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FBD_BMODEL
FASHION BIG DATA BUSINESS MODEL

D7.3

LCA Report

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V5.1	30/11/2020	BEWG-WG	Final version with included widgets screenshots updates from DEL and minor revisions
V5.2	01/12/2020	BEWG-WG	Minor revisions from industrial partners for public submission

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Executive Summary

The purpose of this deliverable is to present the results of the environmental assessment carried out for personalised garments from four selected business case-studies of the European fashion industry, and under the framework of the EU funded project FBD_BModel. The scope is to develop a digital data service providing an environmental footprint assessment for garment products and their manufacturing processes, within the business model proposed by FBD_BModel project. In order to do this, a life cycle perspective has been followed, performing a life cycle assessment (LCA) according to its international ISO standards (14040 and 14044) where possible. The modelling approach followed was attributional, with a cut-off system model "*from cradle-to-gate*" boundaries.

Being garment manufacturing supply and production systems complex and distributed, involving many stakeholders, especially in garments production, data availability, during the material inventory, turned to be an issue for a proper completion of the study. In particular, for the case-studies of Bivolino and Kuvera a life cycle screening instead of a LCA was performed, due to the impossibility of acquiring primary data for the manufacturing of their garments from their suppliers. The screening performed, extensible to all the business case-study missing of in-depth and detailed data, ended with a 'qualitative' environmental footprint assessment, more than 'quantitative'. Data collection for the other business cases, Azadora and Beste, was challenging too because of the broad and diverse portfolio of garment and fabric production taking place at their factories, but difficulties were overcome.

All studies revealed that the critical life-cycle stage is the raw material sourcing and processing for most impact categories analysed, more than the manufacturing of the garments themselves (the core activities of these fashion business models) and much more than their transportation. The processes and materials contributing most to the environmental footprint of the analysed garments were: the wool fibre (Azadora product – sportive women's coat); softener finishing and natural gas combustion for heat (Beste product – technical men's coat); cotton fibre production (Bivolino product – made-to-measure men's shirt); polyamide and polyester fibres (specifically, for the functional t-shirt and leggings) for the Kuvera products.

As a conclusion from this study, some practical recommendations were provided as guidelines, in order to reduce the environmental footprint of the garments object of study. Recommendations that can be the basis to leverage on the environmental value of the garments piloted, especially within the target objectives of FBD_BModel project, that are those to provide fully digitalised local business models, that can capitalise on digital data, and on the

related data services and simulations, to increase the functional and environmental values of the products delivered to the market. Specifically (by order of importance or preference) these guidelines have been focused on:

- Reduce to the minimum the **materials** used in the garment (just enough to fulfil its functional specifications), with special attention to some materials with high embodied impacts like wool or cotton.
- Introduce as many **recycled materials** as possible and consider substituting those that show a high environmental impact.
- Introduce or consider **substituting some plant-origin fibres** like cotton by others that are much better from an environmental point of view (due to their higher productivity and yields), like **flax**, **hemp, jute** or **kenaf** fibres.
- Shift to **organically produced** and **certified** plant-based textiles.

1 Introduction

This study analyses four business cases, focusing on the evaluation of selected garments designed and developed by them, to assess their environmental footprint from a life-cycle point of view. In the following the four industrial business cases are briefly presented, while the analysed garments are described in the following chapter. At the end of this chapter, in section 1.2, the general scientific framework of the utilised methodology is presented, with reference to the main norms and standards that regulate it.

1.1 The Business Cases

1.1.1 Azadora business case

Company Azadora Srl is a modern, technological and versatile garment collections maker, working in close contact with the greater Italian and International fashion brands. Azadora facilities, located in Tuscany (Italy), cover 3,000 square meters, inside of which all manufacturing phases of garments production are performed, by high-skilled professionals with high attention and care of the details. Azadora is specialised in digital manufacturing, comprising novel technologies for garments assembling such as thermo welding, thermal taping, ultrasonic stitching. Azadora has an established production of fashion outerwear in small to medium order sizes, in a wide variety, with a range between 100/300 pieces (small production), up to 1000/3000 pieces (medium production), per model. Generally, its usual order is about 2000 pieces. Traditional artisanal and innovative production technologies characterize Azadora's flexible full-package solutions, which benefit from close contact with customers (B2B) and suppliers, as well as quality management certification. For its customer demand-driven production, Azadora is going to use collected data, e.g. automatically generated by the advanced production technologies mentioned above, and monitoring production and the supply chain, by extending the focus beyond warehousing. Additionally, Azadora is going to use Web services to sell directly to consumer for its make-to-order (MTO) production. Though cost is the main challenge to enhance material sustainability, to date sustainability has been less within Azadora control, however, through direct digital sales and associated interactions with customers, Azadora has the opportunity to overcome this lack, also through the benefit, from the suppling side, to basing its business on relationships and connections made locally/regionally.

1.1.2 Beste business case

Monobi is a fashion brand of Beste SpA textile company. The brand is orientated towards innovation, experimentation, aesthetic style and the quality standards of the fashion sector, with added-value technical features. The main aim of Beste garments production (through Monobi), is to combine functionality and design, offering to the customers men's fashion outerwear that perfectly match with their technical and stylish requirements. Beste is a globally dispersed and vertically integrated company with significant focus on innovative and sustainable fabric production, and fashionable, high-tech apparel products. The focus is on producing highly technical and complex garments, offered in a mix of make-to-order (MTO) and design-to-order (DTO) for its own main brand (Monobi) directly or co-branded with B2B customers. Typical production lots of Monobi are around 1000 pieces, with experimentation down to single piece fashion. Key features of its production system is extensive digital tracking and internal integration (especially for fabric) with greige produced in Asia and finishing conducted in Italy. However, integration not as well established between the fabric and apparel departments/divisions. The apparel brand (Monobi) focuses on complex fashionable/functional products which are shaped by internal and external fabrics and process technologies. The products are increasingly including recycled or sustainable materials, which can be enabled by internal development. Internal product/process development includes experimentation with personalization, particularly focused on colour customization of classic products for end-customers. This approach is based on competence related to fabric production and finishing (through vertical integration), and newly developed digital design technologies, hardware and software for exact colour matching in the dyeing process.

1.1.3 Bivolino business case

Bivolino (commercial name of Sieekrath) is a SME based in Belgium established in 1998. At the current state the company consists of two main business units. The fashion department, that is in charge of the B2C clothing business, and a department developing ICT solutions for the fashion industry. Bivolino has a state-of-art digitally integrated production system for classic and fashionable make-to-order (MTO) and/or made-to-measure (MTM) woven garments, specifically producing and delivering men's shirts to (e-shopping) market, with a system designed to facilitate both B2B services and B2C sales. Bivolino's flexible production system it is based on high skilled workers, along with automated data-based processes, strongly digitally oriented. Thus, the process of development and production specifically demands – for Bivolino – commitment and organization of production supplying companies to ensure extra capacity and ability to scale up and down quickly. Existing processes involve automatic reordering of fabrics, which requires development to improve and create seamless processes, also because Bivolino's front-end processes are focused on seamless services with minimal effort of the customers. Beyond internal development of these production and supply chain management systems, Bivolino's business approach demands efforts of fabric manufacturers to improve ordering systems. Additionally, co-branding with fabric brands are the efforts undertaken to strengthen relationships and appeal to customers. Bivolino's regional hybrid ownership is characterized by investments into CAD/CAM technologies, such as digital cutters, whereby Bivolino production partners invest in workers and facilities. Such digitalised processes are trusted more than interactions between people, and the only challenge is related to the worker-technology interface. Bivolino's distributed manufacturing set-up spread across different established specialized production locations, along with fabric sourcing from different locations, are impacted by import taxes and bilateral agreements. Currency and trade turbulence are leading to the need for new competence in-house focused on supply chain management.

1.1.4 Kuvera business case

Kuvera SpA belongs to a brands group composed by: Yamamay (stylish underwear), Carpisa (accessories and luggage) and Jaked (technical underwear); the products piloted by Kuvera come from Jaked portfolio. Kuvera runs 1278 shops in 43 countries (942 shops in Italy), employs 1700 people in 7 countries, having a turnover of 500 million € by selling more than 32 million pieces. The products piloted belong to a series focused on highly technical sportswear (e.g. for swimming), however currently only running laboratory production for special projects. These niche/highly technical products (particularly for swimming) are anyway going to be offered to a wider group of customers, with development of sourcing nearby (e.g. Italy). Company knowledge gained from co-creating the products with users for their specific requirements is of key importance. These small series products are characterized by a high level of personalization, in contrast to standard and fashion products offered, specifically, including customization for body dimensions (including for physiological issues) i.e. made-to-measure (MTM), fabrics, and use environment. The products are sold in stores (direct customer) and e-commerce. The company has invested in a 3D body scanner but needs to “problem solve” getting these measurements from customers through both channels. This is particularly challenging for e-commerce, and the key point of innovation is the digital interaction with end customers relate to digital visualization and customization experiences. For each product/material the company needs at least two suppliers specialized in 3D knitting or alternative knitting and garment construction methods. These suppliers must be local/regional partners with willingness to integrate digitally and offer full-package solutions.

1.2 Life Cycle Assessment: definition

The Life Cycle Assessment - LCA is defined as a method “to address the environmental aspects and potential environmental impacts (i.e. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)”. This definition is commonly accepted and set up by the standards ISO 14040: Environmental management — Life Cycle Assessment — Principles and Framework, 2006 and ISO 14044: Environmental management — Life cycle assessment — Requirements and guidelines, 2006.

There are four phases in an LCA study (Figure 1):

1. the goal and scope definition phase,
2. the life cycle inventory (LCI) analysis phase,

3. the life cycle impact assessment (LCIA) phase,
4. the interpretation phase.

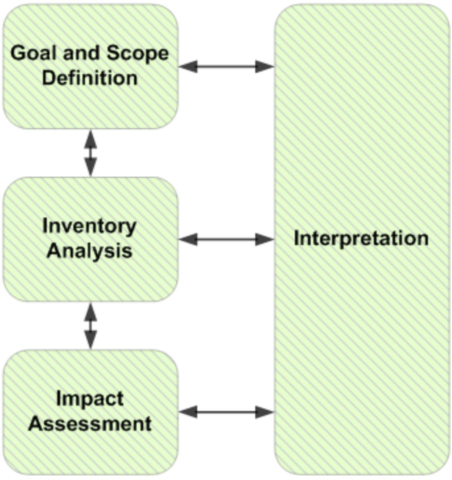


Figure 1. General phases of a life-cycle assessment, as described by the ISO 14040 and ISO 14044.

As set up by the rule, the scope, which includes also the system boundaries and the level of detail, depends on the subject and the intended use of the study. Therefore, the depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA. The life cycle inventory analysis phase (LCI) is an inventory of input/output data with regard to the system under evaluation and it involves the collection of the information necessary to meet the goals defined in the first phase. The life cycle impact assessment phase (LCIA) has the purpose to provide additional information to evaluate the environmental significance of the product, process or service under study. Life cycle interpretation is the final phase of the LCA procedure, in which the results of the LCI and the LCIA are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope defined for the study.

The LCA methodology, sometimes also better known by the more general "life cycle perspective", helps companies and public authorities in the environmental management of their products and services, as well as in the longer-term sustainable development of organizations and society all in all. This is done by identifying the opportunities to improve the environmental performance of products at various points in their life cycle, informing the decision-makers in industry, government or non-government organizations, allowing the selection of relevant indicators of environmental performance including measurement techniques and KPI monitoring, hot-spot identification of environmental issues along the value chain, eco-design support and last but not least, to facilitate the communication of the related environmental aspects (marketing, eco-labelling, certification schemes, etc.).

2 Environmental footprint of four case-studies

2.1 LCA model characteristics

2.1.1 Goal & Scope.

The goal of the present study is to perform a full environmental assessment of a selection of garments of the presented business case-studies. More specifically, the assessment is performed based on the LCA methodology (see chapter 2.2), in order to calculate the environmental footprint of these garments.

The LCA modelling approach followed is the **attributional** one (with a cut-off system model), and the analysed processes end at the factory gate, therefore following a *cradle-to-gate* approach. The garments analysed cover a broad spectrum of functionalities and characteristics, being the end-uses and customers different from each other.

The functional unit (FU), which represents the reference flow by which the life cycle impacts are calculated, is therefore different for each case-study. In general terms, the FU of each case-study can be defined by each single garment and the related protection, warmth and sheltering services that a clothing product generically provides to its user. Being different from each other however, each garment provides a differentiated set of services (quantitatively and qualitatively different). Together with the core functionality of each garment, which is designed with some fundamental properties aligned with its main function and purpose, there are some positioning properties of the garments related to the aesthetic design. The positioning properties are those features of a product that, providing the same service as another equivalent product, make it preferrable to its alternative. Positioning properties like the overall design (shape, colours, fabrics, touch-feeling, etc.), multi-functional configuration or an eco-friendly profile, are extremely important for the present case-studies and in general within the fashion industry.

The FU of each case-study is briefly described together with the short qualitative description of each garment in the results chapters (3.2 to 3.5). In quantitative terms, the FU of each case-study is given by one single garment, e.g. one coat. For the intrinsic differences underlying the purpose, design and functionalities of each garment and all the above-mentioned reasons, it is again emphasized that the presented environmental footprint results of the case-studies are not directly comparable among each other.

