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DEVELOPMENT AND TESTING OF A NEW LIFE CYCLE ASSESSMENT METHOD FOR THE MONETARY EVALUATION OF WATER SCARCITY IMPACTS

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“L’acqua è ‘l vetturale della natura”

Leonardo da Vinci

Abstract

Considering goods for which no market exists (i.e. clean air, freshwater, rainforests, etc.) if on the one hand it is quite simple to quantify them in physical units, on the other hand it seems difficult to give them an economic value, especially when considering their related environmental impacts. Even if international standardize methodology of Life Cycle Assessment (LCA) may support practitioners in performing environmental assessments, because of its intrinsic nature of tool able to provide mainly a biophysical impact characterization the LCA methodology alone to date is not sufficient to provide monetary information about environmental impacts. Existing methods and approaches aimed to give monetary value to environmental impacts and aspects, particularly those focused on water resource, are still absent or very limited by data availability and time-spatial characterization issues, resulting in an almost total absence of consistent economic LCA based indicators focused on water scarcity impacts. The aim of the present research was thus the development and testing of a new Life Cycle Assessment method for the monetary evaluation of water scarcity impacts. The research core was the development of specific monetary characterization factors to convert water consumption related impacts into monetary terms, adopting principles from the theory of the LCA methodology and considering also some economy-related parameters. The resulting new developed method was validated according to sensitivity analysis at different levels and then it was successfully tested in four different real case studies. To be applied the new proposed method was imported into the LCA software SimaPro adopted to process data of each product system collected on the field. Finally, a hotspots analysis of results was performed demonstrating the effectiveness and the applicability of the new proposed method, highlighting also its sensitivity to different real productive contexts and to different existing water scarcity impact assessment methods. Concluding, the new developed method for the monetary valuation of water scarcity impacts provides a simpler framework when compared to the existing monetary methods whose application in LCA is usually limited to few environmental aspects, requiring often significant people involvement to perform surveys and analysis needing a huge amount of time. However, further improvements such as the integration of water qualitative aspects, additional validation procedures and testing in other productive contexts need to be investigated in order to increase the accuracy and the capacity of the proposed method to generate consistent results.

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Introduction

Increasing population grown and consequently the growing demand for both abiotic and biotic resources has led in the last fifty years to the degradation of ecosystems with significant implications on natural capital availability (Millennium Ecosystem Assessment, 2005).
The increasing awareness on these topics has led the scientific community to perform environmental impact assessments adopting different tools like the Life Cycle Assessment (LCA), the most adopted one to perform evaluation on potential environmental impacts of a product, process, and organization along all the life cycle stages (ISO 14072, 2014).
The LCA standardize methodology allows to assess potential environmental impacts considering a range of many different environmental issues (e.g. climate change, acidification, ozone depletion, etc.) with a life cycle perspective. When considering only water related impacts (e.g. freshwater scarcity, freshwater eutrophication, etc.) it is possible to refer to the environmental evaluation specifically as Water Footprint assessment. Many Water Footprint methods aimed to assess different water related aspects have been developed in the last years. For this reason, the LCA community started working on the development of a consistent framework for assessing and reporting Water Footprints in an internationally consistent way. This led to the recent publication of the ISO 14046 standard, providing principles, requirements and guidelines for the assessment of Water Footprint. This LCA based standard is aimed to answer the needs of companies and public administrations in managing water related impacts, implementing in a properly way policies for sustainable water management at local, regional, national and global levels (ISO 14046, 2014).
However, reduction in freshwater availability and increasing competition among users (including agriculture and industry) may have relevant impacts not only on environmental compartment but also on economic growth with high exposure to water risk by companies. The need for economic valuation of environmental aspect like water is thus an emerging challenge.
LCA methodology allows the quantification of potential environmental impacts adopting a cause effect chain approach starting from the analysis of inventory data (ISO 14040, 2006), to mid-point assessment, addressing potential risks of impacting on specific environmental aspects, till endpoint assessment, addressing potential damages to three different areas of protection (AoP) human health,

ecosystem quality and resources (EC-JRC, 2010; Finnveden et al., 2009). However, because of its intrinsic nature of tool able to convert physical inputs/outputs of resources/emissions into potential environmental impacts according to biophysical impact pathways, the LCA methodology to date doesn’t provide monetary information about environmental impacts (Pizzol et al., 2015).

For this reason, in recent years the scientific community started investigating the possibility to perform assessment of environmental impacts and aspects in monetary terms, in order to allow decision makers to better understand LCA outputs (Risz et al., 2012; Bruel et al., 2016; Nguyen et al., 2016). Monetization of environmental impacts is aimed mainly to support organizations and in general decision makers in developing sustainable practices and strategies (ISO/DIS 14008, under publication).

Considering the need for a sustainable management of natural resources, water protection represents a topic of highest concerns, with water crisis universally recognized as a top global risk. Increased competition between water users and other demands has led to a situation where about 40% of the world's population live in water stressed areas, with an expected increase up to 50-65% by 2025 (World Economic Forum, 2016). Even if water on earth is more or less constant in absolute quantity terms, its uneven distribution continues to create growing problems of accessibility. Moreover, water availability is a challenge faced by a growing number of countries, with potential impacts on economic growth.

Considering the possibility to assess water related impacts in order to implement policies for the sustainable management of water resources, this research focuses on the area of interaction between environmental and economic sustainability.

Therefore, the main objective of this research has been: (i) developing a new LCA based method for the monetary assessment of water scarcity impacts; (ii) testing the new developed method through its application to specific real case studies investigating the capacity to provide hotspots analysis.

Results from the research activities are summarized in 5 chapters.

In chapter 1 a brief description about environmental sustainability and related initiatives is reported, introducing the water topic. In this chapter also the standardize LCA methodology to perform environmental assessments is described, introducing Water Footprint and the main available methods to perform water impact assessment. Existing approaches to perform monetary assessment of environmental aspects are also reported, highlighting gaps, opportunities, and defining the research objectives.

In chapter 2 information about materials and methods adopted in the present research work are reported, describing the new proposed method for the assessment in monetary terms of water scarcity impacts in life cycle assessment, providing a description about how the specific monetary characterization factors were developed in order to convert water consumption related impacts into monetary terms, starting from the adoption of an LCA based approach up to the integration of some parameters reflecting economic effects from water consumption on different critical aspects.

Chapter 3 reports the results from the development of the new proposed method, focusing on the proposed set of monetary characterization factors and providing also information about results from the validation performed through a sensitivity analysis at different levels.

In this chapter also outputs from the test on the 4 real case studies, 3 concerning food industry products and 1 concerning a laundry service, are reported.

In chapter 4 results from the research activities are discussed, highlighting the capacity of the new proposed model to provide hotspots analysis and discussing the validity and the applicability of the new proposed method according to its sensitivity to different real productive contexts and different water scarcity impact assessment methods.

Finally, chapter 5 provides conclusions, summarizing the main features of the new proposed LCA based method, highlighting also some future research perspectives for its improvement.

1. Environmental management and water related issues

In this chapter a brief introduction about environment and human pressures in the last decades is reported, highlighting the most important initiatives undertaken by the scientific community in order to promote a sustainable development for the next years, focusing also on water issues.
The widely adopted methodology of Life Cycle Assessment is presented, describing the framework adopted when performing an environmental impact assessment according to the international standard ISO 14040:2006 and ISO14044:2006. Moreover, the Water Footprint methodology is described, providing information about the existing methods developed in the last years by the scientific community to assess water related impacts.
Existing approaches aimed to perform monetary valuation of environmental impacts and aspects are also described, highlighting the main reasons for why to date the application of monetary valuation to Life Cycle Assessment is still limited and explaining the aim of this research.

1.1 The need for a sustainable future

Demographic growth and increasing land occupation with a consequent depletion of natural environment, as well as industrialization coupled with technological development strictly promoted by human needs, are only some of the main stressors that have continuously influenced in the last fifty years the environment, resulting in a negative trend characterized by a constant degradation of ecosystems and loss of biodiversity (Millennium Ecosystem Assessment, 2005).
Recent scientific debate about what should be the role of humanity towards the Earth system has led to the definition of a new geological era named Anthropocene (Crutzen, 2002; Steffen et al. 2011) where humanity is identified as the driving force of global environmental change (Pichler et al., 2017). This new definition implies a common consensus that human impacts on the Earth system will be evident for thousands of years in the future (Waters et al., 2016; Lewis and Maslin, 2015; Dietz, 2017).

In this new epoch the Earth system was subjected to many mutations: global warming has increased quickly, biomes started disappearing, freshwaters suffer scarcity problems and oceans are acidifying, resulting in a high risk for the planet to become not suitable to support the modern society (Richardson et al., 2011).

Considering biodiversity, many different indicators exist aimed to show the state of habitats and natural capital, providing information about the health state of the living species (Tittensor et al., 2014). The Living Planet Index, considering more than 3000 species among mammals, fishes, birds, reptiles and amphibians, provides a measure on the average variation of biodiversity abundance level over the time since the 1970 (Collen et al., 2009).

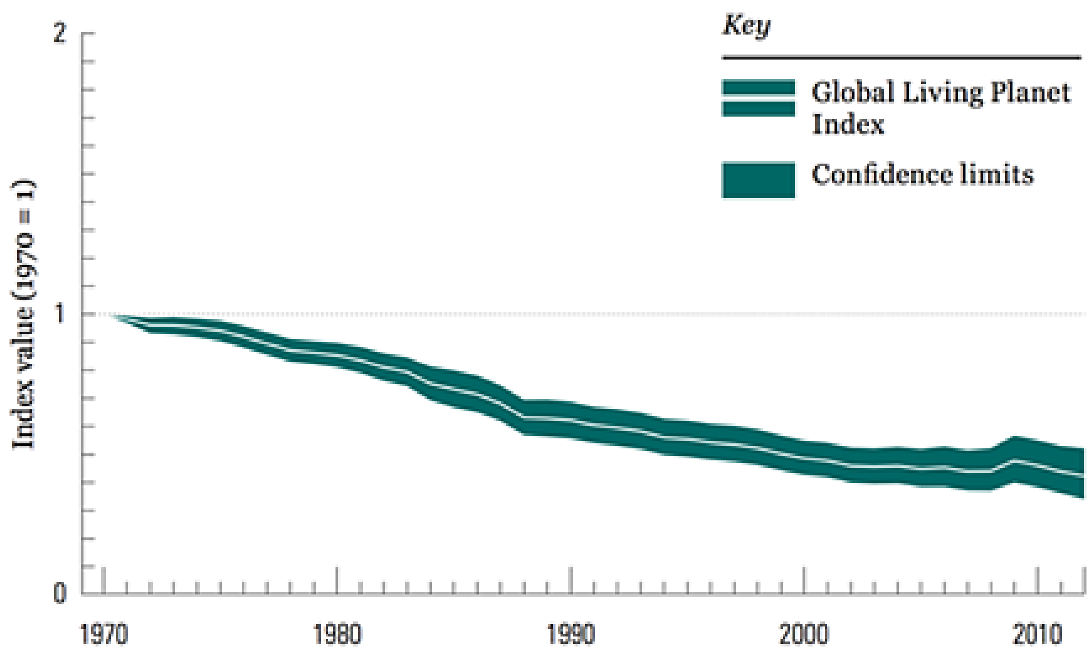

Figure 1.1 *The Global Living Planet Index (WWF, 2016).*

According to Figure 1.1, the Living Planet Index highlights an overall decline in population abundance by 58% up to the 2012, with an average constant annual decline of 2% and the most incidence on the global decline by the freshwater species (WWF, 2016).

