+04	4,17E+06	1,69E+04	1,47E+06	4,30E+05	2,97E+05	2,91E+03
Ozone formation, Human health	kg NO_x eq	1,27E+06	1,15E+06	1,28E+05	1,84E+04	8,44E+04	5,17E+03	-1,50E+04	2,82E+05	2,68E+04	7,49E+02
Human carcinogenic toxicity	kg 1,4-DCB	4,32E+04	4,79E+03	1,43E+04	1,98E+03	1,62E+04	4,92E+02	6,04E+04	9,51E+03	2,53E+04	3,69E+01
Human non-carcinogenic toxicity	kg 1,4-DCB	3,66E+06	1,33E+05	1,08E+06	5,63E+04	1,86E+06	1,53E+04	1,17E+06	4,06E+05	5,27E+06	2,47E+03
Fossil resource scarcity	kg oil eq	2,11E+07	0,00E+00	6,93E+06	0,00E+00	5,64E+06	0,00E+00	2,20E+07	0,00E+00	1,87E+06	0,00E+00

D. Process-based LCA Results

Table 17 – Impact results for crude palm oil exported in Kenya (absolute contribution)

Impact category	Unit	Total	Direct emissions	Palm fruit bunch prod.	Chemical inputs	Water consumption	Waste treatment	Wastewater treatment
Global warming	kg CO2 eq	1,44E+08	1019984	1,41E+08	243497	1075615	24510,74	85136,5
Terrestrial acidification	kg SO2 eq	575027,6	54786,24	513209,9	2465,652	3658,521	54,78134	852,5911
Freshwater eutrophication	kg P eq	9904,136	0	9224,208	9,512108	69,95622	298,4945	301,9649
Marine eutrophication	kg N eq	198774,7	0	196820	2,740991	7,599374	2,145676	1942,166
Terrestrial ecotoxicity	kg 1,4-DCB	1,88E+08	1,03E+08	83706290	794597	775640,5	66868,9	49921,81
Marine ecotoxicity	kg 1,4-DCB	349721,2	68520,09	271931,1	1835,756	1344,953	1626,672	4462,648
Land use	m2a crop eq	8,89E+08	0	8,89E+08	47175,66	109183,3	12766,08	6100,828
Water consumption	m3	4802880	-654977	4497349	14716,45	1244624	55,14018	-298886
Ozone formation, Human health	kg NOx eq	252783,7	168200,4	80889,43	1154,954	2088,487	53,29556	397,1861
Human carcinogenic toxicity	kg 1,4-DCB	225479,2	25024,74	151253,4	20579,5	10804,71	1591,8	16225,13
Human non-carcinogenic toxicity	kg 1,4-DCB	-2,7E+07	5224216	-5,3E+07	182486,8	194677,2	19324102	500239,2
Fossil resource scarcity	kg oil eq	4523111	0	3939133	284755,2	280730,7	2342,849	16149,84

Table 18 – Relevant stages and processes for the set of impact categories, crude palm oil exported in Kenya

Impact category	Relevant stages	Relevant processes
Global warming	Palm fruit bunch production	Direct emissions Land use
Terrestrial acidification	Palm fruit bunch production	Direct emissions
Freshwater eutrophication	Palm fruit bunch production	Direct emissions
Marine eutrophication	Palm fruit bunch production	Direct emissions
Terrestrial ecotoxicity	Palm fruit bunch production	Brake wear (lorry) (from transporting of palm fruit bunches) Zinc concentrate production (for producing ammonium sulfate) Direct emissions Ammonium sulfate production Treatment of copper cake (from ammonium sulfate production) Copper production (for zinc concentrate < ammonium sulfate)
	Direct emissions	Direct emissions
Marine ecotoxicity	Palm fruit bunch production	Direct emissions Brake wear (lorry) (for transporting palm fruit bunches) Zinc concentrate (for producing ammonium sulfate)
	Direct emissions	Direct emissions
Land use	Palm fruit bunch production	Compost production (for producing fertilizers)
Water consumption	Palm fruit bunch production	Irrigation Direct emissions (avoided impact due to water emissions)
	Water consumption	Tap water production (conventional) Tap water production (from underground)