2.1.1.1 System boundaries

The life cycle stages included in the system boundaries of the LCA models go from the raw material extraction, fibre processing, fabric manufacturing to the final garment production phase, including the transportation of the fabrics to the factories and the packaging for the distribution. In other words, in the modelling we considered the environmental loads from primary materials extraction, processing and the manufacturing of the assessed garments. The life cycle stages that have been excluded are the Use phase and the *End of Life* (EoL) of the products. The additional activities that are normally included in these stages are the transportation for the distribution to the retailer; the impacts from the store and warehouse until it is purchased by the customer; a number of washing, ironing and drying cycles during the lifetime of the garments (the Use phase); and finally the disposal at the end of life, which may change from garment to garment (due to the different materials used in their production) and from country to country (due to the waste management infrastructure and cultural differences among nations).

The EoL activities are as a minimum comprised of sorting, transport for the collection and final disposal, as well as the final emissions from incineration and/or landfilling. Nevertheless, the final environmental impacts of the EoL phase can differ substantially according to the treatment and in general, to the fate of the garment. The garments can – and usually do – go through other intermediate stages before the final disposal, ranging from **recycling** (e.g. shredding and use as fill-up material) to **reuse** (e.g. given to charity or sold in second-hand shops and flea markets, which give them a second life) and eventually the final **incineration** and/or **landfilling**.

2.1.1.2 Assumptions and simplifications

In the fashion industry, fabric production, assembling and overall garment manufacturing is generally externalized. Given the complexity of the supply chain, which involves many stakeholders with different interests and placed all around the globe, gathering first-hand data for many processes was not possible. In order to overcome this common issue in LCA studies, LCA practitioners rely on different data sources, literature and big environmental databases like Ecoinvent. Despite its breadth (it covers more than 12.000 industrial processes), geographical and temporal representativity (global coverage, frequently updated), it has its limitations and so does this study. In order to overcome the lack of manufacturing process data of the fabrics utilized in the analysed garments, and based on own expertise and LCA results for other textiles, the fabrics were modelled considering only the main materials, e.g. a polyurethane membrane (used as a layer in one of the fabrics) was modelled as raw "polyurethane, flexible foam"; nylon fabrics, despite being usually integrated with elastane, were modelled as a pure polyamide 6.6 fibres, and so on. This assumption simplifies the unit process of the PU membrane manufacture to its principal component, thereby skipping the emissions and consumption flows that occur during the manufacturing process of a PU membrane-based fabric. Although a considerable simplification, which necessarily leads to an underestimation of the full environmental load of the analysed garments, the main materials used in textile products (and in general the inputs used in other industrial processes and industry sectors) typically represent the biggest share of the total environmental burden of a process. As a consequence, the presented results should be taken as a first-order approximation, meaningful in their order of magnitude, rather than a precise endpoint figure.

An important point to highlight in this study is the different data availability for the core processes in each case-study. Externalizing the garment manufacturing phase is a common practice in the textile industry, due to lower labour costs in other non-EU countries. This is desirable, or even necessary, so as to keep the final price of their end-products in a competitive range. However, for the case being this translates into a practical unsurmountable hurdle for the completion of the life cycle inventory and the manufacturing data gathering process. In two case-studies, the necessary primary data for the LCA does not belong to the analysed garment producing companies but to third organizations, which generally produce for other textile companies too. Without an advanced data monitoring system and an ad hoc data management plan at such textile production sites, acquiring first-hand data for the core processes remains unfeasible. This was the case for Bivolino and Kuvera, who could not provide primary data for the garment manufacturing core processes, because these are externalized to third companies over which they have no control. Therefore, for Bivolino's shirt and Kuvera's underwear, a *life cycle screening* has been performed instead of a LCA (as per ISO 14044:2006). On the other hand, Azadora and Beste have onsite production facilities in Italy with full control over the tailoring and assembly processes, thus the data used for the core processes in these cases is first-hand data as required by the norm.

The difference between a life cycle screening and a LCA is that the norm requires for the latter the use of primary data for the company's "core" processes, while for the former the analysis is mainly done with literature data, proxy estimates and secondary data. The presented results are, consequently, different in terms of reliability and accuracy, being the life cycle screening studies more approximative than the LCA studies.

2.1.2 Input data for the life cycle inventory

As anticipated in the introduction of this chapter, there are considerable differences in the data used to calculate the environmental footprint of the garments. In the business cases of Azadora and Beste, primary data was used for the modelling of the foreground processes (so-called *core* production processes), while secondary data was used for the background processes (e.g. Electricity production, transport, etc.) and proxy data for some others (e.g. *polyurethane foam* used to model a polyurethane membrane inside a fabric). For the life cycle screening studies of Bivolino and Kuvera, only the composition of each garment was known (materials and quantity), as well as the location of the factory and the warehouse (to calculate the transportation emissions).

The primary data of the core processes for Beste and Azadora included the energy consumption (electricity and natural gas bills; self-generation data from solar PV panels – Beste), the consumption of water and other chemicals (Beste); the generated waste. There are no significant onsite air emissions (the companies are not required to analyse or monitor them, due to the type of chemicals used). The waterborne emissions have been neglected, since both companies derive their wastewater to a centralized municipal water treatment plant.

The received primary data from Azadora was allocated per analysed garment, assuming a production of 20,000 coats, while the primary data used for the case of Beste was a four-year average (2016 to 2019), in order to level out the discontinuities and peaks derived from the changes in the production volumes and the changes in the demanded/sold product portfolio. Since Beste is primarily a fabric manufacturing company producing for other textile brands, it was decided that the primary data of Beste was better allocated per length of total fabric produced. The specific consumption per garment was then calculated with the gross amount of fabric used to manufacture one unit (thus including the discarded material).

The main database utilised to model all the background processes and proxy data is Ecoinvent v3.6, which was handled with the LCA specific software SimaPro (version 9.1).

2.1.3 Impact assessment method and impact categories

LCIA method: European Environmental Footprint (EF) method v3.0 from 2019, which follows the International reference Life Cycle Data system (ILCD) guidelines, and which builds on the previous methodology of 2011, EF v1.0. This compendium of environmental impact assessment methods gathers the last developments and updates of characterisation factors (CF) for several impact categories. This methodology also contains the best available science and consensus-based models like the AWARE and USEtox methods for water scarcity and toxicity impacts, respectively.

This methodology has been supported by the European Commission since the beginning of the Product Environmental Footprint (PEF) initiative back in 2013, when it released a communication to the European Parliament (European Commission, 2013): Building the single market for green products by facilitating better information on the environmental performance of products and organizations. Consolidated models for measuring and communicating the environmental performance (the EF) of products and organisations have been pursued and gathered in the ILCD and EF methodologies, to be used together with specific PEF category rules for comparable LCA studies and to achieve harmonized LCA results.

This methodology adopts the format of the ILCD nomenclature, and it has adapted the recommended models to meet the requirements of the PEF guidelines and the ILCD system.

Table 1. Summary table of the midpoint-level impact categories and the respective environmental indicators, models and short explanation.

Impact Category	Method	Indicator name and brief explanation
Climate change	IPCC 2013 (Myhre et al., 2013) + adaptations	*Global Warming Potential, 100 years (GWP$_{100}$)* This indicator represents the warming potential that greenhouse gas (GHG) emissions have on the Earth's surface temperature over time. Due to the scale (global), the irreversibility and permanent nature of this impact, it is considered an overarching environmental indicator. In fact, this impact is a further multiplier and precursor of additional local and regional impacts (ocean acidification, freshwater depletion from glacier loss, sea level rise, etc.), hence its importance.
Ozone depletion	Steady-state ODP, from the World Metereological Organisation (WMO), 2014 + integrations	*Ozone Depletion Potential (ODP)* It shows the degradation potential of the stratospheric ozone layer due to emissions of ozone-damaging substances, such as chlorine-containing gases and long-lasting bromine (e.g. CFC, HCFC,

Impact Category	Method	Indicator name and brief explanation
	(WMO, 2019)	halons). The ozone layer filters carcinogenic UV radiation from the sun.
Human and Eco Toxicity	USEtox consensus model (Rosenbaum et al., 2008)	*Comparative Toxic Unit for Human Health (CTUh) and for Ecosystems (CTUe)* Negative effects on human health (CTUh) caused by the intake of toxic substances by air inhalation, ingestion of food/water, skin penetration. They are subdivided into carcinogenic and non-carcinogenic. Ecotoxicity impacts consider the damage potential of toxic substance releases to water bodies which affect individual species and changes the structure and function of ecosystems.
Particulate matter	UNEP 2016 recommended (Fantke et al., 2016)	*Disease incidences due to kg of PM2.5 emitted* Adverse effects on health caused by inorganic substances inhaled by humans, from particulate matter (PM) emissions and its precursors (NOx , SOx , NH3).
Ionising radiation, human health	Human health effect models from Dreicer et al. 1995 (adapted by Frischknecht et al. 2000)	*Ionizing Radiation Potentials (IRP)* Negative effects on human health caused by radioactive emissions (ionizing radiation), in comparison to Uranium 235
Photochemical ozone formation	LOTOS-EUROS model, as in ReCiPe 2008 (van Zelm et al., 2008)	*Photochemical ozone creation potential (POCP)* Ground-level ozone formation in the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. High concentrations of tropospheric ozone at ground level are harmful to vegetation and

Impact Category	Method	Indicator name and brief explanation
		humans' respiratory system.
Acidification	Accumulated exceedance (M. et al., 2008; Seppälä & Posch, 2006)	*Accumulated Exceedance (AE)* Air emissions of NOx, NH_3 and SOx deposit and result in the release of hydrogen H+ ions when the substances are mineralized. Protons promote acidification of soils and water when released into surfaces where buffer capacity is low, resulting in forest deterioration and lake acidification.
Eutrophication (freshwater and marine)	EUTREND model as in ReCiPe2008 (Goedkoop et al., 2008)	*P and N equivalents* The nutrients (mainly nitrogen and phosphorus) of sewage and fertilized farmland accelerate vegetation growth (phytoplankton blooms). This in turn changes the turbidity of water, worsening the conditions of predatory species. The algal bloom and subsequent degradation of the new organic matter consumes oxygen (hypoxic conditions), eventually causing fish death and abrupt ecosystem changes. The impacts are divided into Freshwater and Marine Eutrophication.
Land use	LANCA model, CFs recalculated by JRC starting from LANCA® v2.2 as baseline model (Bos et al., 2016)	*Soil Quality Index* Land use and land use changes from agriculture, road construction, etc. affect the soil in many ways. This model takes into account different indicators that cover different soil properties like groundwater replenishment or water filtration. These indicators are grouped and re-scaled to obtain a dimensionless index which is spatially differentiated.

Impact Category	Method	Indicator name and brief explanation
Water Scarcity	Available WAter REmaining (AWARE) method, 2016 (Boulay et al., 2018)	*Scarcity-adjusted water use* The model characterizes the water depletion according to scarcity-adjusted mass of remaining water available for aquatic ecosystems
Resource use – energy carriers	CFs from CML v4.8, 2016 (van Oers et al., 2020)	*Abiotic resource depletion (ADP), fossil fuels* It represents the non-renewable resource depletion potential from the extraction, use and disposal (loss) of different fossil energy carriers. This indicator also represents in a way the *Cumulative Energy Demand*, since it is measured in MJ of fossil energy consumed and thus embodied in the product.
Resource use – minerals and metals	CFs from CML v4.8, 2016 (van Oers et al., 2020)	*Abiotic resource depletion (ADP), ultimate reserves* It represents the non-renewable resource depletion potential from the extraction, use and disposal (loss) of different minerals and metals.

2.2 Case-study Azadora: *sportive women's coat*

The analysed product line is focused on the concept of a multi-garment set-up, in which, using a garment modularity approach, the final product can be potentially made of parts attachable/detachable/foldable, through which a multi-configuration of the garment can be easily achieved.

Figure 2. The analysed sportive coat Dora of Azadora.

Dora (that's the name of this family of products), is a multifunctional women's coat with a loose-regular fit, conceived for being worn in Central Europe urban contexts for spring and autumn seasons (i.e. for a temperature range between 10°C and 25 °C), by women aged 25-50. The coat is manufactured with technical (high-performance) fabrics and seamless assembling technologies. It has two variations, Dora "Fashion" and Dora "Sporty", with different fabric compositions that perform differently to fit a more active and sportive activity (more breathable and lighter) and a normal urban lifestyle (warmer).

For the production of the coat, some innovative technologies have been used like ultrasound seams and thermo-welding: these technologies give more resistance, elasticity and softness to the coat, making it lighter and waterproof, while maintaining the traditional seams to give it a smoother touch and a neat design. Its main functional characteristics are:

- Thermal regulation.
- Increased breathability.
- Light weight.
- Windproof.
- Waterproof.
- Stain and oil resistance.

2.2.1 Environmental footprint results

The results for the performed LCA study are presented in Table 2 here below. The scores are not normalized nor weighed and are aligned with the European PEF methodology. The high performance and comfort of both Dora coats come at a price too, seen by the high Carbon and Water Footprint scores of both garments. The biggest share of this environmental burden comes from the wool, as it can be seen in the contribution analysis in Figure 3 and Figure 4 below. Needs to be clarified though that such big impacts do not arise during the manufacturing stage, or core processes of the Dora coats' life cycle, but come along with the provisioning of any animal product or a by-product derived from husbandry activities in the upstream processes, as it occurs with leather- or wool-based garments.

Table 2. LCA *cradle-to-gate* results for Dora "Fashion" coat, according to their size. EF v3.0 impact assessment method.