The main reasons of this decline are pressures from unsustainable practices in agriculture, fisheries and other anthropogenic activities resulting in degradative effects for biodiversity (Rockstrom et al., 2009).

Resources consumption and overexploitation is already having a worrying effect on the planet, measurable in the need for 1,6 equivalent Earth planets to support actual human activities (Global Footprint Network, 2016).

In this context the scientific community was therefore forced to act in order to tackle the adverse effects on the environment more effectively than in the past, resulting in consistent initiatives aimed at promoting a sustainable development for the next future (UN DESA, 2014).

Aware of the weak equilibrium between human and ecosystem, the international community since the ’70s started promoting the prevention and protection of the environment, going from the introduction of the “polluter pay” principle to the official definition of “sustainable development" in the late '80s by the World Commission on Environment and Development as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). The concept of sustainable development introduced the need for an equilibrium among the three different dimensions of the sustainability, environmental, economic and social, and represented the starting point for discussion at the United Nations Conference on Environment and Development that was held in Rio de Janeiro in 1992. Attended by 14 heads of state and thousands of representatives from 178 national governments, the summit was aimed to finalize the first historical international attempt to set action plans and strategies towards a more sustainable development (UNSD, 1992).

The milestone Agenda 21 was an output of this conference, which “recognized each nation’s right to pursue social and economic progress and assigned to States the responsibility of adopting a model of sustainable development.” (UN, 1993).

Another global initiative towards sustainability is represented by the Kyoto who focused for the first time on the emerging topic of climate change in 1997, aimed to create consensus among countries about the necessity to cut the greenhouse gas emissions establishing binding limits for developed countries. This led to the adoption of the Kyoto Protocol, which settled the commitment for industrialized countries to reduce globally the greenhouse gas emissions by 5,2% below 1990 levels for the period 2008–2012 (UN, 1998).

However, it was only in the 2000 that debate on sustainability was effectively reopened, with the Millennium Summit held in New York (UN, 2000) and the next UN Millennium Declaration signed by 189 countries. The most important output of the summit was the definition of 8 Millennium Development Goals (MDGs) to be achieved by 2015. The MDGs (Figure 1.2), basically based on principles like freedom, equity and respect for human right, are aimed to substantially fight poverty and disease, promoting at the same time a sustainable development (UN, 2005).

Figure 1.2 *The eight Millennium Development Goals (UN, 2014).*

The next Johannesburg Declaration on Sustainable Development adopted at the World Summit on Sustainable Development (WSSD), usually known as Earth Summit 2002, substantially confirmed the MDGs, emphasizing the necessity for a whole partnership between governments and organizations in order to address environmental issues, changing consumption patterns, moving to more sustainable production practices, introducing commitments for energy water and basic sanitation (UN, 2002).

Although the adoption of the MDGs was well accepted at the beginning, position of some changed over the time as some correlated limits were emerging: MDGs omitted some basilar objectives of the Millennium Declaration, such as security, human rights and democracy. Furthermore, they failed to underscore values like freedom, tolerance and equality, and didn't address economic development (Vandemoortele, 2011).

To overcome the faults of the MDGs, the United Nations decided to perform a worldwide consultation aimed to collect opinions and comments by stakeholders on what a new set of post 2015 development goals should be based on. This led to the Rio+20 summit in 2012, whose output was the creation of a panel made of representatives from 70 countries for the definition of the Sustainable Development Goals (SDGs), associated to a set of targets to be met by 2030 (UN, 2015). The new proposed SDGs (Figure 1.3) go further the limits of the MDGs, promoting an interconnected approach among economic, social, and environmental challenges (UNSC, 2015).

However, the high complex structural level of the goals needs adequate knowledge investments, for each country who want to reach the targets, in order to identify the proper set of measures and interventions to be implemented (Sachs, 2012).

Figure 1.3 *The eight Millennium Development Goals (UN, 2014).*

The 17 SDGs are reported as follows (UN, 2015):

1) End poverty in all its forms everywhere;
2) End hunger achieve food security and improved nutrition, and promote sustainable agriculture;
3) Ensure healthy lives and promote wellbeing for all at all ages;
4) Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all;
5) Achieve gender equality and empower all women and girls;
6) Ensure availability and sustainable management of water and sanitation for all;
7) Ensure access to affordable, reliable, sustainable and modern energy for all;
8) Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all;
9) Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation;
10) Reduce inequality within and among countries;
11) Make cities and human settlements inclusive, safe, resilient and sustainable;
12) Ensure sustainable consumption and production patterns;
13) Take urgent action to combat climate change and its impacts (taking note of agreements made by the UNFCCC forum);

14) Conserve and sustainably use the oceans, seas and marine resources for sustainable development;
15) Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification and halt and reverse land degradation, and halt biodiversity loss;
16) Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels;
17) Strengthen the means of implementation and revitalize the global partnership for sustainable development.

1.1.1 The planetary boundaries

Sustainable development at all levels, locally, nationally and internationally, has become a fundamental requirement for human health and world economy. The need for humans to operate in a safe planetary space is an evidence which requires a fully participation of both public and private sectors in order to plan and put in operation consistent sustainable policies (UN, 2012).
To do that in a proper manner it is fundamental to promote a consistent integration between policy and science knowledge, in order to identify the priorities to pursue the sustainable development.
Over the time many different definitions have been adopted by the scientific community and stakeholder in general to describe global environmental limits: carrying capacity, sustainable consumption and production, footprints, safe operating space (Rockström and Sachs, 2013).
A concept widely diffused in recent years is planetary boundaries: it refers to the definition of a safe operating space for humanity with respect to the functioning of the Earth system (Rockström et al., 2009). The nine proposed planetary boundaries (Table 1.1) have been defined according to three main forms (Rockström and Sachs, 2013):

1. Boundaries referring to a safe global level of depleting non-renewable fossil resources and fossil groundwater;
2. Boundaries referring to a safe global level of using the living biosphere, including exploitation of ecosystems, protection of biodiversity and consuming renewable resources;
3. Boundaries providing a safe global level of Earth’s capacity to absorb and dissipate human waste flows, including carbon, nitrogen, phosphorus, and toxic chemicals such as pesticides.

Table 1.1 *The planetary boundaries (Adaptation from Rockström et al., 2009).*

Earth System process	Proposed planetary boundary
Climate change	CO2 concentration in the atmosphere should be limited to 350 ppm and/or a maximum change of +1 W m-2 in radiative forcing
Biological diversity loss	An annual rate of a maximum of 10 extinctions per million species
Biogeochemical cycles	Nitrogen (N) cycle - limit industrial and agricultural fixation of N2 to 35 Mt N yr-1) Phosphorus (P) cycle (annual P inflow to oceans not to exceed 10 times the natural background weathering of P
Global freshwater use	Limited to 4000 km3 yr-1 of consumptive use of runoff resources
Land system change	Not more than 15% of the ice-free land surface used as cropland
Ocean acidification	Mean surface seawater saturation state with respect to aragonite at not less than 80% of pre-industrial levels
Stratospheric ozone depletion	Maximum 5% reduction in O3 concentration from pre-industrial level of 290 Dobson Units
Chemical pollution	No boundary defined
Atmospheric aerosol loading	No boundary defined

The aim of the boundaries is to provide a limit within which humanity and wildlife may live in a sustainable way, ensuring at the same time the possibility to promote innovation, growth and development for the society (Steffen et al., 2015). Operating over these limits could be unsafe for the human prosperity, generating irreversible conditions for the Earth system. According to the analysis performed by the scientific community, to date at least 4 of the planetary boundaries have been exceeded (Figure 1.4), particularly climate change, biosphere integrity, land-system change and biogeochemical flows (phosphorous and nitrogen depletion), while some of the boundaries have not been jet defined (functional diversity, novel entities and atmospheric aerosol loading).

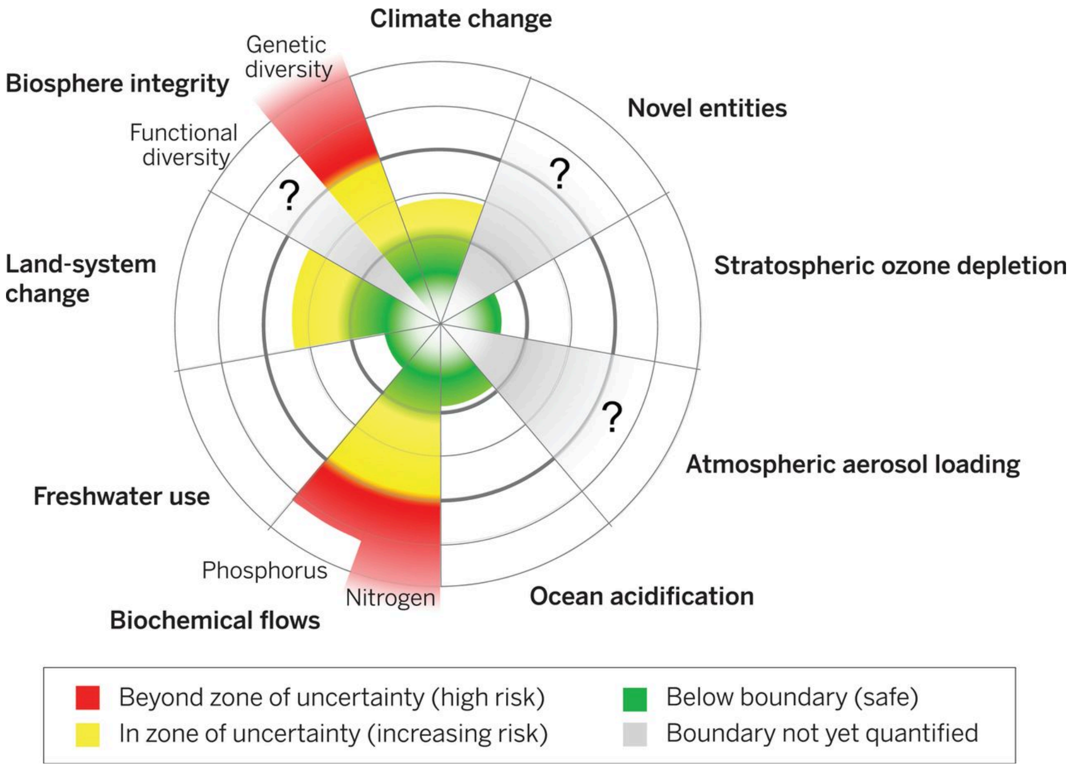

Figure 1.4 *Current status of the control variables for seven of the planetary boundaries. The green zone is the safe operating space, the yellow represents the zone of uncertainty (increasing risk), and the red is a high-risk zone. The planetary boundary itself lies at the intersection of the green and yellow zones. The control variables have been normalized for the zone of uncertainty; the center of the figure therefore does not represent values of 0 for the control variables. The control variable shown for climate change is atmospheric CO2 concentration. Processes for which global-level boundaries cannot yet be quantified are represented by grey wedges; these are atmospheric aerosol loading, novel entities, and the functional role of biosphere integrity (Steffen et al., 2015).*