Impact category	Relevant stages	Relevant processes
Ozone formation, Human health	Palm fruit bunch production	Direct emissions Land use Burning of diesel in building and agricultural machinery Fertilizing (by broadcaster) Transport (train) (for transporting packaging for fertilizers) Wood chipping Transport (container ship) (for transporting packaging for fertilizers) Heat production (from hard coal) (for ammonium sulfate) Transport (lorry) (for transporting packaging for fertilizers) Compost production (for nitrogen fertilizer) Transport (bulk carrier for dry goods) (for transporting potassium chloride) Transport (tractor and trailer) (for transporting fruit bunches from field to farm) Transport (tanker of petroleum) (for transporting petroleum < diesel < wood chipping) Nitric acid production (for calcium nitrate < nitrogen fertilizer) Open burning of waste wood (from waste wood) Burning of diesel in electric-generating set (for natural gas <diesel<wood chipping) Blasting (for ammonium sulfate) Ammonium sulfate production
	Direct emissions	Direct emissions
Human carcinogenic toxicity	Palm fruit bunch production	Zinc concentrate production (for ammonium sulfate) Land use Open burning of waste wood (from waste wood) Landfilling of hard coal ash (from hard coal<electricty<diesel<wood chipping)
	Direct emissions	Direct emissions
	Chemical inputs	Landfilling of hard coal ash (from hard coal<liquid ammonia) Naphta production (for hexane production) Tanker of petroleum (transport of hexane) Heat production from hard coal Landfilling of incineration residue

Impact category	Relevant stages	Relevant processes
		Treatment of lignite ash
		Transport (light commercial vehicle)
		Zinc concentrate
		Heat from heavy fuel oil
		Landfilling of red mud
		Diesel production
		Heat for reuse
		Hard coal import
		Incineration of hazardous waste
		Landfilling of slag
		Styrene production
		Landfilling of basic oxygen
Human non-carcinogenic toxicity	Palm fruit bunch production	Direct emissions (avoided impact)
	Waste treatment	Incineration of waste mineral oil Open burning of municipal solid waste Unsanitary landfilling of municipal solid waste
Fossil resource scarcity	Palm fruit bunch production	Petroleum production (for diesel production < wood chipping) Natural gas extraction and production (for heat production < ammonium sulphate production) Hard coal production (for heat production < ammonium sulphate production) Ethylene production (for polyethylene production < packaging for fertilizers) Lignite production (for electricity production < hard coal production < heat production < ammonium sulfate production)

Table 19 – Impact results for oil-cake from the extraction of sunflower exported in United Republic of Tanzania (absolute contribution)

Impact category	Unit	Total	Direct emissions	Sunflower production	Chemical inputs	Electricity consumption	Heat consumption	Transport	Water consumption	Wastewater treatment	Waste treatment
Global warming	kg CO2 eq	64.322.976,00	0	42771607	47324,25	4093094	11553552	5772399,384	50235,965	12883,57	21880,46
Terrestrial acidification	kg SO2 eq	512419,74	0	452424,2	313,9235	7595,117	19345,001	32416,20016	170,86668	151,91634	2,518761
Freshwater eutrophication	kg P eq	11138,628	0	11065,23	0,586473	2,14259	8,2981573	11,84746597	3,2671354	47,10399	0,152695
Marine eutrophication	kg N eq	278139,83	0	277820,3	0,064468	4,204887	5,5667541	1,613865664	0,35289308	297,16783	10,54011
Terrestrial ecotoxicity	kg 1,4-DCB	1,54E+08	6,022465	53491867	93220,6	3147221	4400630,6	92910851,55	36223,844	7372,3034	346,2152
Marine ecotoxicity	kg 1,4-DCB	1766912,2	0,030205	1686749	169,4713	5589,188	7467,039	66179,27007	62,797527	685,5234	9,403933
Land use	m2a crop eq	1,94E+08	0	1,94E+08	2150,107	21403,9	46729,385	40691,19277	5099,2823	891,21898	62,63718
Water consumption	m3	438577,22	0	320297,9	775,2251	97059,13	6571,5193	1544,004687	58079,88	-45752,258	1,804653
Ozone formation, Human health	kg NOx eq	224305	4455,395	171218,7	276,5899	5438,454	9688,8015	33068,49246	97,540007	58,612056	2,424545
Human carcinogenic toxicity	kg 1,4-DCB	148830,46	148,4107	133822	76,47872	2049,278	2674,2128	7062,581285	504,18173	2453,905	39,41334
Human non-carcinogenic toxicity	kg 1,4-DCB	1,01E+08	67599,09	99530637	6056,586	145559,3	211075,26	1333528,905	9076,4297	124131,71	295,1508
Fossil resource scarcity	kg oil eq	12630942	0	5646807	87788,01	1401634	3626537,9	1852518,27	13111,276	2448,8181	97,20725