Impact category	Unit	S	M	L
Climate change	kg CO2 eq	63.80854	66.46922	69.24502
Ozone depletion	kg CFC11 eq	2.38E-06	2.47E-06	2.57E-06
Ionising radiation	kBq U-235 eq	1.865849	1.936881	2.010986
Photochemical ozone formation	kg NMVOC eq	0.121661	0.126741	0.132041
Particulate matter	disease inc.	8.27E-06	8.63E-06	9E-06
Human toxicity, non-cancer	CTUh	6.16E-07	6.42E-07	6.7E-07
Human toxicity, cancer	CTUh	3.32E-08	3.46E-08	3.61E-08
Acidification	mol H+ eq	1.161885	1.211895	1.264069
Eutrophication, freshwater	kg P eq	0.019115	0.019923	0.020766
Eutrophication, marine	kg N eq	0.346208	0.361167	0.376774
Eutrophication, terrestrial	mol N eq	4.905538	5.117612	5.338863
Ecotoxicity, freshwater	CTUe	1288.954	1343.077	1399.543
Land use	Pt	4856.012	5066.219	5285.521
Water use	m3 depriv.	161.4468	168.409	175.6724
Resource use, fossils	MJ	315.2417	327.7208	340.7399
Resource use, minerals and metals	kg Sb eq	0.000638	0.000666	0.000695

Table 3. LCA *cradle-to-gate* results for Dora "Sporty" coat, according to their size. EF v3.0 impact assessment method.

Impact category	Unit	S	M	L
Climate change	kg CO2 eq	84.63713	88.20158	91.92027

Ozone depletion	kg CFC11 eq	2.74E-06	2.85E-06	2.96E-06
Ionising radiation	kBq U-235 eq	1.88284	1.954568	2.029398
Photochemical ozone formation	kg NMVOC eq	0.142073	0.148037	0.15426
Particulate matter	disease inc.	1.18E-05	1.23E-05	1.28E-05
Human toxicity, non-cancer	CTUh	7.63E-07	7.95E-07	8.29E-07
Human toxicity, cancer	CTUh	3.32E-08	3.46E-08	3.6E-08
Acidification	mol H+ eq	1.665127	1.736977	1.811936
Eutrophication, freshwater	kg P eq	0.023366	0.024358	0.025392
Eutrophication, marine	kg N eq	0.390305	0.407165	0.424755
Eutrophication, terrestrial	mol N eq	7.139848	7.448894	7.771313
Ecotoxicity, freshwater	CTUe	1506.133	1569.637	1635.889
Land use	Pt	7193.694	7505.364	7830.521
Water use	m3 depriv.	123.9175	129.2758	134.8659
Resource use, fossils	MJ	319.4399	332.0978	345.3034
Resource use, minerals and metals	kg Sb eq	0.000738	0.00077	0.000803

In the mentioned figures of the contribution analysis shown here below, it can be observed that around 80% (for the coat Dora “Fashion”) and up to 85% (for the coat Dora “Sporty”) of the cradle-to-gate greenhouse gas (GHG) emissions contributing to the Climate Change derive from the woollen fabric alone. The transport of the materials, the waste flows and the packaging had a negligible impact, while the electricity consumption had a minor but significant contribution (see Figure 3 and Table 4 below).

The contribution analysis for the water footprint shows that the burden is more distributed among the three fabrics that form the multi-layer tissue, having the woollen one a more marginal contribution to it. This is due to the high irrigation requirement of the conventional cotton production, which is present in both fabrics. The modelled cotton production considers almost 15 m^3 of water per 1 kg of cottonseed harvested, as included in the inventory of the related process in the Ecoinvent database.

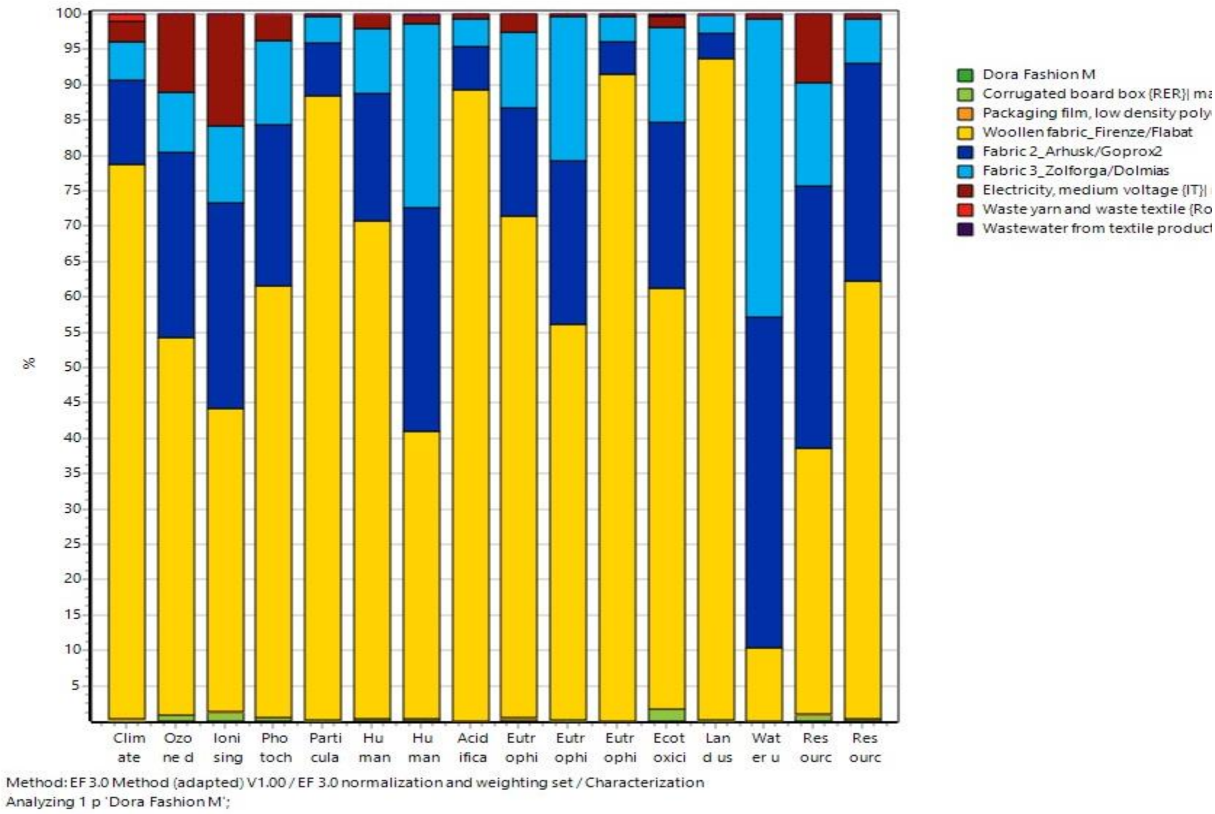


Figure 3. Contribution analysis of the LCA results for the Dora "Fashion" coat.

Table 4. Burden share of the four main contributing processes to the environmental footprint of a Dora "Fashion" coat.

Impact Category	Woollen fabric	Fabric 2	Fabric 3	Manufacturing electricity
Climate change	78%	12%	5%	3%
Ozone depletion	53%	26%	9%	11%
Ionising radiation	43%	29%	11%	16%
Photochemical ozone formation	61%	23%	12%	4%
Particulate matter	88%	7%	4%	0%
Human toxicity, non-cancer	70%	18%	9%	2%
Human toxicity, cancer	41%	32%	26%	1%
Acidification	89%	6%	4%	1%
Eutrophication, freshwater	71%	15%	11%	3%
Eutrophication, marine	56%	23%	20%	0%
Eutrophication, terrestrial	91%	5%	4%	0%
Ecotoxicity, freshwater	60%	23%	13%	1%

Land use	94%	4%	3%	0%
Water use	10%	47%	42%	1%
Resource use, fossils	38%	37%	14%	10%
Resource use, minerals and metals	62%	31%	6%	1%

The contribution analysis for the Dora "Sporty" coat is similar to the "Fashion" model one, but the environmental footprint resulted in even higher impacts than its mate due to a higher woollen fabric content.

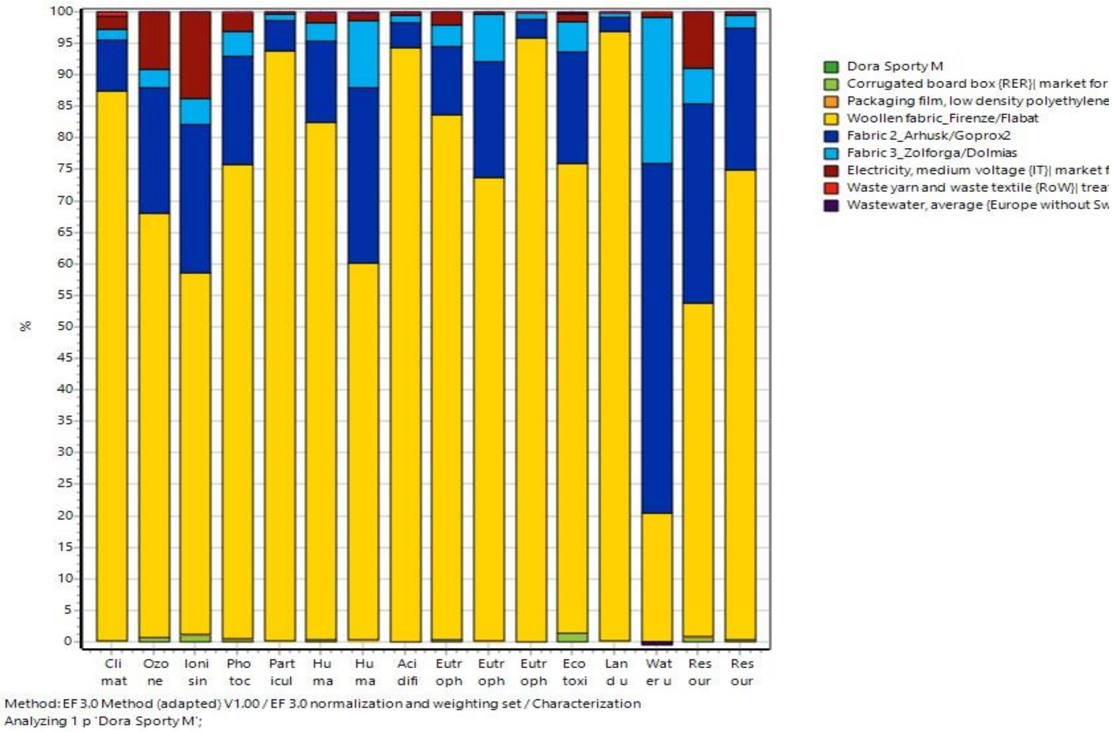


Figure 4. Contribution analysis of the LCA results for the Dora "Sporty" coat.

From a second contribution analysis performed on the fabric, it was found that the sourcing of raw wool itself (process "*sheep fleece in the grease*") is the main cause of these GHG emissions and other impacts like eutrophication (terrestrial, 91%) or acidification (89%). Digging deeper into the fabrics, which are the main cause of the environmental burden of the garment as it can be seen in Table 3, it was thus confirmed that the sourcing of the sheep fleece necessary for the wool production is the main contributor to the overall environmental footprint of both Dora coats. In the following figures (Figure 5, Figure 6 and Figure 7) the contribution analysis of the three fabrics is presented.

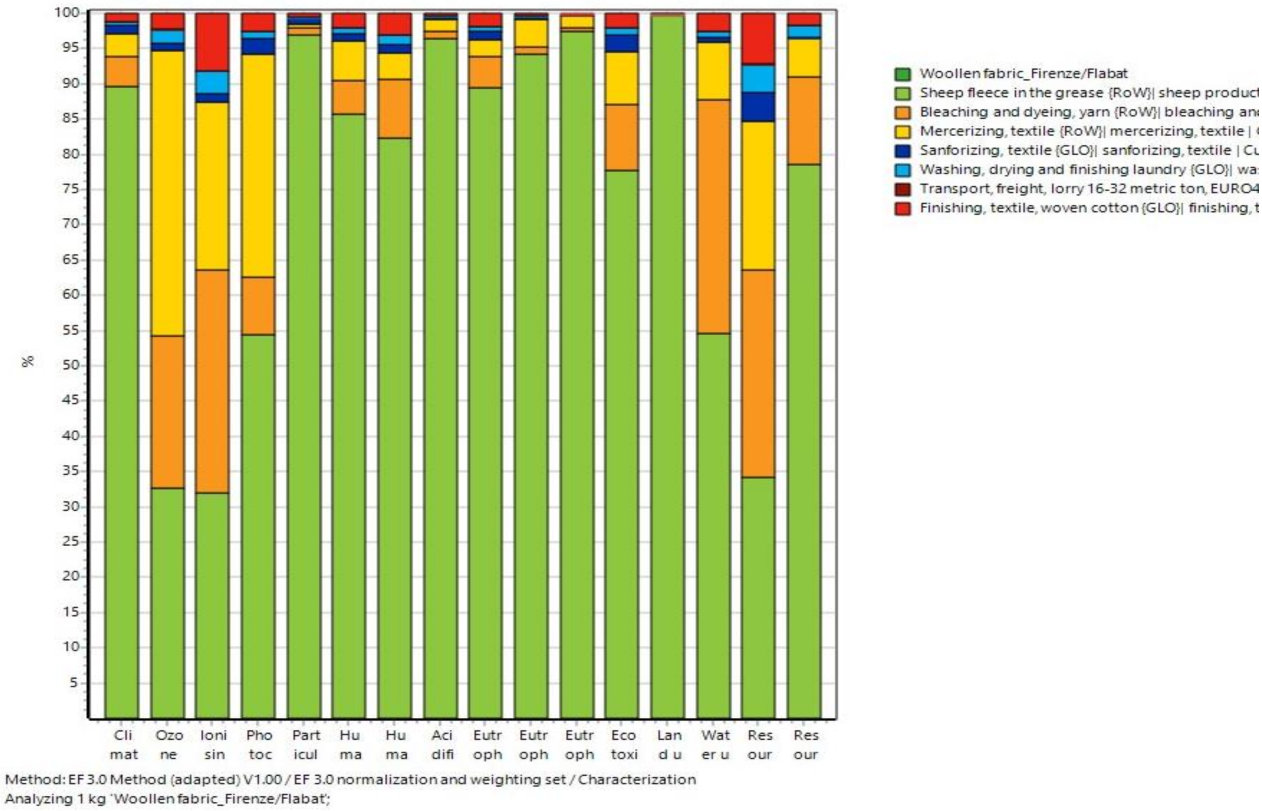


Figure 5. Contribution analysis of the woollen fabric, one of the three layers of the Dora coats.