Moreover, some authors suggest that even the freshwater use boundary has been already exceeded a safe limit (Vörösmarty et al., 2010; Jaramillo F. et al., 2015; Mekonnen and Hoekstra, 2016). Despite the alarming outcomes on the current status of the Earth planet according to the planetary boundaries concept, a hard debate in the scientific community is still ongoing since a certain rate of uncertainty is attributed to limits quantification made by the authors. Nevertheless, negative effects from the increasing anthropogenic pressures of the last decades on the environmental system are supported by scientific evidences (MEA, 2005; CBD, 2014; Brito and Stafford-Smith, 2012; UNEPa, 2012; IPCC, 2014).

Even if biophysical and societal consequences, as well as the risk of irreversible ecosystem degradation, from the overcoming of the planetary boundaries are quite uncertain, a hotspot is that humanity is facing a new era, the Anthropocene, characterized by a high level of stress at planetary scale (Crutzen, 2002), needing to define a new framework to promote and ensure a sustainable development below the identified safe operational planetary limits (Griggs et al. 2013).

1.1.2 Water crisis

One of the greatest environmental issues of the last century is water scarcity (Vörösmarty et al., 2013; Davidson, 2014; Jiménez et al., 2014). The lack of water, mainly due to interconnected factors like climate change and human activities, is universally recognized as an increasing issue (Bates et al., 2008; Addams et al., 2009; UNEPb, 2012). Many projects and initiatives in the international context have recognized the risks related to water (Millennium Ecosystem Assessment, 2005; IPCC, 2014).

Even if water on earth is more or less constant in absolute quantity terms, its uneven distribution in time and space continues to generate growing problems of freshwater availability and accessibility.

The continuous circulation of water within the Earth's hydrosphere occurs in the so named hydrologic cycle (or natural water cycle). Water, in many different phases (solid, liquid, gas), moves above and below the Earth surface due to the physical processes of evaporation, condensation, precipitation, sublimation, infiltration and runoff (U.S.G.S., 2016). Sun acts as driver for the activation of water cycle, heating seas and oceans generating the evaporation of water that moves into the atmosphere where lower temperatures lead to its condensation into clouds. Then, thanks to the precipitations, water falls on the Earth surface, being accumulated (e.g. icecaps, glaciers) or not (runoff). The fraction of water infiltrated can flows back to surface water bodies and then into the seas and oceans where water cycle starts again (U.S.G.S., 2016). Three-quarters of the Earth's surface is covered by water, however only a very small amount fraction (less than 1%) is freshwater that can meet human needs and support ecosystems (Revenga et al., 2000).

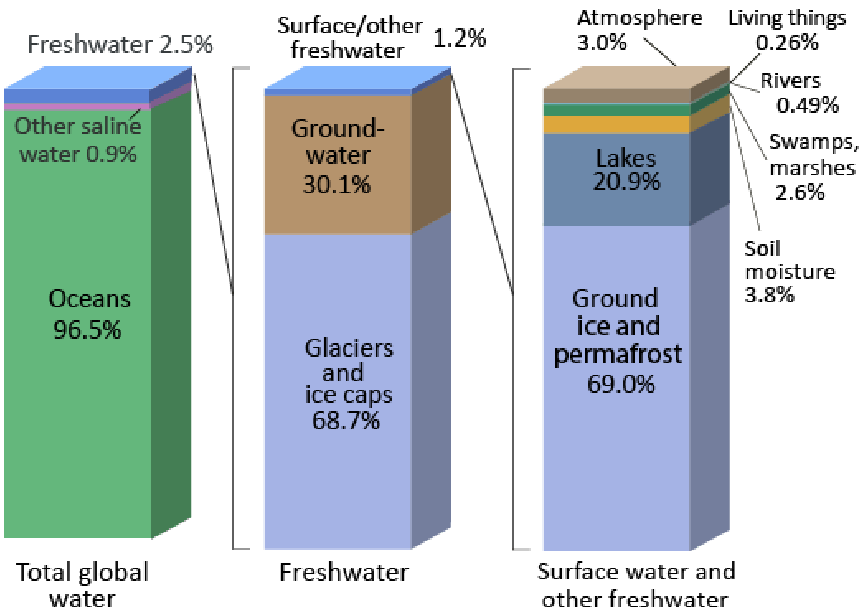

Figure 1.5 *Percentage distribution of water on Earth (Shiklomanolov et al., 1993).*

About 70% of the global freshwater withdrawals are addressed to the agricultural sector, with an increasing amount up to more than 90% in developed countries (UNESCO, 2015).

The increasing competition between water users (agriculture, energy, industry, cities) will result in a worrying expected situation by 2025 where 1,8 billion people will live in regions characterized by absolute water scarcity, and about 50-65% of the world's population will live in water stressed areas (WWAP, 2012). Moreover, insufficient basic sanitation services expose 2.3 billion people to several diseases like diarrhoeal, which is the third leading cause of death among children under five years (WHO, 2017).

Even if the concepts of water stress and water scarcity may be considered similar, they are quite different. According to the Water Scarcity index developed by the United Nation Environmental Programme, a situation of water scarcity occurs when the amount of water withdrawn from freshwater bodies in a specific area is so great that water supplies are no more able to fully satisfy human or ecosystem needs in that area (UNEP, 2008). Specifically, an area is under water stress conditions when annual water supplies drop below 1.700 m3 per person, while it is under scarcity conditions when annual water supplies drop below 1.000 m3 per person and under absolute scarcity conditions when water supplies drop below 500 m3 (Falkenmark et al., 1989).

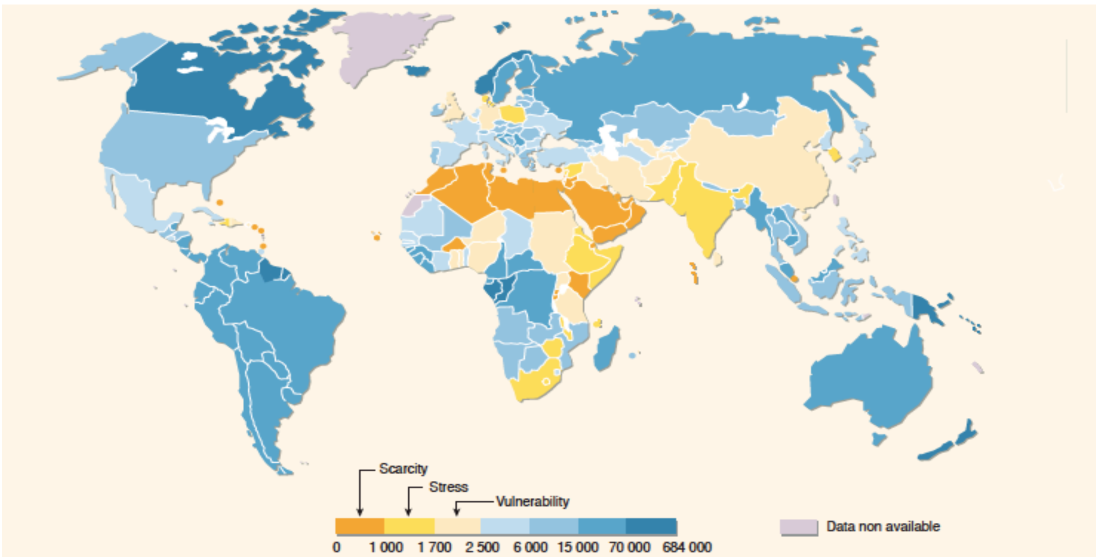

Figure 1.6 *Freshwater availability in m3 per person per year in 2007 (UNEP/GRID-Arendal. 2008).*

Moreover, it is important to highlight that low water stress doesn't imply ready access to water, since the concept is a function of both water resources availability and water resources access. Even though water is available in a certain area to meet human demands, economic water scarcity (Figure 1.7) mainly because of institutional and financial capital constrains may limits people accessing to water resources, resulting in malnutrition effects (WWAP, 2012).

Essential to sustain life, development and the environment, water may be considered as an economic good. (García-Rubio et al., 2015).

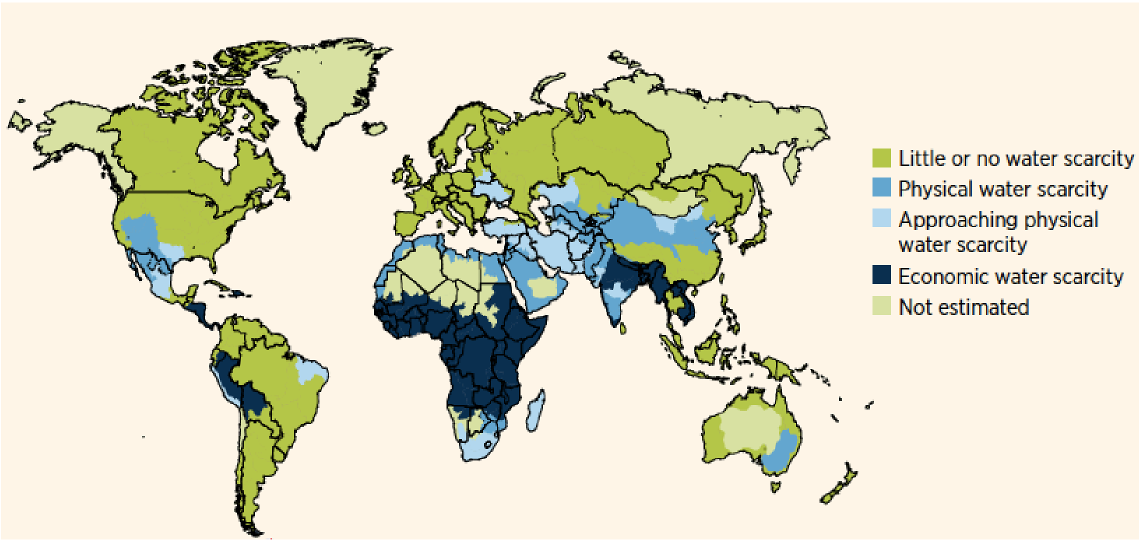

Figure 1.7 *Global physical and economic water scarcity (IWMI, 2007).*

Urban expansion, industrialization and population growth hardly affect the natural water cycle, with consistent implications for processes like pollutants transportation, erosion, water chemistry, responsible for the alteration of ecosystems and ecological stability. Furthermore, recent estimations suggest that hot topic like climate change will hardly affect the water cycle in the next years, accounting for about 20% of the increase in global water scarcity (WWAP, 2012).