Table 20 – Relevant stages and processes for the set of impact categories – Oil-cake from the extraction of sunflower exported in United Republic of Tanzania

Impact category	Relevant stages	Relevant processes
Global warming	Sunflower production	Land use Direct emissions Combine harvesting Ammonia (for ammonium nitrate production) Tillage (ploughing) Fertilizing by broadcaster Heat from natural gas (ammonia production < nitric acid production < ammonium nitrate)
	Heat consumption	Heat from light fuel oil
Terrestrial acidification	Sunflower production	Direct emissions Combine harvesting
Freshwater eutrophication	Sunflower production	Direct emissions
Marine eutrophication	Sunflower production	Direct emissions
Terrestrial ecotoxicity	Transport	Brake wear (lorry) (for transporting)
	Sunflower production	Combine harvesting Emissions from herbicides Tillage (ploughing) Fertilizing by broadcaster Application of plant protection Sowing Emissions from insecticides Diphenyl ether-compound production (for herbicide production) Steam production (for potassium chloride production)
Marine ecotoxicity	Sunflower production	Emissions from herbicides Emissions from insecticides Direct emissions

Impact category	Relevant stages	Relevant processes
Land use	Sunflower production	Direct changes
Water consumption	Sunflower production	Direct consumption Ammonia production (for nitric acid production < ammonium nitrate production) Sunflower seed production Urea production Combine harvesting Sulfuric acid production (for phosphoric acid production < diammonium phosphate production) Phosphoric acid production (for diammonium phosphate production)
	Electricity consumption	Electricity production from hydro reservoir
Ozone formation, Human health	Sunflower production	Combine harvesting Direct emissions Tillage (ploughing) Fertilizing by broadcaster Diphenyl ether-compound production (for herbicide production)
	Transport	Transport (transoceanic ship) Transport (lorry)
Human carcinogenic toxicity	Sunflower production	Combine harvesting Tillage (ploughing) Fertilizing by broadcaster Application of plant protection product Sowing Direct emissions Electricity production (for ammonia production < ammonium nitrate production) Emissions from fungicides Diphenyl ether-compound (for herbicide production) Biomass burning (for land clearing < land-use change) Emissions from herbicides Incineration of hazardous waste (from ammonium nitrate phosphate production)

Impact category	Relevant stages	Relevant processes
Human non-carcinogenic toxicity	Sunflower production	Direct emissions
Fossil resource scarcity	Sunflower production	Combine harvesting Natural gas production (ammonia production < nitric acid production < ammonium nitrate production) Tillage (ploughing) Fertilizing by broadcaster Heat from natural gas (ammonia production < nitric acid production < ammonium nitrate production) Steam production (for urea production) Application of plant protection product Sowing Diesel production (for tillage)
	Heat consumption	Petroleum production (for light fuel oil production < heat production)
	Transport	Petroleum production (for diesel production)

Table 21 – Impact results for jute yarn exported in Bangladesh (absolute contribution)

Impact category	Unit	Total	Jute fibre production	Electricity consumption	Chemical inputs	Wastewater treatment
Global warming	kg CO2 eq	5,23E+08	3,21E+08	1,25E+08	76939632	0
Terrestrial acidification	kg SO2 eq	6080039	5454730	303144,4	322165,4	0
Freshwater eutrophication	kg P eq	1370693	1367917	346,2125	2429,712	0
Marine eutrophication	kg N eq	1187129	1176159	39,88275	10930,06	0
Terrestrial ecotoxicity	kg 1,4-DCB	1,41E+09	1,16E+09	1,36E+08	1,15E+08	6,03E-15
Marine ecotoxicity	kg 1,4-DCB	11479674	11163178	114540,6	201826	129,2346
Land use	m2a crop eq	2,02E+10	2,01E+10	403981,3	75563503	0
Water consumption	m3	1,27E+08	1,26E+08	238205,6	570520,1	0
Ozone formation, Human health	kg NOx eq	2826208	2261860	201797,2	362550,9	0
Human carcinogenic toxicity	kg 1,4-DCB	4986500	4684686	80674,82	220970,5	168,8629
Human non-carcinogenic toxicity	kg 1,4-DCB	-1,95E+09	-1,96E+09	2053925	7956333	1838,661
Fossil resource scarcity	kg oil eq	1,64E+08	39204221	46856010	78309297	0