While the environmental load is dominated by the production of sheep for the woollen fabric, the load is more balanced among other materials for the Fabric 2 ("Arhusk"), as it can be seen in Figure 6. The contributions to the Climate Change impact category for example, are equally distributed among the four main materials: viscose fibre (22%), cotton fibre (29%), polyamide thread (33%) and polyurethane membrane (15%). However, the production of cottonseed is the main contributor in most impact categories of this compound fabric.

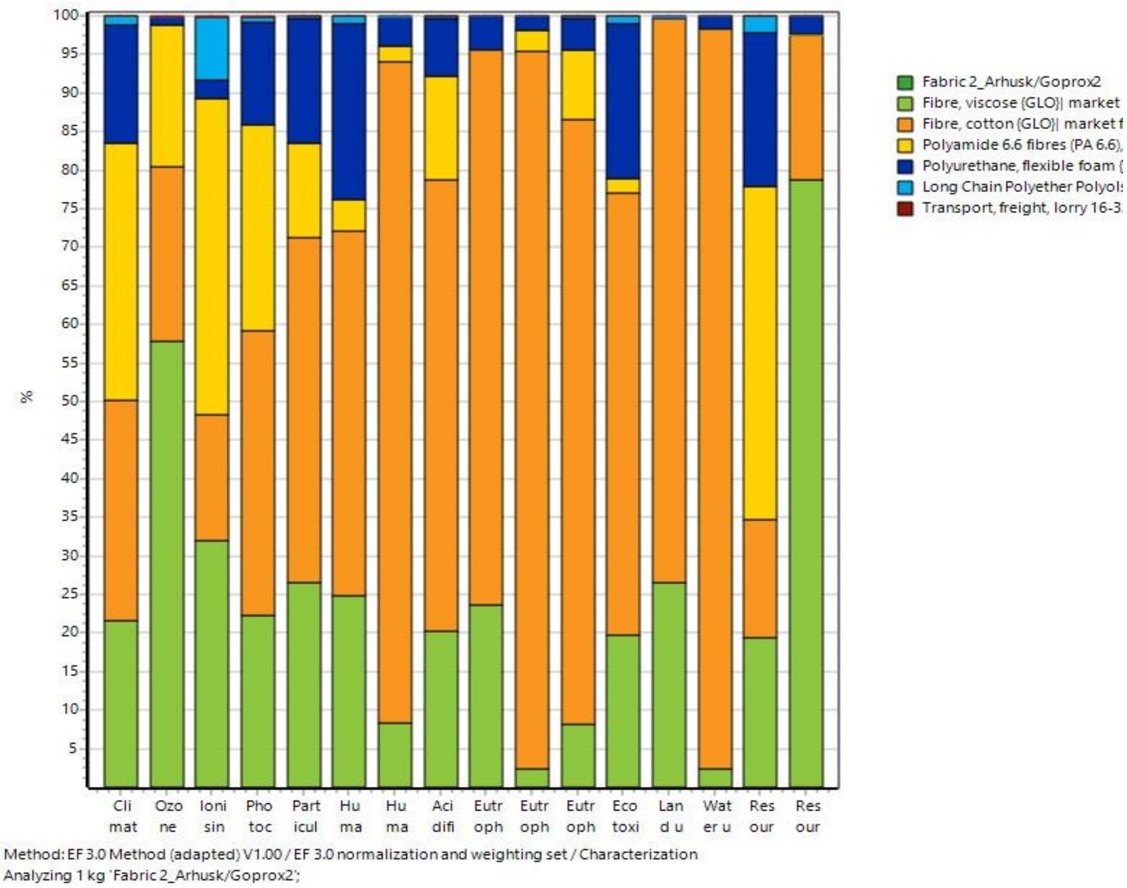


Figure 6. Contribution analysis of the "Arhusk" fabric (Fabric 2), one of the three layers of the Dora coats.

Regarding the last fabric of Dora coats, the single process of conventional cotton fibre is the principal contributor to the environmental load of the whole fabric, as it can be seen in Figure 7. All in all, the core processes considered did not have a significant impact in the environmental footprint of the analysed garments. Moreover, just two materials (wool and cotton), together with their upstream production processes, explain most of the environmental impacts of these coats.

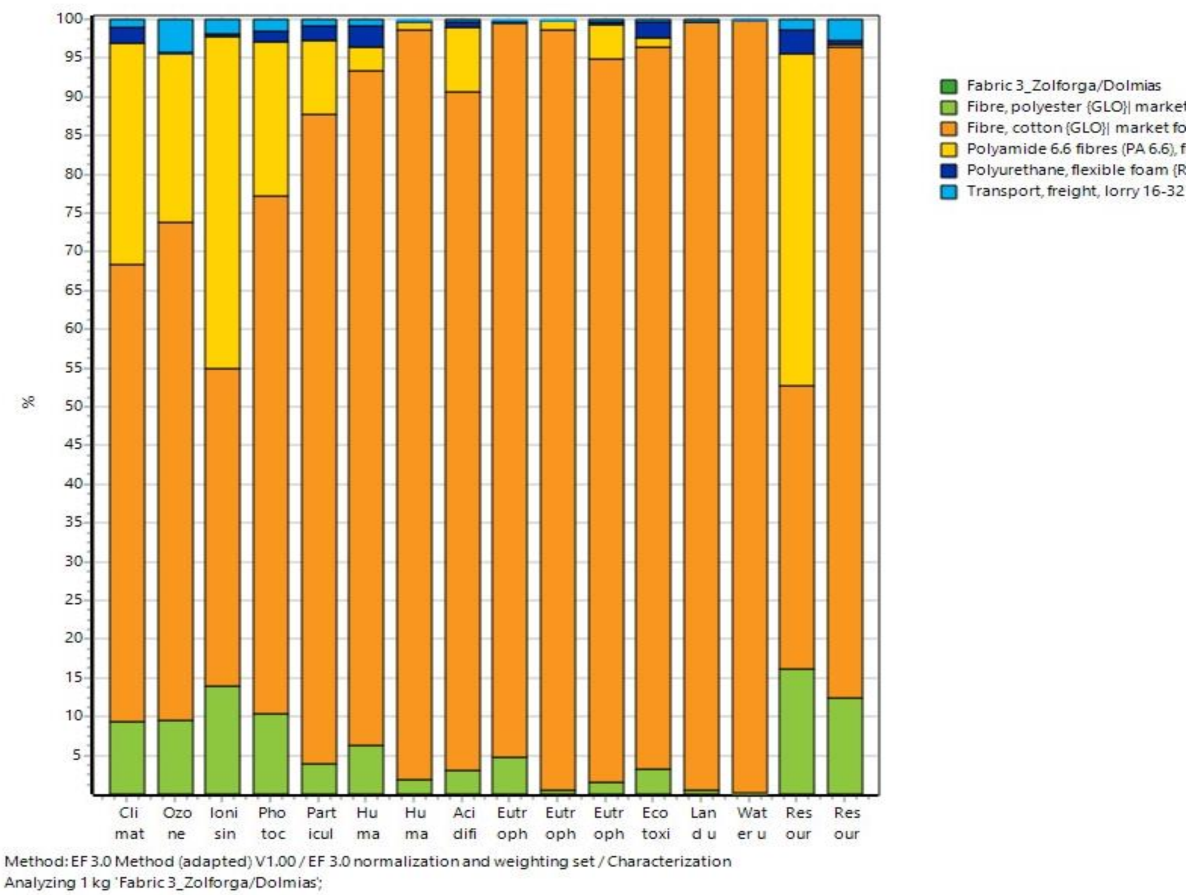


Figure 7. Contribution analysis of the "Zolforga" fabric (Fabric 3), one of the three layers of the Dora coats.

Given the dominance shown by the wool as main driver of most environmental impacts of both Dora coats, another fine-tuning iteration would be desirable to collect more information on the real sheep production processes, involving the main wool supplier(s) of Azadora. Acquiring first-hand data for this process, otherwise modelled with a generic dataset for sheep production, would be crucial to obtain more reliable environmental footprint results.

2.2.2 Normalization of selected impact category results

In order to render the environmental footprint results more tangible to the user, a normalization of a selection of impact category results has been performed. This step converts the results of Climate Change, Water Use and Resource Use (fossils) depicted in Table 2 and Table 3, into more "normal" units or better, they are brought into a more familiar scale and are the selected results that will be shown in the online widgets of the project. The normalized results for the selected impact categories are shown in Table 5.

The Climate Change results are renamed to *Carbon Footprint* and they converted into car-driven distance, taking the global warming equivalent greenhouse gas emissions of an average passenger (medium size, EURO5) petrol car from Europe. The conversion factor used is 318 gCO2eq per km driven.

The Water Use results are renamed to *Water Footprint* and converted into personal daily water consumption equivalents, taking the average European tap water consumption (per capita per day) of 120 litres[1].

For the Resource Use (fossils) results, it is renamed to *Fossil Energy Use* and the mean energy content of a litre of petrol is taken to convert the embodied fossil energy into petrol litre equivalents. The conversion factor used is 32.7 MJ/litre.

Table 5. Normalized *cradle-to-gate* results for selected impact categories for the Dora "Fashion" coat of Azadora.

Widget indicator	Unit	Dora Fashion		
		S	M	L
Carbon Footprint	car-driven distance (km)	200.7	209.0	217.8
Water Footprint	personal daily consumption (days)	1345.4	1403.4	1463.9
Fossil Energy Use	petrol volume equivalent (litres)	9.6	10.0	10.4

Table 6. Normalized *cradle-to-gate* results for selected impact categories for the Dora "Sporty" coat of Azadora.

Widget indicator	Unit	Dora Sporty		
		S	M	L
Carbon Footprint	car-driven distance (km)	266.2	277.4	289.1
Water Footprint	personal daily consumption (days)	1032.6	1077.3	1123.9
Fossil Energy Use	petrol volume equivalent (litres)	9.8	10.2	10.6

1 https://www.europarl.europa.eu/news/en/headlines/society/20181011STO15887/drinking-water-in-the-eu-better-quality-and-access

2.3 Case-study Beste: *technical men's coat*

The technical men's coat of Beste it is a trackable coat, manufactured with a multilayered technical fabric suitably developed by Beste, with internal pockets and a regular fit, partially 'adjustable' at the order stage. It is designed for males over 25 and it can be worn in any season thanks to the use of natural fabrics coupled with a (bio-derived) membrane, that make the garment comfortable and breathable. From the technical point of view, the coat is equipped with windproof and water repellent features. It is a highly performing, technical yet urban, fashionable lightweight garment. Its main technical features are (in order of relevance):

1. Breathability/thermal comfort.
2. Easy-care.
3. Made-to-measure.
4. Windproof and water repellent.

Figure 8. The analysed technical coat "Sergio" of Beste (Monobi brand).