Reducing water availability may generates high stress on economic growth, with regions expected to suffer a decrease in gross domestic production up to 6% by 2050 (World Bank, 2016).

Outcomes from Carbon Disclosure Project show an exposure for water risks for 405 big companies resulting in a total of more than 2,5 billion dollars in 2015 (CDP, 2015), highlighting the necessity for a quick change in water management policies.

1.1.2.1 Initiatives towards water management

To promote the protection of the environment, particularly considering the possibility to solve water resources issues and problems, many initiatives were recently undertaken by governmental and non-governmental organizations aimed to provide consistent tools in order to support decision-makers and companies in promoting sustainable practices for a better water management at local and global scale.

In 1992, the organization for food and agricultural of the United States (FAO) proposed the development of a global water information system to provide information on water resources and uses, mainly for agriculture, as a basis for analysis and planning at national and international levels (FAO, 2016). Thus in 1993 the Global Water Information System (GWIS) was launched.

According to the necessity to start collecting and processing data from many different countries in the World, generating statistical analysis and water resources related indicators for agriculture sector, one year later AQUASTAT was born.

Focusing first on the collection and publishing of statistical information, the program has then evolved over the years mainly because of the necessity to integrate, together with the agriculture sector, also data about water withdrawals from municipal and industrial sectors (FAO, 2014). This was fundamental for the improvement of the program in order to provide a more complete picture of the water situation in the World, especially considering the increasing competition between different sectors leading to high stress on water resources.

The World Business Council for Sustainable Development (WBCSD, 2010), who involves about 200 international companies from more than 30 countries, is another example of initiative towards water sustainability. WBCSD, which represent the 20 most important industrial sectors, in 2007 launched the Global Water Tool to help companies in mapping their water uses and assessing the risks of global operations along the supply chains.

The tool makes a comparison between water volumes managed by a company and local water supply and consumption in order to check the water efficiency. Furthermore, the tool generates indicators useful for the Global Reporting Initiative (GRI).

A particular feature of this tool is the capacity to estimate the risks incurred by a company according to its water resources management. Data adopted in the development of the Global Water Tool come from many different organizations like FAO (Food and Agriculture Organization) and WHO (World Health Organization) (WBCSD, 2010).

Water Footprint Network (WFN) is another non-profit organization, founded by Hoekstra in 2008 to coordinate stakeholders in the promotion of Water Footprint Assessment to address challenges of unsustainable water use (Hoekstra et al., 2009). The Water Footprint Network is involved in activities as follows (Wessman, 2011):

- Developing standards and tools to support decision makers and organizations in performing Water Footprint accounting;
- Promoting meetings, publications, education, research and development with regard to the Water Footprint concept;
- Promoting exchange, communication and dissemination of knowledge;
- Supporting government bodies, institutions, non-governmental organizations, companies in the implementation of Water Footprint and the development of a sustainable water policy.

Promoted by the UNEP/Society for Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative, the WULCA is an international working group founded in 2007 with the aim to focus on water use assessment and Water Footprint (Koehler and Aoustin, 2008). WULCA, connecting people from industries, academia and public institutions, is specifically involved in activities like the development of a general assessment framework for freshwater use accounting and reporting, modeling of the impacts generated by freshwater use according to the geographical context, harmonization of the LCA scheme towards freshwater use accounting and water impact assessment; application of the methods and indicators developed on industrial case studies; communication and dissemination within industry and the scientific community (WULCA, 2018).

At the European level, since the 2007 with the first European water conference, the EU has started promoting a consistent water policy to tackle important challenges facing water resources management, such as risk of floods, decrease in water availability and degradation of water quality (EC, 2007).

The main instrument in EU water protection is represented by the Water Framework Directive (EC, 2000) introduced in 2000 to ensure a water use sustainable for ecosystems and human health (EEA, 2016).

To address water related issues, the United Nations included water topic within the Millennium Development Goals (Ki-Moon, 2013). Aimed by the necessity to promote a responsible water resources management to protect the environment and to improve human health and well-being, water related targets have been introduced in many different MDGs.

Moreover, according to this vision, also several of the Sustainable Development Goals introduced by the United Nation in the post MDGs address water use and availability issues (United Nations, 2015). Particularly, SDG 6 is directly linked to water and aimed to ensure sustainable management of water and sanitation, while SDG 1, 3, 11, 12, and 15 are indirectly linked to water through many different sub-targets. (UN General Assembly, 2015).

1.2 Environmental management and ISO 14000 series

The emergence of a growing environmental awareness in public opinion, together with the need for decision-making tools to support the definition of policies more oriented to the sustainability principle, has certainly encouraged the development of methodologies aimed to manage environmental issues.

Among the existing family of standards provided by the International Organization for Standardization (ISO), the ISO 14000 is the one specifically related to environmental management aimed to support organizations in minimizing negative effects of their activities on the environment, complying at the same time laws, regulations and other environmentally oriented requirements (ISO, 2010).

The Technical Committee responsible for the coordination of the working groups for the development of ISO 14000 series standards is the ISO/TC 207, promoting the philosophy of improve management practices in order to increase the environmental performance of organizations. The ISO 14000 series standards addresses a wide range of environmental management challenges such as the reduction of raw material consumption, the reduction of energy consumption, the improvement of process efficiency, the reduction of waste generation.

Thus, standards published by ISO/TC 207 address many different areas, from the environmental management systems to the Life Cycle Assessment. Table 1.2 provides the updated available standards according to the ISO 14000 family.

Table 1.2 *The planetary boundaries (Adaptation from ISO, 2018).*

Thematic area	Published standard
Environmental management systems	ISO 14001:2015 - Environmental management systems - Requirements with guidance for use
	ISO 14004:2016 - Environmental management systems - General guidelines on implementation
	ISO 14005:2010 - Environmental management systems - Guidelines for the phased implementation of an environmental management system, including the use of environmental performance evaluation
	ISO 14006:2011 - Environmental management systems - Guidelines for incorporating ecodesign
Environmental auditing and related environmental investigations	ISO 14015:2001 - Environmental management – Environmental assessment of sites and organizations (EASO)
Environmental labelling	ISO 14020:2000 - Environmental labels and declarations - General principles
	ISO 14021:2016 - Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling)

Thematic area	Published standard
	ISO 14024:2018 - Environmental labels and declarations - Type I environmental labelling -- Principles and procedures ISO 14025:2006 - Environmental labels and declarations - Type III environmental declarations -- Principles and procedures ISO 14026:2017 - Environmental labels and declarations - Principles, requirements and guidelines for communication of footprint information
Environmental performance evaluation	ISO 14031:2013 - Environmental management - Environmental performance evaluation - Guidelines ISO/TS 14033:2012 - Environmental management - Quantitative environmental information - Guidelines and examples ISO 14034:2016 - Environmental management - Environmental technology verification (ETV) ISO 14063:2006 - Environmental management - Environmental communication - Guidelines and examples
Life Cycle Assessment	ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework ISO 14044:2006 - Environmental management - Life cycle assessment - Requirements and guidelines ISO 14044:2006 - Environmental management - Life cycle assessment - Requirements and guidelines ISO 14045:2012 - Environmental management - Eco-efficiency assessment of product systems - Principles, requirements and guidelines ISO 14046:2014 - Environmental management - Water footprint - Principles, requirements and guidelines ISO/TR 14047:2012 - Environmental management - Life cycle assessment - Illustrative examples on how to apply ISO 14044 to impact assessment situations ISO/TS 14048:2002 - Environmental management - Life cycle assessment - Data documentation format ISO/TR 14049:2012 - Environmental management - Life cycle assessment - Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis ISO/TS 14071:2014 - Environmental management - Life cycle assessment - Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006 ISO/TS 14072:2014 - Environmental management - Life cycle assessment - Requirements and guidelines for organizational life cycle assessment ISO/TR 14073:2017 - Environmental management - Water footprint - Illustrative examples on how to apply ISO 14046
Greenhouse gas management and related activities	ISO 14064-1:2006 - Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals ISO 14064-2:2006 - Greenhouse gases - Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements ISO 14064-3:2006 - Greenhouse gases - Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions

Thematic area	Published standard
	ISO 14065:2013 - Greenhouse gases - Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition
	ISO 14066:2011 - Greenhouse gases - Competence requirements for greenhouse gas validation teams and verification teams
	ISO 14067:2018 - Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification
	ISO/TR 14069:2013 - Greenhouse gases - Quantification and reporting of greenhouse gas emissions for organizations - Guidance for the application of ISO 14064-1
	ISO 14080:2018 - Greenhouse gas management and related activities - Framework and principles for methodologies on climate actions

Among all the developed standards listed in Table 1.2, only those relevant for the purpose of this research work will be described below, in particular for their correlation with the thematic area of Life Cycle Assessment (LCA), thus ISO 14040-44 for the methodology itself and ISO 14046 for the Water Footprint.

1.2.1 The Life Cycle Assessment methodology

The Life Cycle Assessment (LCA) methodology was born in the 60's aimed at first to support industries in performing energy valuations, evolving then in a more complex tool useful to investigate potential consequences of companies' activities according to a range of environmental metrics in order to support policy makers and standards bodies addressing challenging decisions (Guinée et al., 2011). A first example of LCA application comes from The Coca-Cola Company that in the early 70s' performed an internal study to make a comparison of different beverage containers in order to establish which was the one characterized by the lowest releases into the environment.
In general, in the early years of its diffusion the LCA methodology was applied to assess solid waste issues of manufacturing and use systems, particularly for packaging products. However, after few years, in the late 80s' the primary interest moved to the areas of resource use and environmental emissions (Hunt and Franklin, 1996).
A wide range of researchers and expertise from all the World has been then promoter of an increasing refinement of the methodology, pushed by the necessity to go further in the life cycle impact assessment stage (SETAC, 1997).