Table 22 – Relevant stages and processes for the set of impact categories, jute yarn exported in Bangladesh

Impact category	Relevant stages	Relevant processes
Global warming	Jute fibre production	Jute plant production Treatment of waste wood in open burning, dump, or unsanitary landfill (from jute plant production) Treatment of stalk in wood heater Liquid ammonia production (for urea production < jute plant production) Nitric acid production (for calcium nitrate production < nitrogen fertilizer production < jute plant production) Electricity production from hard coal and hard coal production (for irrigation < jute plant production) Water pump operation (for irrigation < jute plant production) Tillage (harrowing and ploughing) (for jute plant production) Transport (lorry) (for transporting jute fibre) Manure production (for jute plant production)
	Electricity consumption	Electricity production from natural gas and oil
Freshwater eutrophication	Jute fibre production	Jute plant production
Marine eutrophication	Jute fibre production	Jute plant production
Terrestrial ecotoxicity	Jutte fibre production	Treatment of stalk in wood heating (from jute fibre production) Break wear (lorry) (from the transport of jute fibre) Liquid ammonia production (for urea production < jute plant production)
Marine ecotoxicity	Jute fibre production	Jute plant production
Land use	Jute fibre production	Compost from biowaste (for jute plant production)

Impact category	Relevant stages	Relevant processes
Water consumption	Jute fibre production	Irrigation (for jute plant production) Jute plant production (avoided impact due to water emissions)
Ozone formation, Human health	Jute fibre production	Treatment of stalk in wood heater Jute plant production Open burning of waste wood (from jute plant production) Tillage (harrowing and ploughing)
Human carcinogenic toxicity	Jute fibre production	Open burning of waste wood (from jute plant production) Treatment of stalk in wood heater
Human non-carcinogenic toxicity	Jute fibre production	Jute plant production (avoided impact due to the withdrawal of heavy metals from the soil by plants or water)
Fossil resource scarcity	Jute fibre production	Hard coal production (for electricity production < irrigation < jute plant production) Petroleum production (for electricity production < irrigation < jute plant production) Natural gas extraction and production (for electricity production < irrigation < jute plant production)
	Electricity consumption	Natural gas production Petroleum production
	Chemical inputs	Petroleum production (for diesel production < lubricating oil production < jute yarn production) Natural gas extraction and production (natural gas liquids production < jute yarn production) Ethylene production (N-olefins production < lubricating oil production < jute yarn production) Hard coal production (for fatty acid production < jute yarn production) Paraffin production (for N-olefins < lubricating oil production < jute yarn production)

Table 23 – Impact results for articles of woven cotton exported in Pakistan (absolute contribution)

Impact category	Unit	Total	Woven cotton production	Bleaching	Batch dyeing	Finishing (textile)	Finishing (article)
Global warming	kg CO2 eq	5143555	4550848	51752,53	144643,7	219976,5	176334
Ozone formation, Human health	kg NOx eq	14360	13156,4	117,1252	357,963	509,3661	219,1514
Terrestrial acidification	kg SO2 eq	31332,94	28891,63	205,5328	801,353	1061,252	373,1795
Freshwater eutrophication	kg P eq	1647,131	1632,993	0,943047	3,355666	9,763032	0,07601
Marine eutrophication	kg N eq	20378,46	20374,75	0,746074	1,540903	1,365799	0,057359
Terrestrial ecotoxicity	kg 1,4-DCB	8324328	7321003	108717,8	342639,6	322323,5	229644,6
Marine ecotoxicity	kg 1,4-DCB	52321,87	48254,36	309,4438	2779,087	786,251	192,7248
Human carcinogenic toxicity	kg 1,4-DCB	14793,88	8444,35	819,291	4050,826	1369,825	109,5845
Human non-carcinogenic toxicity	kg 1,4-DCB	2957609	2812351	7960,263	56597,68	77321,62	3378,909
Land use	m2a crop eq	2,23E+08	2,23E+08	2155,435	11172,65	11647,96	914,1478
Fossil resource scarcity	kg oil eq	1277760	1126063	15479,08	44669,86	64083,44	27465,07
Water consumption	m3	2139253	2102796	3289,596	28993,26	3942,958	231,3304