2.3.1 *Environmental footprint results*

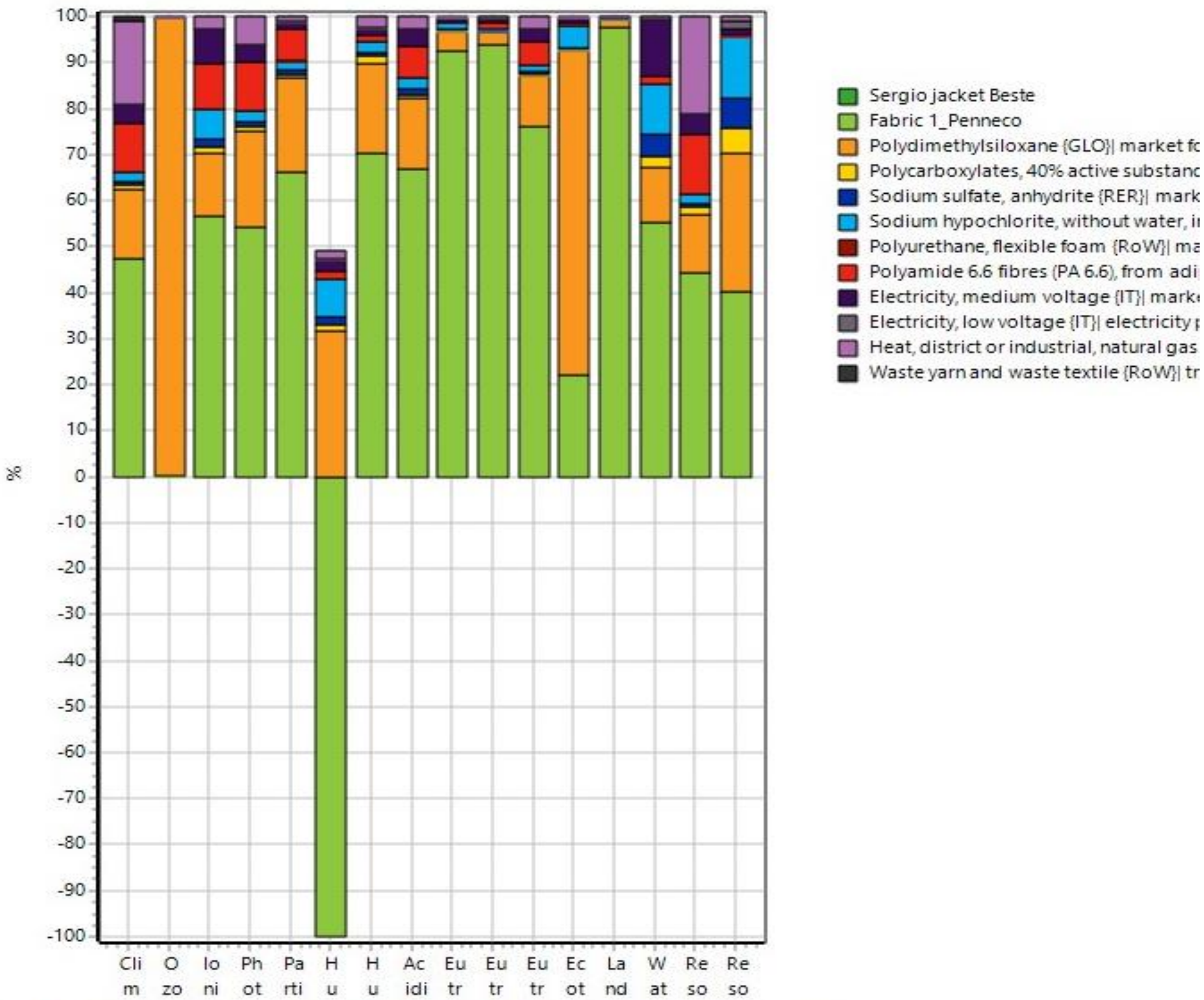
The LCA results that represent the environmental footprint of the are shown in Table 7 and Figure 8. Although the "Sergio" technical coat from Beste and the Dora coats from Azadora are not directly comparable, for they have different characteristics and functionality, they are the garments that resemble the most to each other, among the ones analysed in this study. In this sense, the Beste coat shows a lower environmental footprint for several reasons. First and foremost, the absence of a woollen fabric in its components. Second, the use of 100% certified organic cotton (Better Cotton Initiative, BCI), instead of conventional cotton. Third, the use of recycled materials for the manufacture of the fabrics: recycled polyamide (nylon from recovered fishing nets dumped in the oceans) and recycled polyurethane (discarded PU material from other industrial processes). Other initiatives carried out by Beste, like self-producing part of its own electricity consumption via solar PV panels, have also a positive impact on the final environmental profile of the coat, but it is more marginal.

Table 7. LCA *cradle-to-gate* results for the "Sergio" technical coat from Beste, according to their size. EF v3.0 impact assessment method.

Impact category	**Unit**	**S**	**M**	**L**
Climate change	kg CO2 eq	10.6512	10.75316	10.85511
Ozone depletion	kg CFC11 eq	0.000116	0.000116	0.000116
Ionising radiation	kBq U-235 eq	0.724533	0.732841	0.741149
Photochemical ozone formation	kg NMVOC eq	0.027558	0.027859	0.028161
Particulate matter	disease inc.	5.02E-07	5.08E-07	5.15E-07
Human toxicity, non-cancer	CTUh	-5.1E-08	-5.4E-08	-5.6E-08
Human toxicity, cancer	CTUh	6.35E-09	6.44E-09	6.53E-09
Acidification	mol H+ eq	0.061316	0.062147	0.062978
Eutrophication, freshwater	kg P eq	0.009974	0.010162	0.01035
Eutrophication, marine	kg N eq	0.061422	0.062596	0.063769
Eutrophication, terrestrial	mol N eq	0.17347	0.176149	0.178829
Ecotoxicity, freshwater	CTUe	440.9321	442.8994	444.8667
Land use	Pt	474.4211	483.8747	493.3284
Water use	m3 depriv.	2.087306	2.110642	2.133977
Resource use, fossils	MJ	146.7586	148.0727	149.3867
Resource use, minerals and metals	kg Sb eq	5.01E-05	5.05E-05	5.09E-05

It is worth mentioning the negative Human Toxicity impact (non-cancer effects), which derives from the use of organic cotton. This single material also explains the very low water footprint of the coat, which is modelled by Ecoinvent without any irrigation as per the certification of EPIDA. This contrasts with the high-water input modelled in the conventional cotton production (around 15 m^3 per kg of cotton seed). As for the negative toxicity impact (thus an environmental benefit), this is explained by the very low-input agricultural phase of the organic cotton production process, which is only fed with cattle manure and compost. The organic cotton production has a much lower yield than the conventional cotton production (1450 kg/ha instead of 2460 kg/ha), but the high inputs required for the extra yield output does not seem to compensate the investment from an environmental point of view.

The inventoried soil emissions modelled by Ecoinvent for this case reflect a net subtraction (negative emissions) of several heavy metals (Chromium, Cadmium, Lead, Mercury, Zinc, Nickel). These metals appear in a mineralized form which is highly available to the plants, which absorb them (some used by the plants as key micronutrients) and retain them in their tissues. In order to have a net subtraction of heavy metals from the soil, and therefore an environmental benefit (or negative impact), the absorbed metals must be carried away from the fields and so along in the cotton seeds – and eventually, into the fabrics.



Method: EF 3.0 Method (adapted) V1.00 / EF 3.0 normalization and weighting set / Characterization
Analyzing 1 p 'Sergio jacket Beste';

Figure 9. Contribution analysis of the environmental footprint for the “Sergio” technical coat.

As in the previous case, a deeper analysis was carried out to pinpoint the main contributors to the environmental footprint of the coat (Figure 9). In this case, the fabric results again in one of the outstanding processes contributing the most to the environmental impacts. A graphical representation of the contribution analysis for the Penneco fabric is presented in Figure 10. Other important processes to look into are the polydimethylsiloxane (a silicon-based active ingredient of the softener finishing treatment used in the fabric manufacturing process), the polyamide fibres and the heat production from natural gas (used in different phases of the fabric manufacturing process). The latter is the only significant impact in the environmental profile of the “Sergio” technical coat that derives directly from the company’s core processes in the manufacturing site in Tuscany. In order to improve further the environmental footprint of its garments, Beste could focus on reducing the heat consumption (efficiency initiatives), or by introducing a renewable source of heat (e.g. geothermal, biomethane).

Last but not least, another data collection and fine-tuning iteration would be desirable to acquire more representative data for the organic cotton production process. The current Ecoinvent process relies on rainfed water alone, which is the case for 75-80% of the total organic cotton production[2]. However, according to the same report, the average blue water consumption (from irrigation alone) of organic cotton lint is about 182 liters/kg versus 2120 liters/kg of the conventional cotton production (pg. 7 of referred report). According to this report, which relies on primary cotton production data, organic cotton does indeed save a lot of blue water (more than 90% respect to the conventional production) – yet these figures are not aligned with the water consumption inventoried in both Ecoinvent processes. Assuming that the Textile Exchange's report provides more reliable and representative data than that of Ecoinvent, the reported water footprint here would be overestimated for all the garments using conventional cotton (by perhaps as much as 100%) while being slightly underestimated for the "Sergio" technical coat from Beste.

[2] https://textileexchange.org/wp-content/uploads/2017/06/TE-Material-Snapshot_Organic-Cotton.pdf

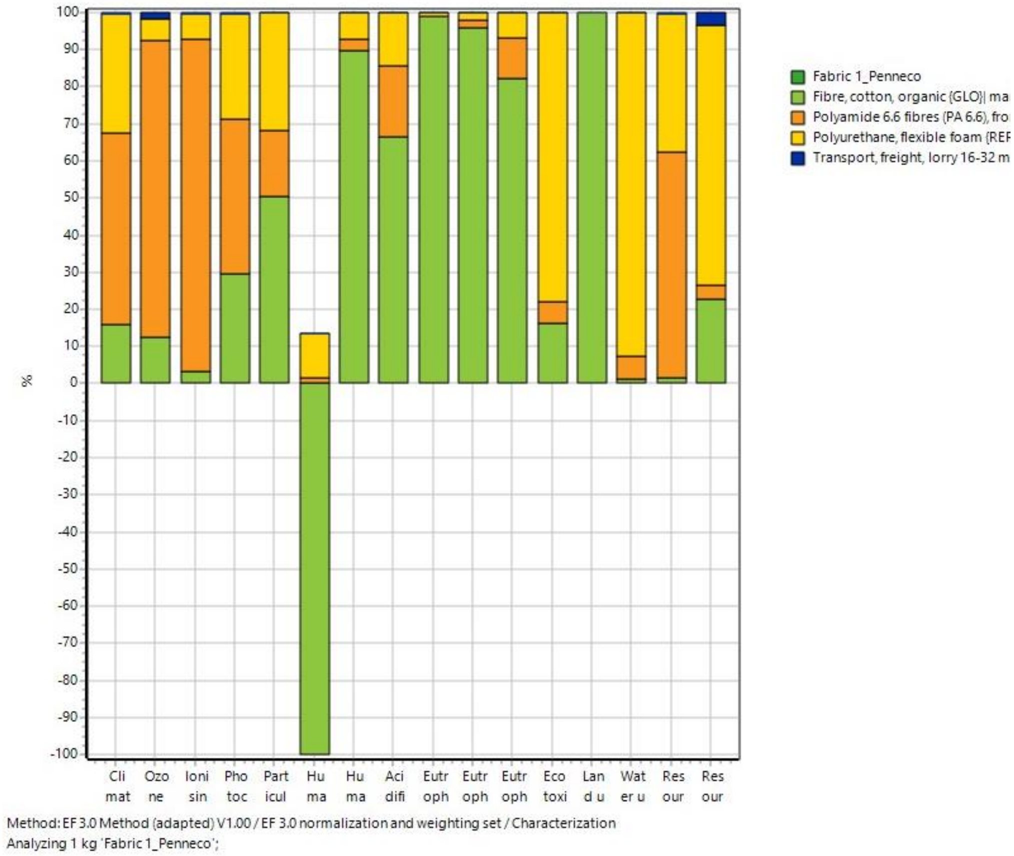


Figure 10. Contribution analysis of the main fabric of the "Sergio" technical coat from Beste.

2.3.2 Normalization of selected impact category results

In order to render the environmental footprint results more tangible to the user, a normalization of a selection of impact category results has been performed. This step converts the results of Climate Change, Water Use and Resource Use (fossils) depicted in Table 7 into more "normal" units or better, they are brought into a more familiar scale and are the selected results that will be shown in the online widgets of the project. The normalized results for the selected impact categories are shown in Table 8.

The selected impact category results are renamed to *Carbon Footprint*, *Water Footprint* and *Fossil Energy Footprint* and are converted into units that are more familiar to an average citizen. The conversion factors used are those explained in section 2.2.2.

Table 8. Normalized *cradle-to-gate* results for selected impact categories for the "Sergio" technical coat of Beste.

Widget indicator	Unit	Sergio		
		S	**M**	**L**
Carbon Footprint	car-driven distance (km)	33.5	33.8	34.1
Water Footprint	personal daily consumption (days)	17.4	17.6	17.8
Fossil Energy Use	petrol volume equivalent (litres)	4.5	4.5	4.6

2.4 Case-study Bivolino: *made-to-measure men's shirt*

The third business case-study covers a made-to-measure (MTM) men's shirt. Bivolino's shirts are produced on demand within 10 days (from the order by Web), covering all possible sizes and fits, including the choices of double cuff, short sleeves, with pocket, with monogram etc. Bivolino's shirts, use a biometric sizing technology (algorithm-based), that guarantees a perfect fit without measuring tape, but only providing by Web, four (biometric) consumer measures, specifically: height, collar size, weight, age and fit (regular, loose, slim and super slim). Bivolino guarantees that if the first delivered shirt does not fit, a 2nd shirt will be sent to the customer, free of charge.