In the next years, the need for a uniform method to be used by practitioners to perform environmental assessments, led to the standardization of the LCA methodology resulting in the final to date adopted ISO 14040 series.

The Life Cycle Assessment (LCA) methodology is to date a widely adopted environmental management tool universally recognized by the scientific community, adopted to perform evaluation on potential environmental impacts of a product/process/organization along all the life cycle stages from the origins (raw materials) until the end (final disposal as waste) (ISO 14072, 2014).

Principles and requirements for performing an LCA study refer to the ISO 14000 family related to the environmental management, particularly two:

- ISO 14040:2006 - Environmental Management - Life Cycle Assessment, Principles and Framework: providing a description of LCA methodology and framework to adopt.
- ISO 14044:2006 - Environmental management – Life Cycle Assessment – Requirements and Guidelines: containing all the technical requirements and indications for the implementation of the methodology.

According to the ISO standards, the LCA methodology follows a framework made of mainly four steps: (i) goal and scope definition; (ii) inventory analysis; (iii) impact assessment; (iv) interpretation (Figure 1.8).

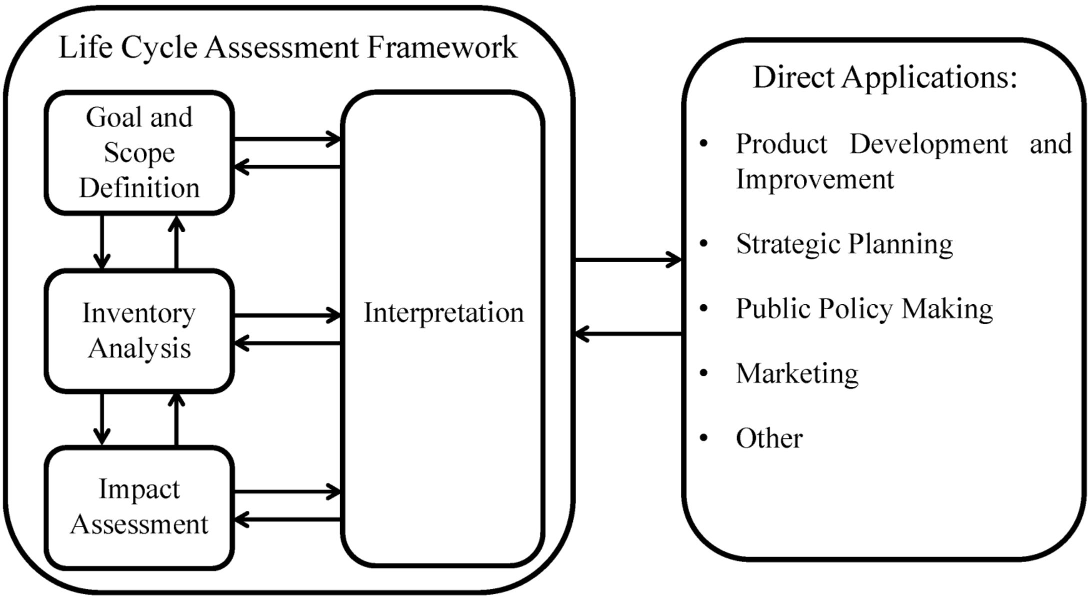

Figure 1.8 *The LCA framework (ISO 14040, 2006).*

According to Figure 1.8 it is possible to see the interdependency (double arrows) of the different steps, highlighting that the LCA methodology is characterized by an iterative process in which subsequent revision of the analysis may increase the accuracy of final results (Sonnemann et al, 2004). In the next following paragraphs, a brief description of each LCA phase will be reported.

1.2.1.1 Goal and scope definition

In the first stage of LCA the aim of the study is provided, describing also the investigated system and the different impact categories subjected to the analysis. The importance of this phase comes from the very narrow dependence of final results by goal and scope enunciated. Considering the goal definition, it has to describe the kind of study application, the reasons why the study is conducted, the final user (ISO 14040, 2006). Concerning the scope, it has to define some different key elements as follows:

- Functional unit: it provides the quantification of the identified functions of the product/system., representing the reference to which inputs and outputs of the investigated system are related.
- System boundaries: they illustrate the involved operations contributing to the life cycle of the product/process/service under study, showing all the key elements of the physical system.
- Data quality requirements: they refer to the characteristics of the data needed for the study, considering environmental, geographical and technological factor.

1.2.1.2 Life cycle inventory analysis

This is the stage where, according to the ISO definition, inputs and outputs of the considered product system are collected and quantified (ISO 14040, 2006).
The inventory analysis is the life cycle phase requiring a high amount of time since all the environmental inputs (e.g. energy, water, raw materials) and outputs (e.g. emissions to soil, water, air) need to be accounted accurately. Primary data (e.g. from on-site surveys), secondary data (e.g. from literature, manuals, etc.) and tertiary data (e.g. statistics and estimations) need to be collected and organize in the best way in order to be processed in the next LCA step. The inventory analysis is an iterative based approach performed according to the pathway represented in Figure 1.9.

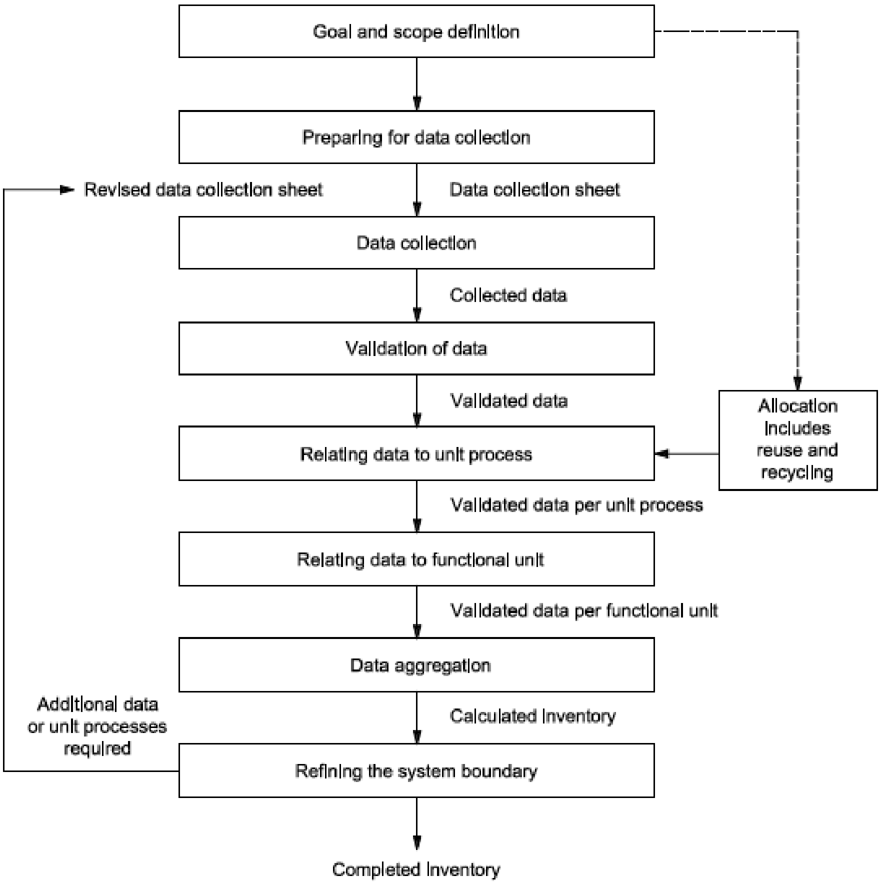

Figure 1.9 *Simplified procedure for inventory analysis (ISO 14044, 2006).*

In this stage a flow chart of the system is elaborated to represent graphically the main fluxes and processes involved in the system under study. Moreover, allocation procedure can be adopted in order to allocate inputs and outputs to the different products according to approved procedures that shall be documented and explained.

1.2.1.3 Life cycle impact assessment

Differing from other assessment methods like environmental performance evaluation and risk assessment, the life cycle impact assessment, according to the ISO principles, is the phase of the LCA where the LCI results are elaborated and converted into potential environmental impacts (ISO, 2006). Effects on human health and environment are assessed, within the framework of the goal and scope of the study. In the LCIA phase the inventory results are converted into different impact categories representing the environmental issues of concern (e.g. climate change, ozone depletion, acidification, biodiversity, etc.). Since impact analysis is influenced by the hypothesis made during the study, it is important to perform sensitivity analysis in order to check the consistency of the assumptions observing the effects on final results.

The LCIA consists of mandatory and optional elements (Figure 1.10). According to the mandatory elements, they consist in (ISO 14044, 2006):

- selection of impact categories, category indicators and characterization models;
- assignment of LCI results to the selected impact categories (classification);
- calculation of category indicator results (characterization).

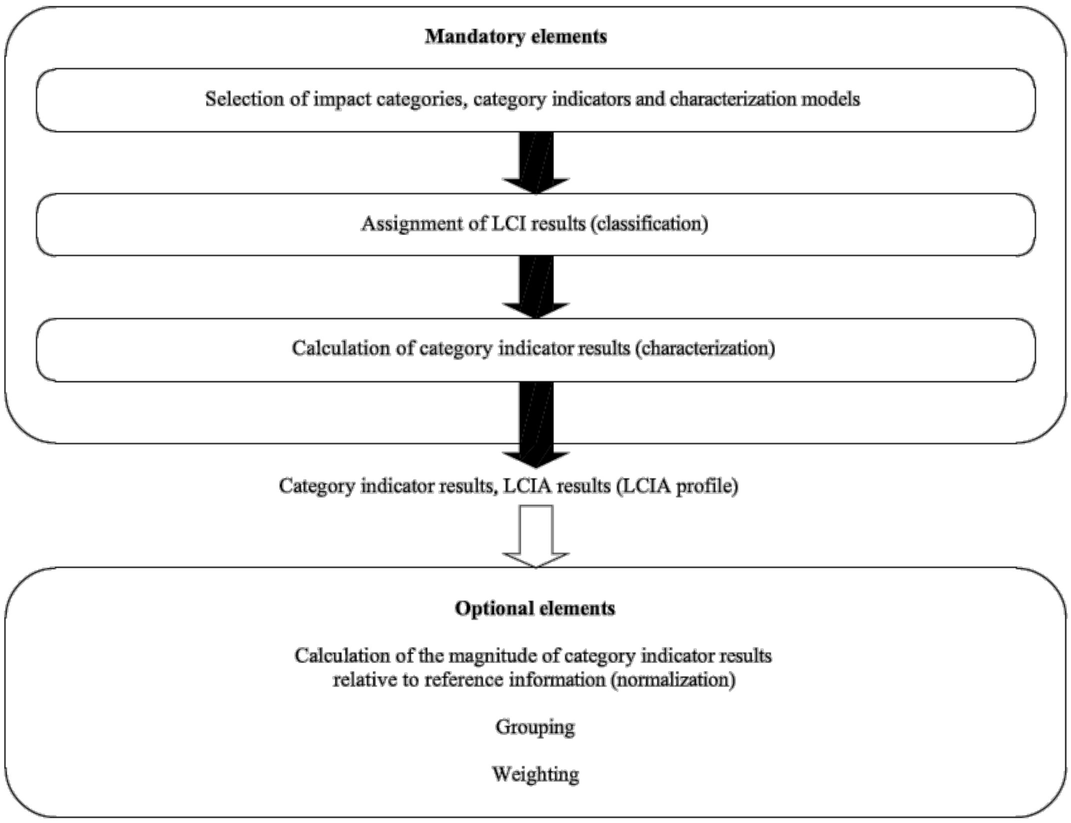

Figure 1.10 *Elements of the LCIA (ISO 14040, 2006).*

In the classification, each data collected in the LCI is classified according to the related potential environmental impact. This has to be made through the characterization process, where characterization factors are used to convert data from LCI into final numerical indicators (see Figure 1.11 for an example of characterization process).