Table 24 – Relevant stages and processes for the set of impact categories – Articles of woven cotton exported in Pakistan

Impact category	Relevant stages	Relevant processes
Global warming	Woven cotton production	Electricity production from oil Cottonseed production Electricity production from natural gas Heat from light fuel oil Tillage (ploughing /harrowing) (for cottonseed production) Liquid ammonia production (for urea production < cottonseed production) Sanitary and unsanitary landfilling of waste yarn and waste textile (from cotton yarn production) Land-use change (annual crop) (for cottonseed production) Electricity production from hard coal (for irrigation < cottonseed production) Water pump operation (for irrigation < cottonseed production) Hard coal production (for irrigation < cottonseed production) Nitric acid production (for calcium nitrate production < nitrogen fertilizer production < cottonseed production) Burning of sweet gas (for natural gas production < electricity production) Heat from natural gas and others Natural gas production (for petroleum production < heavy fuel oil production < electricity production) Burning of waste natural gas (from petroleum production < heavy fuel oil production < electricity production)
Terrestrial acidification	Woven cotton production	Cottonseed production Electricity production from oil Tillage (ploughing) (for cottonseed production) Burning of waste natural gas (from petroleum production for heavy fuel oil production for electricity production)

Impact category	Relevant stages	Relevant processes
		Hard coal production (for heat production < petroleum production < electricity production) Urea production (for cottonseed production) Transport (tanker for petroleum) (for transporting petroleum < heavy fuel oil production < electricity production) Heat from light fuel oil Transport (container ship) (for transporting cotton yarn) Electricity from hard coal (for irrigation < cottonseed production) Maize grain production (for maize starch production)
Freshwater eutrophication	Woven cotton production	Cottonseed production
Marine eutrophication	Woven cotton production	Cottonseed production
Terrestrial ecotoxicity	Woven cotton production	Electricity from oil Brake wear (lorry) (from transporting of cotton yarn) Cottonseed production Liquid ammonia (for producing urea used < cottonseed production) Tillage (ploughing) (for cottonseed production) Zinc monosulfate production (for cottonseed production)
Marine ecotoxicity	Woven cotton production	Cottonseed production
Land use	Woven cotton production	Compost production (for cottonseed production)

Impact category	Relevant stages	Relevant processes
Water consumption	Woven cotton production	Irrigation (for cottonseed production) Cottonseed production (avoided impact due to water emissions)
Ozone formation, Human health	Woven cotton production	Electricity production from oil Cottonseed production Tillage (ploughing /harrowing) (for cottonseed production) Compost production (for cottonseed production) Water pump operation (for irrigation < cottonseed production) Electricity production from natural gas Transport (tanker of petroleum) (for transporting petroleum < heavy fuel oil production < electricity production) Transport (container ship) (for transporting cotton yarn) Burning of diesel in electric generating set (for cotton yarn production) Electricity production from hard coal (for irrigation < cottonseed production) Blasting (for producing hard coal < electricity production < irrigation < cottonseeed production) Transport (bulk carrier for dry goods) (for transporting urea < cottonseed production) Heat from light fuel oil Burning of diesel in agricultural machinery (for cottonseed production) Burning of waste natural gas (from petroleum production < heavy fuel oil production < electricity production < in cotton yarn production) Processing of sweet gas (from petroleum production < heavy fuel oil production < electricity production < cotton yarn production) Combine harvesting (for cotton-seed production)

Impact category	Relevant stages	Relevant processes
		Nitric acid production (for calcium nitrate production < nitrogen fertilizer production < cottonseed production) Transport (train) packaging (for fertilizers cottonseed production) Transport (light commercial vehicle) (for transporting cotton yarn) Transport (lorry) (for transporting cotton yarn)
Human carcinogenic toxicity	Woven cotton production	Landfilling of hard coal ash (from electricity production < irrigation < cottonseed production) Electricity production from oil Treatment of lignite ash (from electricity production < cottonseed production) Hard coal import from ZA (for electricity production < irrigation < cottonseed production) Water pump operation (for irrigation < cottonseed production) Zinc concentrate production (for sulfuric acid production < phosphoric acid production < cottonseed production) Liquid ammonia production (for urea production < cottonseed production) Transport (light commercial vehicle) (for transporting cotton yarn) Landfilling of slag (from transporting cotton yarn) Light fuel oil production (for heat production) Landfilling of decarbonizing waste (from decarbonized water < electricity production < cotton yarn production) Compost production (for cottonseed production)
	Batch dyeing	Direct disposal of wastewater from textile production Landfilling of H3PO4 Purification residue (from phosphoric acid production)