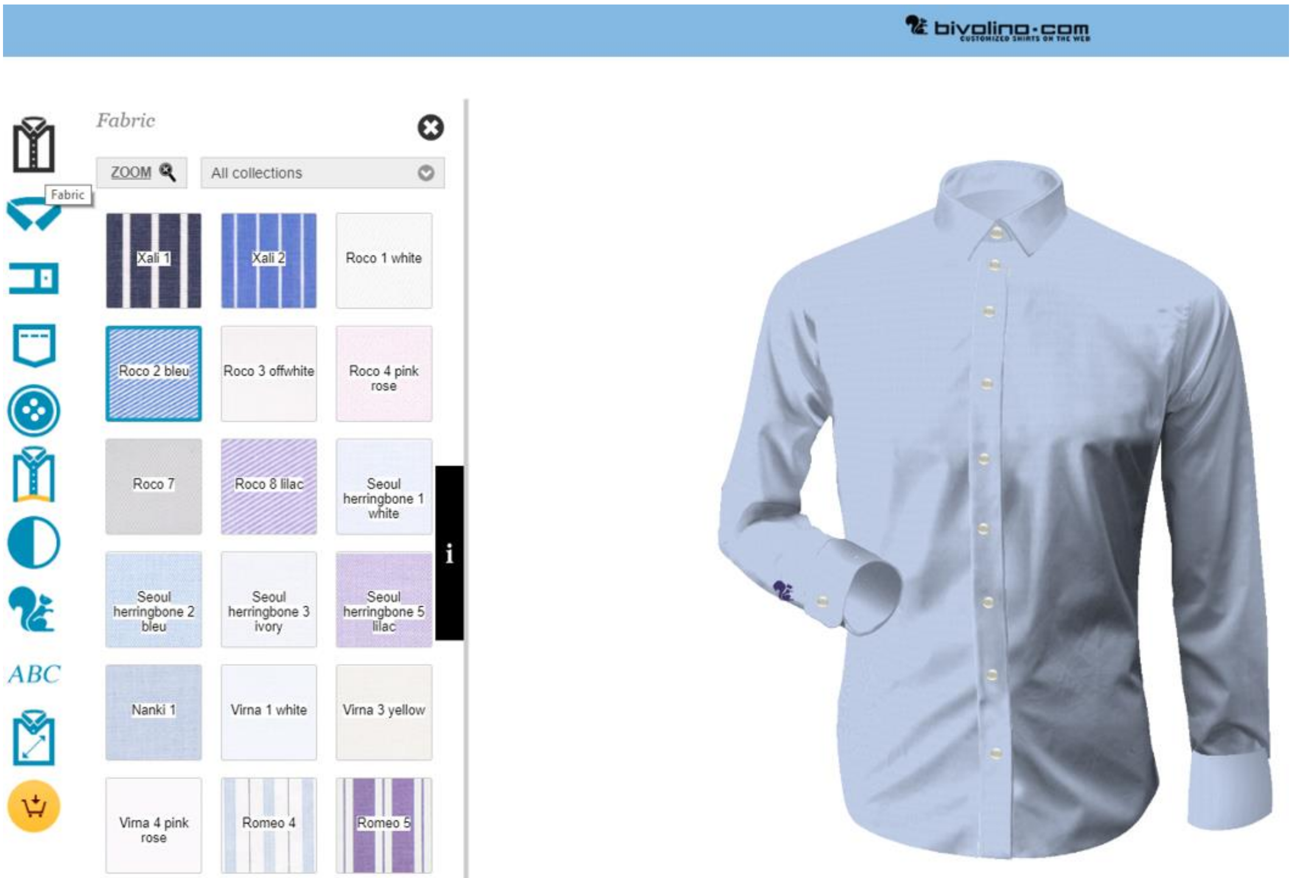


Figure 11. The analysed made-to-measure (MTM) shirt of Bivolino.

Apart from the different materials that can be chosen, from the Bivolino e-shop, Bivolino applies a wearing strategy based on guaranteeing the maximum comfort, due to the optimal fit, and the materials proposed, weather or season depending (winter/summer).

Transport, worst-case scenario for returns (30%), given that nearly zero returns are expected from the made-to-measure (MTM) men's shirt. This was done to cover the data gaps (thus some missing impacts) and to present a more conservative figure rather than an idealistic one.

2.4.1 Environmental footprint results

In Table 9 below the numeric results of the study are presented, which show the environmental footprint of a standard Bivolino cotton (75%) – polyester (25%) shirt. From the contribution analysis shown in Figure 12, it can be seen that the packaging and transportation phases of the materials and shirt represent only a minor – yet significant for this case-study – part of the whole life-cycle impacts. The transportation emissions were modelled as a worst-case scenario, with a high percentage of returns (purple bars in Figure 12), which in reality are unlikely to happen given its made-to-measure nature. The final distribution emissions play a significant role though (red bars in Figure 12), since the final delivery was modelled as a courier shipment from the main warehouse in Marseille to its final customer (assumed in Bruxelles).

Table 9. Life cycle screening results for the made-to-measure (MTM) shirt from Bivolino. EF v3.0 impact assessment method.

Impact category	**Unit**	**S**	**M**	**L**
Climate change	kg CO2 eq	3.45722	3.50796	3.5587
Ozone depletion	kg CFC11 eq	3.24E-07	3.27E-07	3.3E-07
Ionising radiation	kBq U-235 eq	0.272311	0.275999	0.279688
Photochemical ozone formation	kg NMVOC eq	0.014868	0.015057	0.015246
Particulate matter	disease inc.	2.89E-07	2.93E-07	2.97E-07
Human toxicity, non-cancer	CTUh	5.96E-08	6.05E-08	6.13E-08
Human toxicity, cancer	CTUh	5.84E-09	5.94E-09	6.04E-09
Acidification	mol H+ eq	0.035108	0.035705	0.036303
Eutrophication, freshwater	kg P eq	0.001772	0.001803	0.001835
Eutrophication, marine	kg N eq	0.040366	0.041153	0.041941
Eutrophication, terrestrial	mol N eq	0.128919	0.131166	0.133414
Ecotoxicity, freshwater	CTUe	145.469	147.7026	149.9361
Land use	Pt	90.15108	91.71618	93.28128
Water use	m3 depriv.	33.83924	34.52672	35.2142
Resource use, fossils	MJ	41.46574	42.00562	42.5455
Resource use, minerals and metals	kg Sb eq	8.46E-05	8.59E-05	8.72E-05

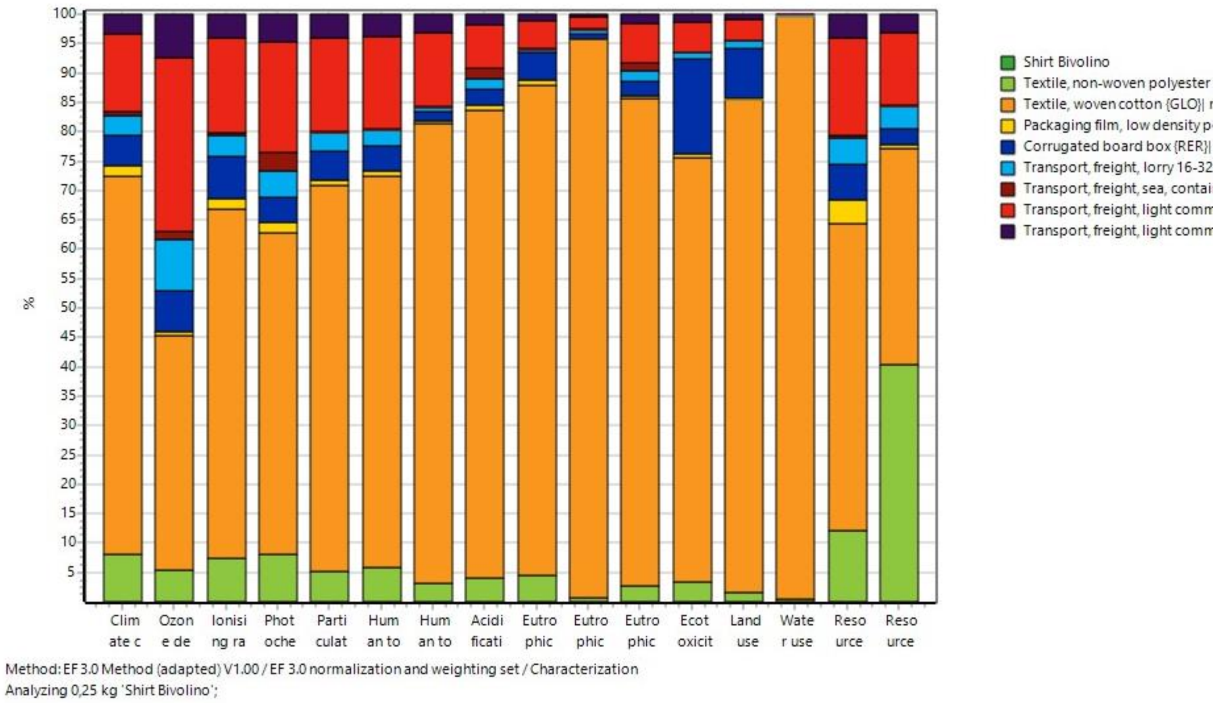


Figure 12. Contribution analysis for the made-to-measure (MTM) shirt of Bivolino.

Another option to reduce the environmental footprint of the Bivolino shirt was investigated, by changing the type of cotton (the main driver of all environmental impacts, as it can be seen in Figure 12), from conventional to organic production. The comparison results are shown in Table 10, where we can see similar patterns in some impact categories as in the case of Beste. Here too, for the case of an organic cotton shirt, there are some negative impacts on human toxicity (non-cancer effects), due to the mentioned removal of heavy metals from soil in a traditional, low-input farming system of India. These heavy metals are absorbed by the plant and are carried away in the cottonseed fibres. The water footprint is here as well remarkably lower for the organic cotton shirt, although it remains to be assessed more in detail the irrigation aspect in a traditional Indian farming system. As for the rest of impacts, the use of organic cotton has the potential to reduce significantly the whole environmental footprint of the shirt.

Table 10. Comparison of LCA *cradle-to-gate* results for a Bivolino standard shirt (size M) and the same shirt produced with organic cotton (hypothetical scenario). EF v3.0 impact assessment method.

Impact category	Unit	Shirt Bivolino (organic)	Shirt Bivolino
Climate change	kg CO2 eq	2.422573	3.50796
Ozone depletion	kg CFC11 eq	2.42E-07	3.27E-07
Ionising radiation	kBq U-235 eq	0.234548	0.275999
Photochemical ozone formation	kg NMVOC eq	0.010409	0.015057
Particulate matter	disease inc.	1.86E-07	2.93E-07
Human toxicity, non-cancer	CTUh	-2.5E-08	6.05E-08
Human toxicity, cancer	CTUh	2.83E-09	5.94E-09
Acidification	mol H+ eq	0.019599	0.035705
Eutrophication, freshwater	kg P eq	0.003744	0.001803
Eutrophication, marine	kg N eq	0.023055	0.041153
Eutrophication, terrestrial	mol N eq	0.065816	0.131166
Ecotoxicity, freshwater	CTUe	62.9872	147.7026
Land use	Pt	189.4608	91.71618
Water use	m3 depriv.	0.433823	34.52672
Resource use, fossils	MJ	32.18891	42.00562
Resource use, minerals and metals	kg Sb eq	6.09E-05	8.59E-05

2.4.2 Normalization of selected impact category results

In order to render the environmental footprint results more tangible to the user, a normalization of a selection of impact category results has been performed. This step converts the results of Climate Change, Water Use and Resource Use (fossils) depicted in Table 9 into more "normal" units or better, they are brought into a more familiar scale and are the selected results that will be shown in the online widgets of the project. The normalized results for the selected impact categories are shown in Table 11.

The selected impact category results are renamed to *Carbon Footprint*, *Water Footprint* and *Fossil Energy Footprint* and are converted into units that are more familiar to an average citizen. The conversion factors used are those explained in section 2.2.2.

Table 11. Normalized *cradle-to-gate* results for selected impact categories for the Bivolino made-to-measure (MTM) shirt.

Widget indicator	Unit	MTM shirt		
		S	M	L
Carbon Footprint	car-driven distance (km)	10.9	11.0	11.2
Water Footprint	personal daily consumption (days)	282.0	287.7	293.5
Fossil Energy Use	petrol volume equivalent (litres)	1.3	1.3	1.3

2.5 Case-study Kuvera: *functional t-shirt and leggings*

For the last business case-study, functional t-shirt and leggings were analysed (technical skin-contact garments). The material used for these garments, the patented NILIT® fabric, it was selected to be as a second layer of the skin, guaranteeing warmth and natural insulation, as well as having antibacterial properties with a strong anti-odour effect and continuous dry feeling. The material is highly tight-knit and breathable, with flat seams to prevent irritation and rubbing, for total comfort.

This style of the t-shirt, with long raglan sleeves and a high neck, has a practical zip closure under the chin and a maxi contrast print on the front. The wrist openings for thumbs ensure comfort and practicality. The leggings are wearable all year round thanks to their thermoregulatory properties and the absorbency of the fibres, which remain intact even after repeated washing. Made with NILIT® seamless fabric, both garments move moisture away from the body thanks to special micro-canals formed by the fabric, guaranteeing optimal breathability and keeping skin dry. The elastic component of the material, together with the ergonomic mapping/design of the garments, ensures a practical and comfortable fit.

Figure 13. The two technical underwear garments (functional t-shit and leggings) analysed from Kuvera.

2.5.1 Environmental footprint results

In Table 12 below the numeric results of the study are presented, which represent the environmental footprint of the two underwear items analysed. Having no animal-origin nor plant-origin tissues, impact categories related to agricultural production like Land use, Water use or Eutrophication show low scores. Since the manufacturing process is externalized and takes place outside Europe, the transportation impacts have a bigger share of the total impacts for these two garments, as it can be seen in Figure 14.

Table 12. LCA *cradle-to-gate* results for the functional t-shirt of Kuvera. EF v3.0 impact assessment method.

Impact category	Unit	S	M	L
Climate change	kg CO2 eq	2.319918	2.360161	2.400405
Ozone depletion	kg CFC11 eq	6.74E-08	6.74E-08	6.75E-08
Ionising radiation	kBq U-235 eq	0.031213	0.03127	0.031327
Photochemical ozone formation	kg NMVOC eq	0.006928	0.007025	0.007123
Particulate matter	disease inc.	9.35E-08	9.49E-08	9.63E-08
Human toxicity, non-cancer	CTUh	8.23E-09	8.3E-09	8.37E-09
Human toxicity, cancer	CTUh	4.45E-10	4.5E-10	4.54E-10
Acidification	mol H+ eq	0.010464	0.010631	0.010799
Eutrophication, freshwater	kg P eq	0.000159	0.000161	0.000163
Eutrophication, marine	kg N eq	0.003759	0.003823	0.003886
Eutrophication, terrestrial	mol N eq	0.022767	0.023085	0.023404
Ecotoxicity, freshwater	CTUe	7.693429	7.755977	7.818525
Land use	Pt	2.835254	2.840244	2.845234
Water use	m3 depriv.	2.26182	2.306737	2.351655
Resource use, fossils	MJ	34.96621	35.55876	36.15131
Resource use, minerals and metals	kg Sb eq	1.31E-05	1.32E-05	1.33E-05

Table 13. LCA *cradle-to-gate* results for the functional leggings of Kuvera. EF v3.0 impact assessment method.