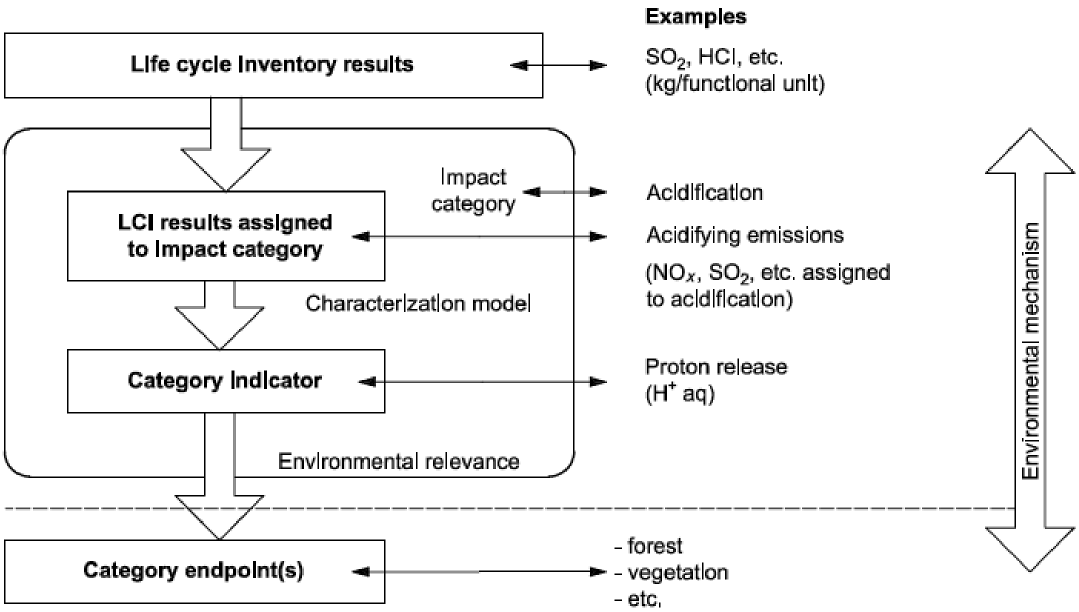

Figure 1.11 *Concept of category indicator according to the environmental mechanism (ISO 14044, 2006).*

The characterization phase, which is adopted to derive the characterization factors, reflects the environmental mechanism by describing the relationship between the LCI results, category indicators and, in some cases, category endpoint(s). The environmental mechanism, which is specific for each different impact category, is the total of environmental processes linked to the characterization of the impacts (ISO 14044, 2006). In order to simplify characterization modelling of LCI results, as well as to highlight the scientific and technical validity and accuracy of the characterization model of each impact category, some elements need to be defined: (i) identification of the category endpoint(s); (ii) definition of the category indicator for a specific category endpoint(s); (iii) identification of appropriate LCI results that can be assigned to the impact category; (iv) identification of the characterization model and the characterization factors. The category indicators can be chosen anywhere along the environmental mechanism between the LCI results and the category endpoint(s) (Figure 1.10) (ISO 14044, 2006).

As described above, characterization factors thus have to be based on environmental mechanisms, resulting in different set of midpoint impact categories and endpoint damage category (Figure 1.11).

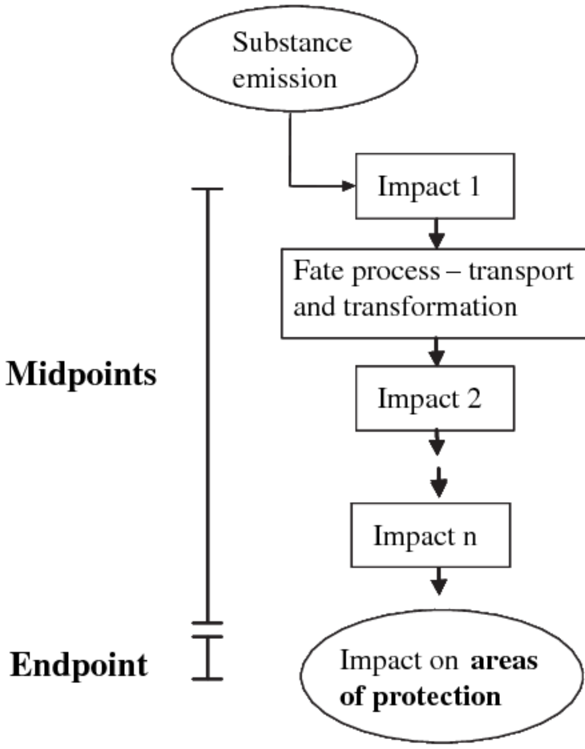

Figure 1.12 *Schematic representation of the environmental mechanism (or cause-effect chain) in a LCIA (Finnveden et al., 2009).*

Midpoint indicator concerns impacts placed somewhere in the cause-effect chain between the emission and the endpoint indicators. Different specific characterization factors can be calculated to express the relative importance of an emission/resource in a Life Cycle Inventory (Bare et al., 2000). Examples of commonly used midpoint impact categories are given by global warming, acidification, eutrophication, aquatic ecotoxicity, ozone depletion, etc. These and many others refer to specific impact assessment methods developed by authors and organizations within the life cycle community, resulting in many different proposals: Eco-indicator 98 (Goedkoop, 1998), EDIP (Wenzel et al., 1997), CML 2002 (Guinée et al., 2002), IMPACT 2002+ (Jolliet et al., 2003), Swiss Ecoscarcity 2006 (Frischknecht et al., 2009), ILCD (EC-JRC, 2011), ReCiPe 2008 (Goedkoop, 2012).

Considering the endpoint indicators, they concern elements of the environmental mechanism that are in themselves of value for the society (Udo de Haes and Lindeijer, 2001). Characterization modelling at the endpoint level, sometimes also named damage modelling, follows a framework from elementary flows to final areas of protection (AoP) (Figure 1.13) that are defined as classes of category endpoints (Udo de Haes et al., 1999). Usually the three main categories mentioned are: human health, natural environment and natural resources.

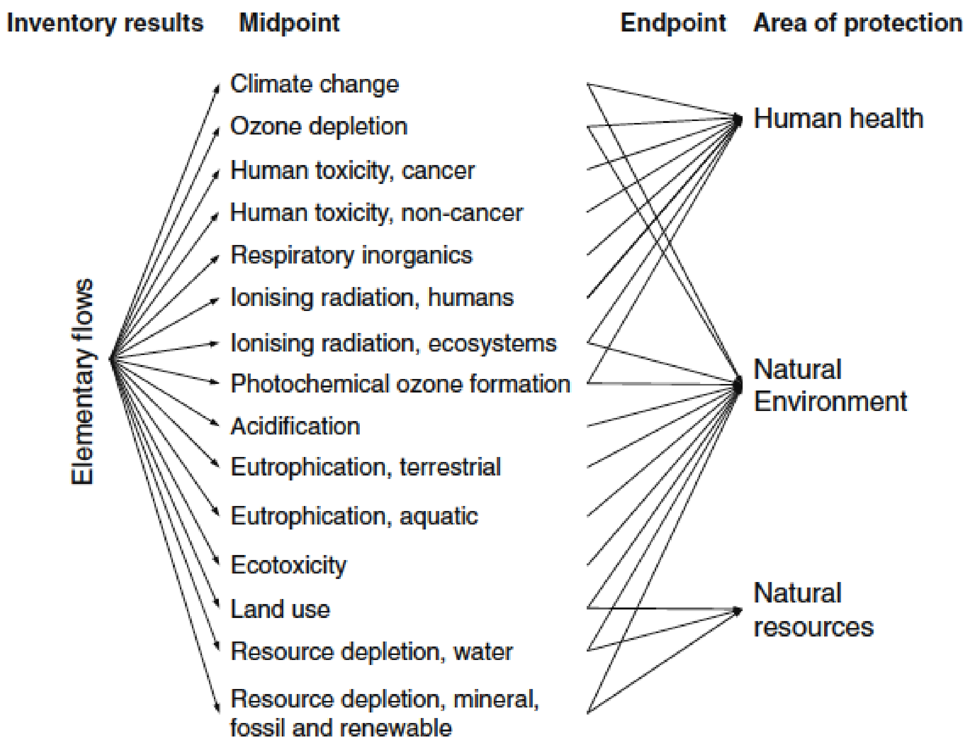

Figure 1.13 *Framework illustrating the relation to the areas of protection (Hauschild et al., 2013).*

According to the areas of protection, some different methods were proposed by the LCA community to perform and endpoint impacts assessment: EPS 2000 (Steen, 1999a), EI99 (Goedkoop and Spriensma, 2000), IMPACT2002+ (Jolliet et al., 2003), LIME2 (Itsubo and Inaba, 2012a), ReCiPe 2008 (Goedkoop, 2012).

According to the LCIA, once the environmental impact profile of the product/process investigated has been defined, some additional optional steps can be considered in the LCA study, in particular (ISO 14044, 2006):

- Normalization: it is the stage where potential impacts are divided by a reference value to calculate the magnitude of each environmental impact. This optional stage is aimed to provide a better understanding of the relative magnitude for each indicator result of the product system investigated.
- Grouping: it refers to sorting and ranking of the indicators.
- Weighting: it is aimed to obtain a single index of environmental performance by converting and aggregating indicator results across impact categories.