Impact category	Relevant stages	Relevant processes
Human non-carcinogenic toxicity	Woven cotton production	Cottonseed production Tillage (ploughing) (for cottonseed production) Landfilling of hard coal ash (from electricity production < irrigation < cottonseed production)
Fossil resource scarcity	Woven cotton production	Natural gas extraction and production (for electricity production) Petroleum production (for heavy fuel oil production < electricity production) Hard coal production (for electricity production < irrigation < cottonseed production)

E. Interpretation in Life Cycle Impact Assessment

Considering EXIOBASE is not a usual database used in LCA, a check of the inventoried elementary flows that were not characterized by the selected indicators was done to support the interpretation of the results[3]. Some substances were then included in the characterization factors lists Table 25, as they are not included in the selected indicators precisely with the same name as they appear in the database, but they have proxies at these lists.

Table 25 – Substances included in the characterization factors lists used for the impact assessment in IO-LCA

Substance (compartment)	Proxy	ReCiPe category	Characterization factor	Unit
Benzo(b)fluoranthene (air)	Polycyclic aromatic hydrocarbons (PAH)	Terrestrial ecotoxicity	3,24E+01	kg 1,4-DCB
		Marine ecotoxicity	8,56E+00	kg 1,4-DCB
		Human carcinogenic toxicity	3,38E+01	kg 1,4-DCB
		Human non carcinogenic toxicity	6,01E+00	kg 1,4-DCB
Gas, natural, 46.8 MJ per kg (raw material)	Gas, natural, 46.8 MJ per kg (ReCiPe 2008)	Fossil resource scarcity	1,11E+00	Kg oil
Indeno (1,2,3-cd) pyrene (air)	Polycyclic aromatic hydrocarbons (PAH)	Terrestrial ecotoxicity	3,24E+01	kg 1,4-DCB
		Marine ecotoxicity	8,56E+00	kg 1,4-DCB
		Human carcinogenic toxicity	3,38E+01	kg 1,4-DCB
		Human non carcinogenic toxicity	6,01E+00	kg 1,4-DCB
Nitrogen, total (water)	Nitrogen	Marine eutrophication	2,97E-01	Kg N

[3] The comprehensive translation of the inventory into potential environmental impacts may not occur if some of the elementary flows are not covered by the chosen characterization models. Thus, a check of the inventoried elementary flows that are not characterized at the LCIA phase should always be done to support interpretation of results (Zampori et al., 2016).

A sensitivity analysis was not performed in terms of inventory. In IO-LCA, this is justified since elementary and intermediate inventory flows were not altered (they were used exactly as they come from EXIOBASE), and the modelling was restricted to the product flows (based on export data). In process-based LCA, this is also justified since datasets mainly originate from LCA databases, with adaptions of electricity, water, and waste treatments. A sensitivity analysis was not performed likewise in terms of impact assessment, considering the absence of other methods with global scope available in the software and the robust support given by the scientific references considered for selecting the indicators set.

Interpretation of results is made based on the procedure to identify the most relevant processes described in the "Guide for interpreting life cycle assessment result" published by the Joint Research Centre (JRC) of the European Commission (Zampori et al., 2016). In IO-LCA, four of the impact categories included in the twelve indicators are not contemplated in the analysis: Freshwater and Marine eutrophication, Land use, and Fossil resource scarcity. In EXIOBASE, the only emissions to water considered are the emissions of nitrogen and phosphorus to water and soil, which are accounted for as generated only by agricultural and waste treatment activities. As these activities are not included in the gate-to-gate system boundary, eutrophication categories have null results in this perspective. Flows that result in land use impact and fossil resource scarcity are accounted in the supply chain system boundary. Therefore, results are also null in these two categories in the gate-to-gate system boundary.