Impact category	Unit	S	M	L
Climate change	kg CO2 eq	2.269113	2.305984	2.342854
Ozone depletion	kg CFC11 eq	2.02E-07	2.04E-07	2.07E-07
Ionising radiation	kBq U-235 eq	0.171753	0.174484	0.177215
Photochemical ozone formation	kg NMVOC eq	0.010876	0.011039	0.011201
Particulate matter	disease inc.	1.29E-07	1.31E-07	1.33E-07
Human toxicity, non-cancer	CTUh	2.93E-08	2.97E-08	3.02E-08
Human toxicity, cancer	CTUh	1.52E-09	1.54E-09	1.57E-09
Acidification	mol H+ eq	0.012652	0.012847	0.013042
Eutrophication, freshwater	kg P eq	0.000599	0.00061	0.000621
Eutrophication, marine	kg N eq	0.002798	0.002837	0.002876
Eutrophication, terrestrial	mol N eq	0.032932	0.033405	0.033877
Ecotoxicity, freshwater	CTUe	39.03734	39.7081	40.37887
Land use	Pt	13.06253	13.2572	13.45187

Impact category	Unit	S	M	L
Water use	m3 depriv.	0.841914	0.857738	0.873563
Resource use, fossils	MJ	40.78362	41.46021	42.13679
Resource use, minerals and metals	kg Sb eq	0.000237	0.000241	0.000246

For the case of the functional t-shirt, the transportation share of the environmental load is much higher than for the case of the functional leggings (see Figure 15). This is because of the different material composition of both garments (the leggings use mainly polyester fibre, while the t-shirt uses mostly polyamide) and their different weights (330 grams the leggings, 235 grams the t-shirt). As we have seen in all the results by now, the environmental impacts of the garments are directly proportional to the materials they are composed of (the quantity and the type). Since the leggings weight much more than the t-shirt, the transportation impacts in the former become more diluted than in the latter.

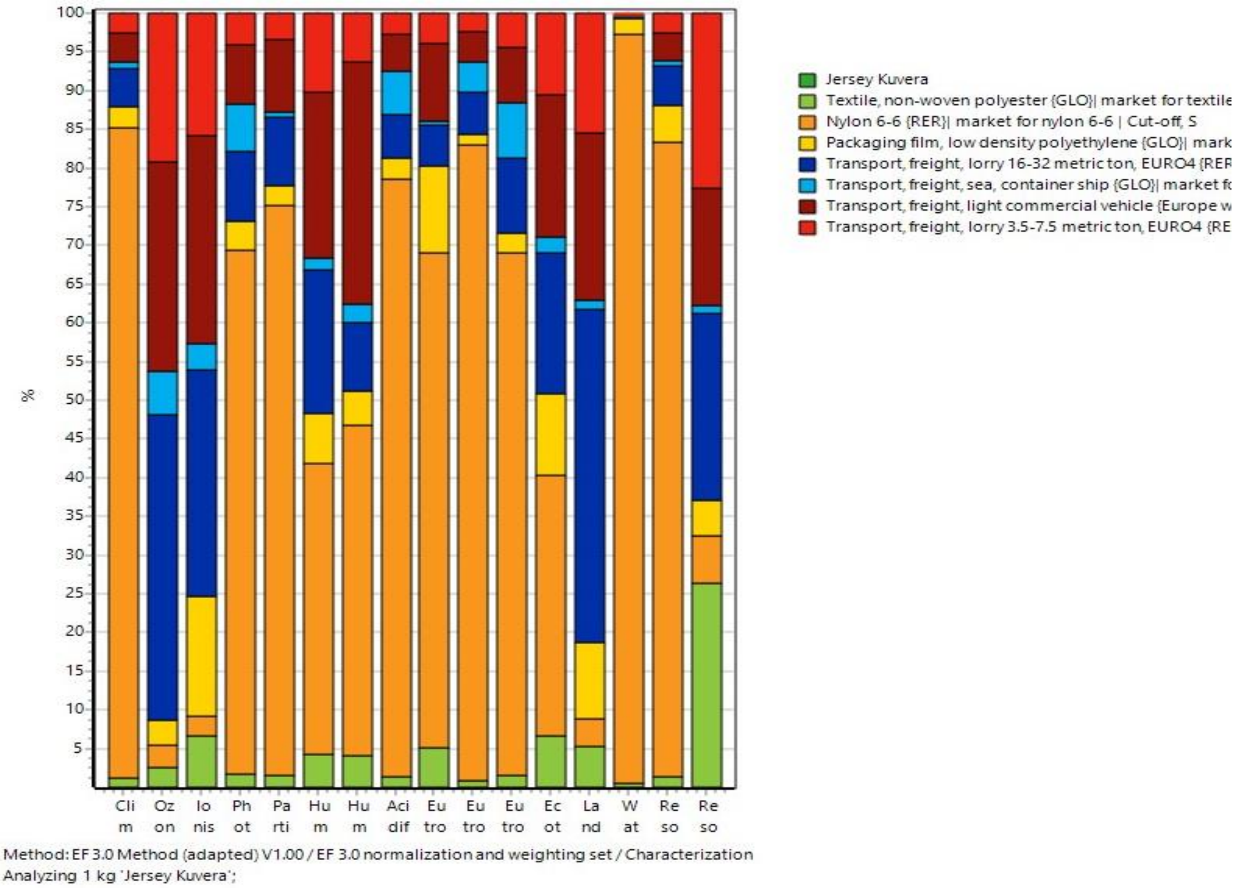


Figure 14. Contribution analysis of the functional t-shirt from Kuvera.

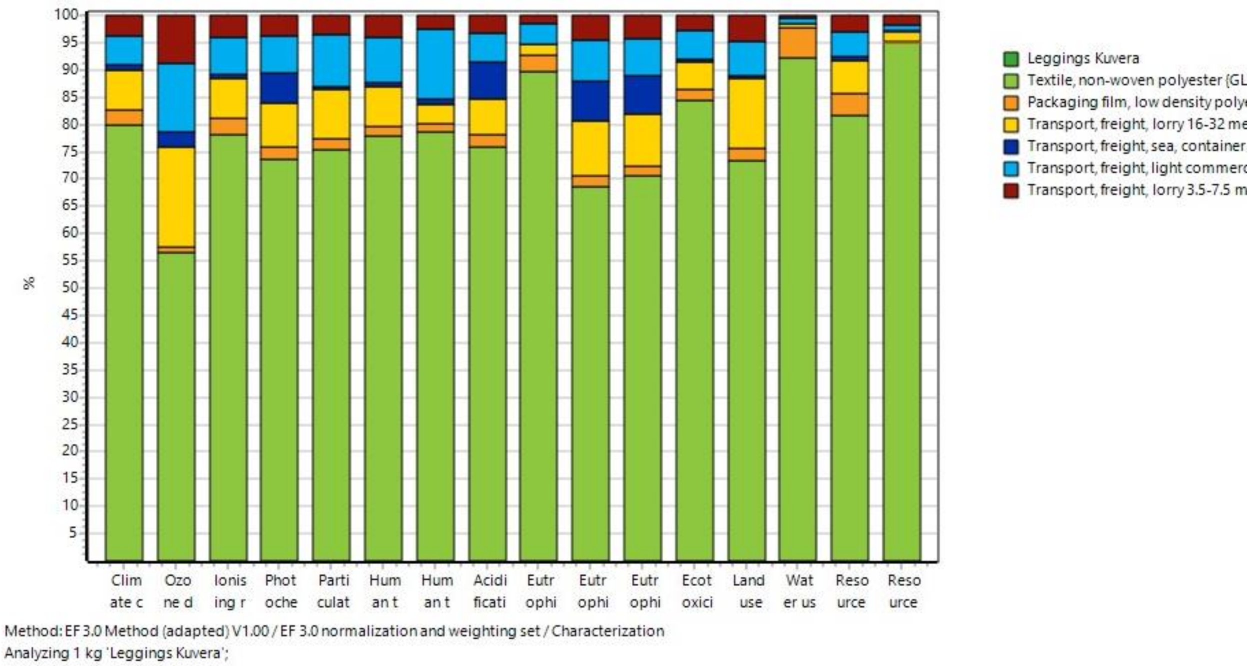


Figure 15. Contribution analysis of the functional leggings from Kuvera.

2.5.2 Normalization of selected impact category results

In order to render the environmental footprint results more tangible to the user, a normalization of a selection of impact category results has been performed. This step converts the results of Climate Change, Water Use and Resource Use (fossils) depicted in Table 12 and Table 13 into more "normal" units or better, they are brought into a more familiar scale and are the selected results that will be shown in the online widgets of the project. The normalized results for the selected impact categories are shown in Table 14 and Table 15.

The selected impact category results are renamed to *Carbon Footprint*, *Water Footprint* and *Fossil Energy Footprint* and are converted into units that are more familiar to an average citizen. The conversion factors used are those explained in section 2.2.2.

Table 14. Normalized *cradle-to-gate* results for selected impact categories for the functional t-shirt of Kuvera.

Widget indicator	Unit	T-shirt		
		S	M	L
Carbon Footprint	car-driven distance (km)	7.3	7.4	7.5
Water Footprint	personal daily consumption (days)	18.8	19.2	19.6
Fossil Energy Use	petrol volume equivalent (litres)	1.1	1.1	1.1

Table 15. Normalized *cradle-to-gate* results for selected impact categories for the leggings of Kuvera.

Widget indicator	Unit	Leggings		
		S	M	L
Carbon Footprint	car-driven distance (km)	7.1	7.3	7.4
Water Footprint	personal daily consumption (days)	7.0	7.1	7.3
Fossil Energy Use	petrol volume equivalent (litres)	1.2	1.3	1.3

3 Conclusions

Several garments of four innovative business case-studies from the European fashion industry were analysed in this report, following the life cycle assessment (LCA) methodology. The different business set-ups, with some companies having externalized the garment manufacturing to third organizations, had an important impact on the data availability to perform the LCA on all the garments in equal terms. In fact, it was not possible to acquire primary manufacturing data for the core processes of the companies that have their production externalized, specifically Bivolino and Kuvera. Due to this important lack of first-hand data for the foreground life-cycle processes, which is also a requisite by the respective ISO norm 14044:2006 (Environmental management — Life cycle assessment — Requirements and guidelines), a life-cycle screening (more "qualitatively", or of first-order) was carried out instead for the garments of these business cases. The presented results for these case-studies should be therefore taken as a first-order approximation of their potential *cradle-to-gate* environmental footprints.

In the business case of Azadora, a sportive women's coat was analysed with two personalisation variants (Dora "Fashion" and Dora "Sporty"). This technical and fashionable coat showed a considerable environmental footprint (Table 2 and Table 3), mainly due to the wool inside the main fabric and the overall material content (2.8 kg weight per coat), as it was shown in the contribution analysis (Figure 3 and Figure 4).

In the business case of Beste, a technical menswear coat was analysed ("Sergio" variant). Given its lightweight (less than 1.5 kg) for a high performance (windproof, PFC-free water repellent and breathable features), it showed a rather low environmental footprint (Table 7). Besides its lightweight, the good environmental performance shown by the "Sergio" technical coat was also due to the recycled material content used in the main Penneco fabric (recycled nylon from recovered fishing nets and recycled polyurethane from discarded materials in other industrial processes), which avoid the production of virgin materials. Moreover, the use of 100% certified BCI organic cotton resulted in a considerable saving of all sorts of environmental impacts too (respect to the conventional cotton alternative), with particular emphasis on the low water, carbon and toxicity footprints. Last but not least, Beste's commitment to reduce the environmental burden of its products can be seen in the solar PV installation on their factory in Tuscany as well, which contributed (and saved) around 8% of its total annual electricity consumption.

In the business case of Bivolino, a made-to-measure (MTM) shirt was analysed (75% cotton, 25% polyester), which can be ordered online, and shipped directly to the customer. Even under a worst-case scenario, neglecting manufacturing emissions and assuming long distances and a high rate of returns (30%) for the transportation phase of the cradle-to-customer-door life cycle screening, the transportation impacts resulted to be significant but generally minor (Figure 12), ranging from 7% (eutrophication) to 28% (climate change) with a maximum contribution to the total burden of 55% (ozone depletion). An extra analysis was performed to show the improvement potential of the environmental performance of such shirt, only by shifting to organic cotton (Table 10).

Finally, for the business case of Kuvera, two technical underwear garments were analysed: a t-shirt and a pair of leggings. They both resulted in a similarly low environmental footprint (Table 12). In these cases, the environmental load from transportation phases was rather important for the case of the t-shirt (Figure 14) and significant but minor for the case of the leggings (Figure 15).

Overall, expected impacts of the project is to actually enable small-series, EU-based, end-consumer demand-driven system/value chain. While this supports bringing back production to EU with the abatement of transportation environmental load, it also allows to narrow and slow the resource loops associated with textile and fashion industry.

In all cases, the **biggest share of the environmental burden comes from the amount and type of materials used in the fabrication of the garments**. This conclusion reinforces one of the main assumptions done in this study – the one related to approximating the life-cycle impacts of the fabrics/garments to the sum of its main components (skipping manufacturing inputs and outputs to and from the environment), when data was unavailable. Manufacturing processes seemed to contribute marginally to the environmental footprint of those garments for which primary data was available, with the exception of heat from natural gas and the use of some chemicals (softener) for the case of Beste. Impacts from packaging resulted to be completely negligible for all the cases analysed.