1.2.1.4 Life cycle interpretation

This is the last phase of LCA where evaluation of results from the previous LCI and LCIA are provided. Significant environmental issues are identified, providing conclusions and recommendations according to the fixed goal and scope of the study. Outcomes from this stage are used to identify strategies for impacts reduction and for the improvement of the environmental performance of the system investigated. Life cycle interpretation is a systematic process to identify quantitative and qualitative solutions for the environmental performance's improvement.
Conclusion, recommendations and revisions have to be performed together with uncertainty and sensitivity analysis included in a final technical report.

1.2.2 The Water Footprint assessment

Introduced at first under the terminology of virtual water, which refers to the sum of the water used in the different steps of the supply chain (Allan, 1998), the Water Footprint concept was defined in 2002 by Hoekstra to identify a volumetric approach to account for both direct and indirect use of freshwater in a certain system investigated (Hoekstra et al., 2003). The same author, after an improvement of the concept, proposed a manual containing a methodological framework for the Water Footprint assessment, according to the proposed multidimensional indicator of freshwater use including quantity and quality information linked to water (Hoekstra et al., 2011). The method, which is the first water related method totally oriented to a life cycle perspective (Boulay et al., 2013), requires first the goal and scope definition to fix the aim and the subject of the study, and then the Water Footprint accounting, referring to the assessment of 3 water components whose sum gives the final Water Footprint accounting result. The 3 components are defined as follows (Hoekstra et al., 2011):

- Blue Water Footprint: it refers to the consumption of surface and groundwater resources and the consequently loss of water availability for these resources in the catchment area.
- Green Water Footprint: it refers to the consumption of water resource in terms of evapotranspiration of rainwater.
- Grey Water Footprint: it refers to the volume of freshwater required to dilute the polluted water used until it reaches the water quality standards.

Considering the LCA tool it emerges that, probably because it was born to address environmental issues related to industrial sector often less dependent on water resource availability than the agricultural one, the methodology in the past didn't consider in a consistent way water related impacts.

This resulted in a very poor assessment of water impacts within the LCA framework, with existing methods focused mainly on water quality degradation impacts, such as eutrophication (Bennet et al., 2001), acidification (Jolliet et al., 2003) and eco-toxicity (Rosenbaum et al., 2008).

As a consequence, according to the necessity recognized by the scientific community for the improvement of the environmental assessment performed within the LCA in order to address in a better way water related impacts (Bayart et al., 2010), combined with the increasing attention given by the companies in the last years to the critical issue of water management along the whole supply-chain, led to the diffusion of many different methods related to freshwater use that can be categorized according to type of water use and level of assessment (Bayart et al. 2010; Kounina et al, 2013; Pfister et.al, 2014; Quinteiro et al., 2017).

To provide a standardized framework in which all these proposed methods may be applied, the International Organization for Standardization (ISO) in 2014 published the ISO 14046 standard, in order to provide a standardize scheme containing principles, requirements and guidelines related to Water Footprint assessment of products, processes and organizations based on Life Cycle Assessment (ISO 14046, 2014).

According to the definition introduced by the standard, the Water Footprint is a "metric(s) that quantifies the potential environmental impacts related to water", focusing thus not only on a mere quantification of the volume of water used, but rather on the potential impacts generated (Pfister et al., 2017). The international standard establish that a Water Footprint assessment has to consider the four typical phases of Life Cycle Assessment (Figure 1.14):

a) Goal and scope definition;
b) Water Footprint inventory analysis;
c) Water Footprint impact assessment;
d) Interpretation of the results.

Moreover, when performing a Water Footprint inventory study, it has to include the previously listed phases except that for the Water Footprint impact assessment. In this case is not possible to refer to results as Water Footprint (ISO 14046, 2014).

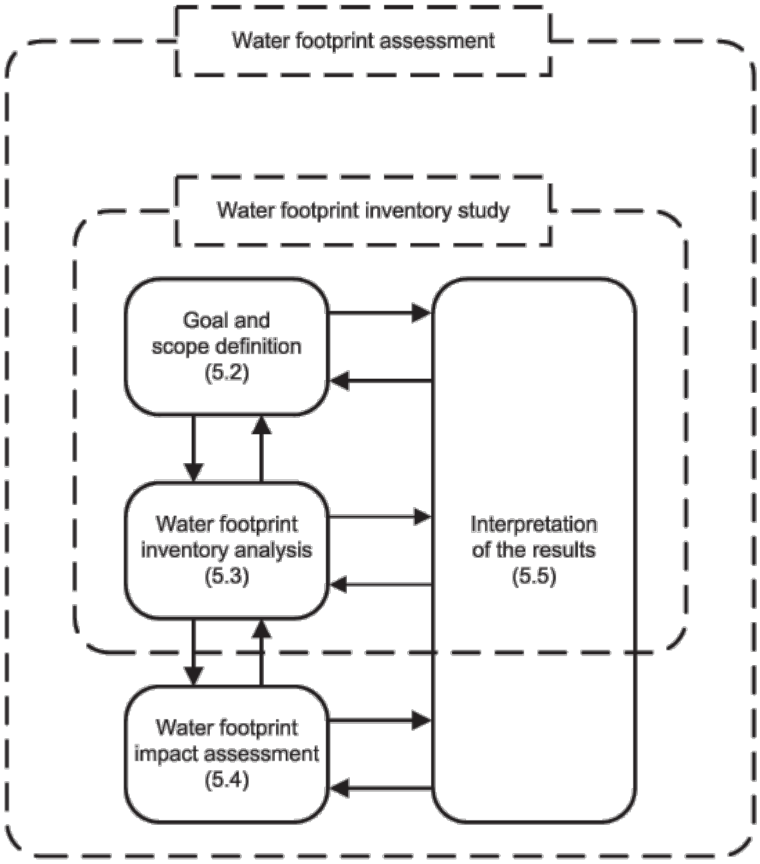

Figure 1.14 *The Water Footprint study framework (ISO 14046, 2014).*

According to the type of water use, in the last 20 years several methods (Table 1.3) have been developed to perform quantitative and qualitative assessment of water resources vulnerability (Brown and Matlock, 2011). Two main groups of methods can be identified to date in the literature: one to address water impacts related to its quantity (or availability) and one to address water impacts related to its quality (WWAP, 2009).

Table 1.3 *Main characteristics of to date available midpoint/endpoint Water Footprint methods (Adaptation from Quinteiro et al., 2017).*

Approach	Midpoint	Endpoint	Accounting/ impact assessment	Characterization model
WFA	Hoekstra et al. (2011)	n.a.	Water Footprint (WF) accounting Chapagain and Tickner (2012) (units – m^3 eq.)	WFSA: - green water scarcity indicator (dimensionless) - blue water scarcity indicator (Hoekstra et al. 2012) (dimensionless)

Approach	Midpoint	Endpoint	Accounting/ impact assessment	Characterization model
			WF Sustainability Assessment (WFSA) (environmental, social and economic criteria), (units – m^3 eq.)	- water pollution level (WPL) (Liu et al. 2012) (dimensionless)
LCA	Maes et al. (2009)	n.a.	Land use impacts on terrestrial green water flow (TWI) (units – m^3 eq.) Land use impact on aquatic blue water flow (AWI) (units – m^3 eq.)	Regional and CFs for TWI and AWI
LCA	Núñez et al. (2012)	n.a.	Blue water deprivation (units – m^3 eq.) Green water deprivation (units – m^3 eq.)	Blue water deprivation: water scarcity index (WSI) from Pfister et al. (2009) Green water deprivation: - Green water scarcity index (Hoekstra et al. 2011) - net green water flow assessed taking into account the WSI for blue water from Pfister et al. (2009)
LCA	Quinteiro et al. (2015)	n.a.	Impacts on terrestrial green water (TGWI) (units – m^3 eq.) Reductions in surface blue water production (RBWP) caused by reductions in surface runoff (units – m^3 eq.)	Regional and species-specific CFs for TGWI and RBWP
LCA	Milà i Canals et al. (2009)	n.a.	Freshwater ecosystem impact (FEI) (units – m^3 eq.) Freshwater depletion impact (FD) (units – kg Sb-eq.kg-1)	CFs not provided for green water flow impacts CF for FEI (surface water): - Water scarcity indicator at river basin level (Smakhtin et al. 2004) - Total renewable water resources per capita (WRPC) at country level (Falkenmark, 1986) - Water use per resource (WUPR) at country level (Raskin et al. 1997) CF for FEI (land-use effects): percentages for rainfall “lost” derived from Zhang et al. (1999) CF for FD: abiotic depletion potential of aquifer (Guinée and Heijungs 1995; Guinée et al. 2002)

Approach	Midpoint	Endpoint	Accounting/ impact assessment	Characterization model
LCA	Ridoutt and Pfister (2010a) Ridoutt and Pfister (2010b)	n.a.	Stress-weighted WF (units – m^3 eq.)	For all interventions, WSI developed by Pfister et al. (2009) at 0.5º grid cell, watershed and country level
LCA	Frischknecht and Knöpfel (2013)	n.a.	Scarcity-weighted consumptive use (units – eco-points)	CFs (eco-factors) are calculated based on actual emission flow and political targets, and available at basin and country level
LCA	Loubet et al. (2013)	n.a.	Water deprivation integrating downstream cascade effects (units – m^3 eq.)	CFs based on freshwater scarcity at sub-river basin considering weighting parameters for downstream sub-river basin: area (U.S.G.S. 2012); river volume (Hanafiah et al., 2011); and number of inhabitants (CIESIN/CIAT 2005)
LCA	Berger et al. (2014)	n.a.	Risk to freshwater depletion (RFD) (units – m^3 eq.)	CFs for RFD are based on consumption-to-availability ratios, considering surface water stocks and aquifers, at basin scale
LCA	Boulay et al. (2016)	n.a.	AWARE – water scarcity (units – m^3 eq.)	AWARE is based on the quantification of the relative available water remaining per area once the demand of humans and aquatic ecosystems has been met AWARE is calculated at the sub-watershed level and monthly time-step Indicators are available for agricultural, non-agricultural and unknown use
LCA	Yano et al. (2015)	n.a.	Water unavailability factor – water scarcity (units – m^3 eq.)	The model assumes that the potential impact of a unit of water used is proportional to the land area or time required to obtain a unit of water from each water source: precipitation, surface water and groundwater CFs based on a global hydrological model (H08) (Hanasaki et al. 2008) at 0.5º grid cell
Stand-alone LCA-based indicator: Bayart et al. (2014)	n.a.	n.a.	Water impact index (units – m^3 eq.)	WSI from Pfister et al. (2009) Quality indexes of intake and released freshwater are considered Compensation mechanisms not considered