In order to include, at the end of the analysis, some **practical recommendations** and lessons learned from this study, a list of potential initiatives and especially suggestions is presented here, which may be used as useful guidelines by these companies to reduce further the environmental footprint of their garments acting on the materials, therefore on the suppliers selection (by order of importance or preference):

- Reduce to the minimum the **weight** of the garment (just enough to fulfil its specifications), with special attention to some materials with high embodied impacts like wool or cotton.
- Introduce as many **recycled materials** as possible and consider substituting those that show a high environmental impact.
- Introduce or consider **substituting some plant-origin fibres** like cotton by others that are much better from an environmental point of view (due to their higher productivity and yields), like **flax**, **hemp, jute** or **kenaf** fibres.
- Shift to **organically produced** and **certified** plant-based textiles.

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5 Annex I - SCPMS Data Service n.6

As for the Revision of the Scope of the Data Services to be offered through the FBD_BModel Platform *DS6 - SCMPS6: Environmental footprint assessment (Life Cycle Analysis) and certification of products and manufacturing processes* has been made available as a "static" service only related to the pilot cases (products and actual supply chains) of the industrial partners, providing via dedicated Widgets through the FBD_BModel Platform and App the normalized *cradle-to-gate* results for selected impact categories to the end-customer.

The selected categories, showed in readable way for the final customer, has the main aim to introduce the environmental footprint of the garments selected and personalised (by the customer itself), in an informative way, in order to render the environmental footprint results more tangible.

Specifically, the selected impact category results are renamed to *Carbon Footprint*, *Water Footprint* and *Fossil Energy Footprint* and are converted into units that are more familiar to an average citizen and represented by symbols. The conversion factors used are those explained in section 2.2.2.

Table 16. Normalized *cradle-to-gate* for selected impact categories

Widget indicator	Unit
Carbon Footprint	car-driven distance (km)
Water Footprint	personal daily consumption (days)
Fossil Energy Use	petrol volume equivalent (litres)

Widgets examples are hereafter represented:

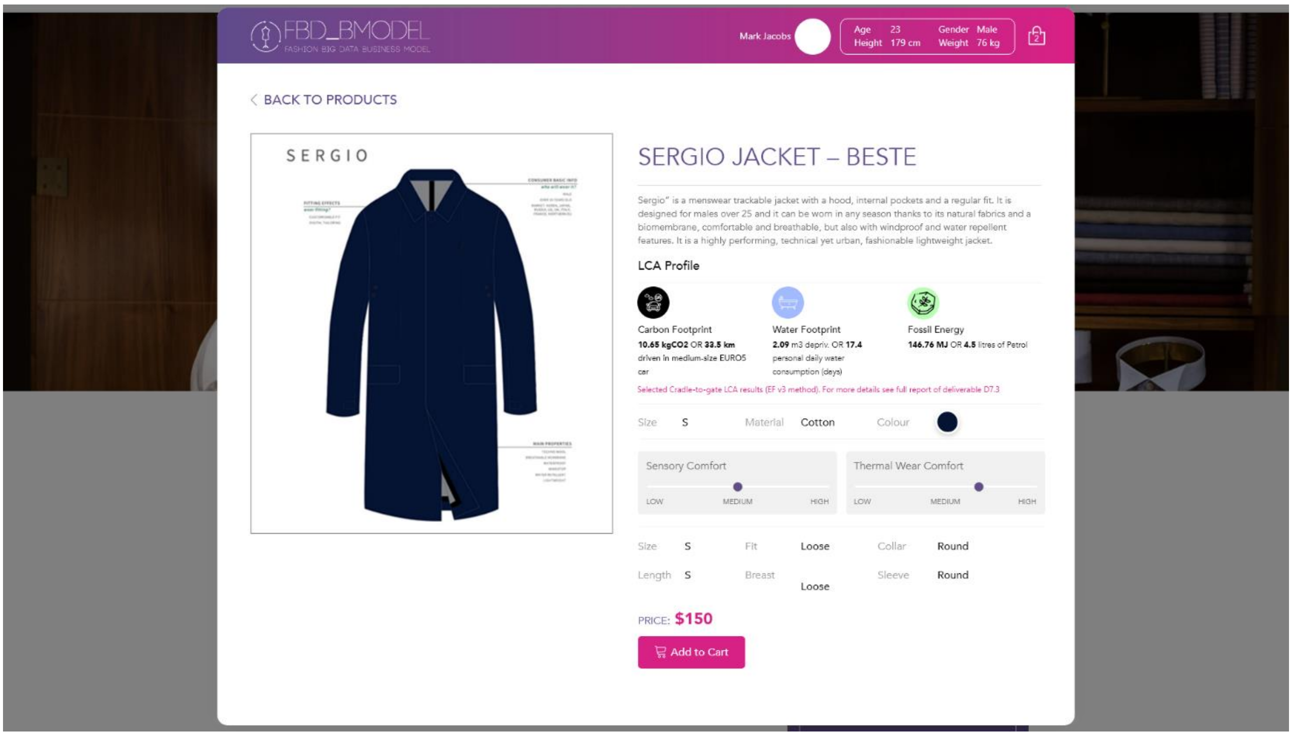
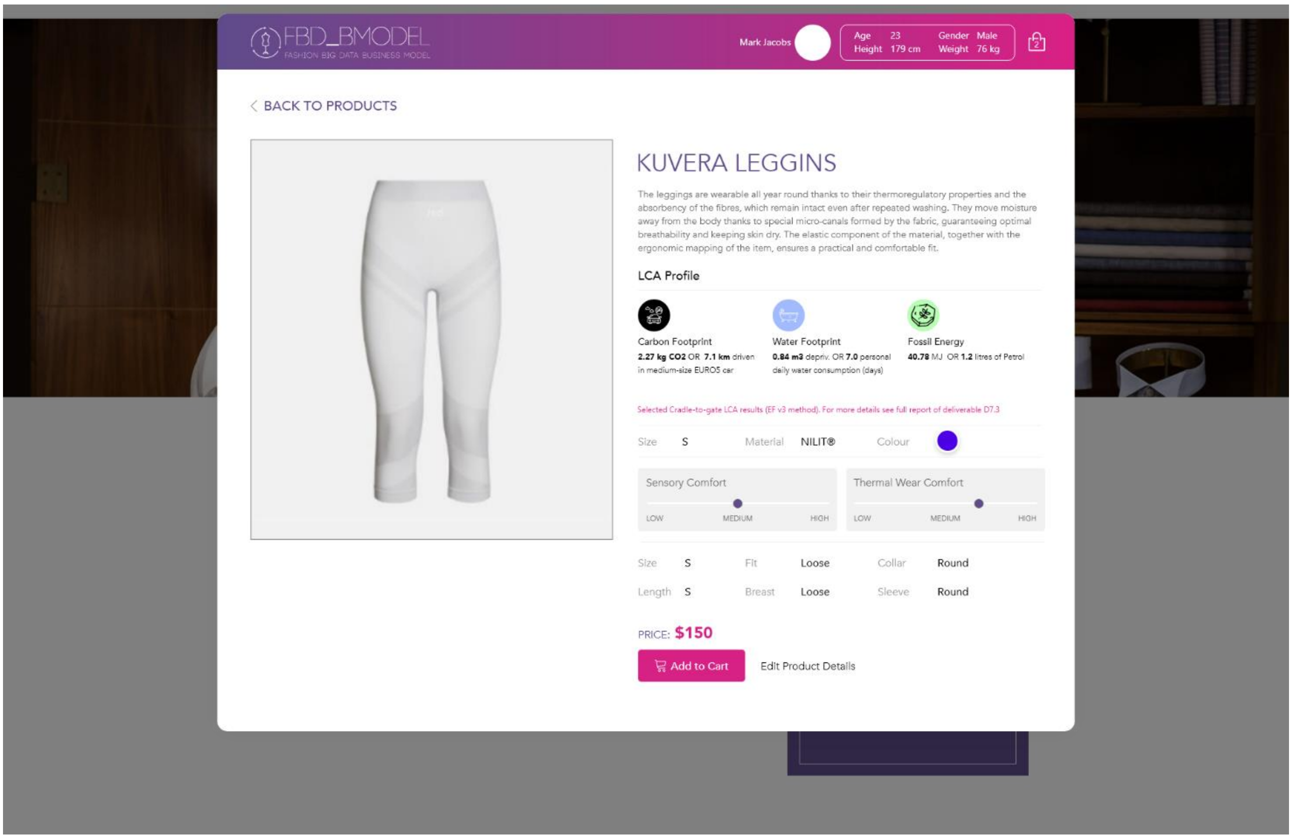


Figure 16. Beste business case - SCPMS DS6 Widget.


FBD_BMODEL
FASHION BIG DATA BUSINESS MODEL
Mark Jacobs
Age 23
Gender Male
Height 179 cm
Weight 76 kg
BACK TO PRODUCTS
KUVERA LEGGINS
The leggings are wearable all year round thanks to their thermoregulatory properties and the absorbency of the fibres, which remain intact even after repeated washing. They move moisture away from the body thanks to special micro-canals formed by the fabric, guaranteeing optimal breathability and keeping skin dry. The elastic component of the material, together with the ergonomic mapping of the item, ensures a practical and comfortable fit.
LCA Profile
Carbon Footprint
2.27 kg CO2 OR 7.1 km driven in medium-size EURO5 car
Water Footprint
0.84 m3 depriv. OR 7.0 personal daily water consumption (days)
Fossil Energy
40.78 MJ OR 1.2 litres of Petrol
Selected Cradle-to-gate LCA results (EF v3 method). For more details see full report of deliverable D7.3
Size S
Material NILIT®
Colour
Sensory Comfort
LOW MEDIUM HIGH
Thermal Wear Comfort
LOW MEDIUM HIGH
Size S
Fit Loose
Collar Round
Length S
Breast Loose
Sleeve Round
PRICE: $150
Add to Cart
Edit Product Details

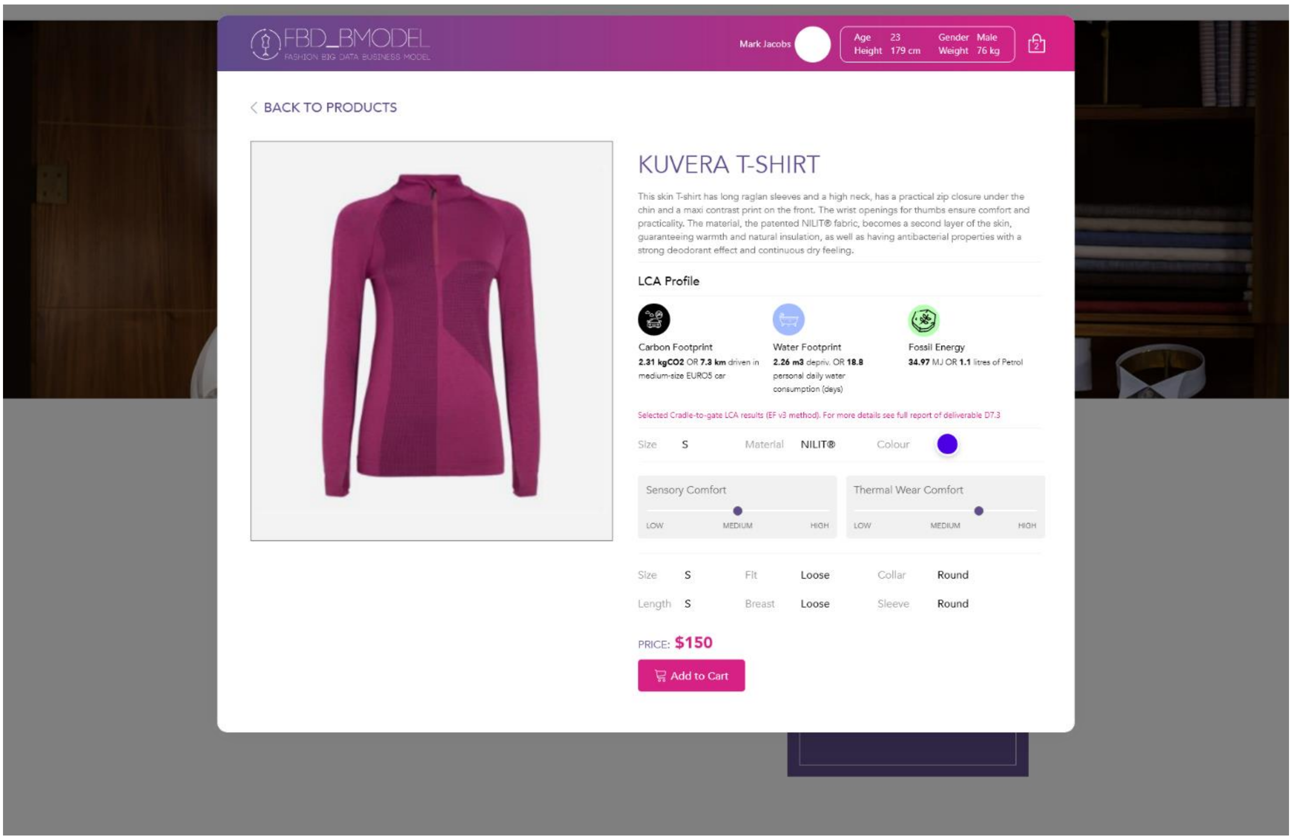


Figure 17. Kuvera business case - SCPMS DS6 Widget.