Approach	Midpoint	Endpoint	Accounting/ impact assessment	Characterization model
Stand-alone LCA-based indicator: Ridoutt and Pfister (2013)	n.a.	n.a.	Consumptive freshwater (CWU) and freshwater degradation (DWU) expressed as a single stand-alone WF result (units – m^3 eq.)	CWU uses WSI from Pfister et al. (2009) weighted by the global average WSI of 0.602 (Page et al. 2011) DWU based on ReCiPe method (Goedkoop and Huijbregts 2013) with some adjustments (Pfister et al. 2011) Midpoint: WSI based on withdrawal-to availability ratios, developed at 0.5º grid cell, watershed and country level
LCA	Pfister et al. (2009)		Midpoint: water deprivation (units – m^3 eq.) Endpoint: damages to human health, ecosystem and resources (units – DALY, PDF.m^2.yr^{-1}, MJ, respectively)	Endpoint: characterization factors (CFs) developed at 0.5º grid cell, watershed and country level CFs for human health evaluate to agriculture freshwater use (not domestic freshwater and fisheries), considering scarcity and economic development levels. CFs for ecosystem consider freshwater scarcity and freshwater ecological value (through net primary production) CFs for resources evaluate freshwater use portion that contributes to depletion
LCA	Boulay et al. (2011a,b)		Midpoint: water stress (units – m^3 eq.) Endpoint: impacts on human health caused by malnutrition and disease from water deprivation (units – DALY)	Midpoint: water stress indicator, at watershed and country level Endpoint: - CFs take into account the level of competition among users, addressing quality and seasonal variations of freshwater availability - CFs at watershed and country level
LCA	Motoshita et al. (2014)	Motoshita et al. (2010), Motoshita et al. (2014)	Midpoint: agricultural production – crop production loss by irrigation (units – m^3 eq.) Endpoint: impacts on human health caused by undernourishment related to agricultural water scarcity (units – DALY)	Midpoint: CFs consider irrigated crop production vulnerability, physical vulnerability of freshwater resources and social compensation capacity Endpoint: CFs consider relationships between the supply shortage of a commodity, the human development index, and changes in the undernourished population rate caused by changes in average daily dietary supply CFs at country level

Approach	Midpoint	Endpoint	Accounting/ impact assessment	Characterization model
LCA	n.a.	Motoshita et al. (2010)	Damage to human health caused by infectious diseases from domestic freshwater use (units – DALY)	CFs developed based on non-linear multiple regression analysis (modelling relationships between freshwater scarcity, accessibility to safe water and damage to health caused by infectious diseases) CFs at country level
LCA	n.a.	Hanafiah et al. (2011)	Damage to fish species richness from freshwater consumption (units – $PDF.m^3.yr^{-1}$)	CFs derived based on generic species-river discharge curve for 214 global river basins (Xenopoulos et al. 2005). They express the change in potentially disappeared faction of freshwater (PDF) fish species due to a change in river mouth discharge
LCA	n.a.	Van Zelm et al. (2011)	Impacts on the species richness of terrestrial vegetation caused by groundwater extraction (units – $PNOF.m^2.yr^{-1}$)	CFs for groundwater (only available for Netherlands): - express the change in potentially not occurring fraction of plant species (PNOF) due to a change in extraction of groundwater - Changes in groundwater levels were addressed by MODFLOW model (Facchi et al. 2004; Gedeon et al. 2007; McDonald and Harbaugh 1984) - the occurrence of plant species was predicted by the statistical MOVE model (Bakkenes et al. 2002)
LCA	n.a.	Verones et al. (2010)	Damage to ecosystem: thermal pollution in freshwater aquatic biota (units – $PDF.m^3.day$)	CFs (available for nuclear power plant in Switzerland): - express the impact of cooling water discharges on aquatic ecosystems express the change in potentially disappeared faction (PDF) of aquatic species due to a change in river temperature - to estimate the river temperature profiles, the Qual2Kw model (Pelletier et al. 2006) was used - to address the direct temperature-induces mortality in species, a species sensitivity distribution following a normal temperature-response function was established

Approach	Midpoint	Endpoint	Accounting/ impact assessment	Characterization model
LCA	n.a.	Pfister and Suh. (2015)	Damage to ecosystem: thermal pollution in freshwater aquatic biota (units – PDF.m^3.yr)	CFs developed at 0.5º grid cell: - express the change in potentially disappeared fraction (PDF) of aquatic species due to a change in river - local fate factors were a function of the water runoff, while long-range fate factors are a function of residence time of heat emissions - the effect model of increased river temperature on the ecosystem was assessed based on a temperature tolerance interval of aquatic species from Verones et al. (2010)

According to Table 1.3, it is possible to distinguish two main approaches to date available in the life cycle community to perform a Water Footprint assessment (Quinteiro et al., 2017):

I. The Water Footprint Network approach (Hoekstra et al. 2011) to account for direct and indirect water use along the whole supply chains;
II. The impact-based approach to perform LCA based evaluation, according to the specific Water Footprint standard (ISO 14046, 2014).

Considering the life cycle impact assessment phase (§ 1.2.1.3), also the impact-based approach of Water Footprint adopts the same approach through the cause-effect chain (or environmental mechanism) to perform specifically freshwater use impacts assessment, adopting characterization factors (CFs) along the cause-effect chain to perform evaluation at midpoint or endpoint level (Kounina et al. 2013; Núnez et al., 2016; Quinteiro et al., 2017).
At the midpoint level, impacts of freshwater use are translated through specific characterization factors into final impacts (e.g. freshwater acidification, freshwater eutrophication, etc.) according to the different relevance of freshwater consumption and degradation (Bare et al. 2000; Goedkoop et al. 2013). Analysis at the endpoint level, starting from the previously assessed environmental impacts (midpoint level), allows to evaluate the damage according to the different areas of protection, thus human health, ecosystem quality or resources (Goedkoop et al. 2013). A schematic representation of the cause-effect chain of freshwater use and existing methods for the Water Footprint assessment is provided in Figure 1.15.

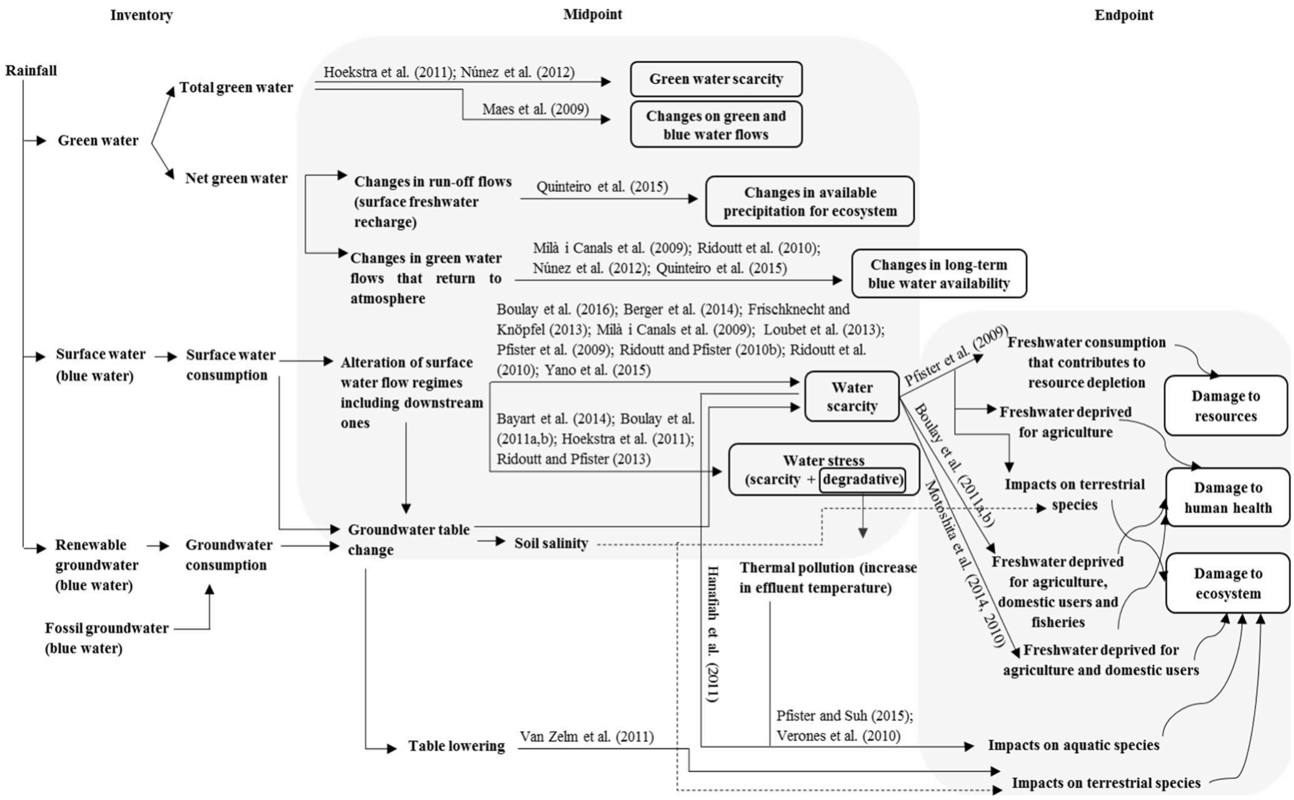

Figure 1.15 *The cause-effect chain of freshwater use and related Water Footprint methods (Quinteiro et al., 2017).*

1.3 The value of water

Since Ancient Greece the value of water has been a high debated issue. As stated by Plato about 2400 years ago "Only what is rare is valuable, and water, which is the best of all things…is also the cheapest." (Hanemann, 2005).

Many centuries later, in 1776 the economist Adam Smith promoted the water-diamond paradox, by stating that: "Nothing is more useful than water: but it will purchase scarcely anything; scarcely anything can be had in exchange for it. A diamond, on the contrary, has scarcely any use-value; but a very great quantity of other goods may frequently be had in exchange for it." (Hanemann, 2005).

Compared to the time in which such statements were made, characterized by high water richness, to date the planet is facing water scarcity problems mainly due to the increase of water demand over the decades, with and exacerbation of the fact that water will be more and more a strategic resource for every kind of purpose (UNEPb, 2012; World Economic Forum, 2018).

Water represents the main resource input for companies with many different uses according to the productive context, with agriculture sector as the most impactful in terms of consumptions with about

70% of the global water withdrawal, followed by industry with 20% and municipal sector with the remaining 10% (Morrison et al., 2009; FAO, 2017).

The high dependence of companies on water results in a high potential exposure to water risks, mainly linked to physical, regulatory, and reputational aspects (Morrison et al., 2009).

Furthermore, considering the spatial variability of water uses, water related risks can be referred to the river basin level (e.g. risk strictly connected to the state of the) and to the specific company performances level (Figure 1.16).

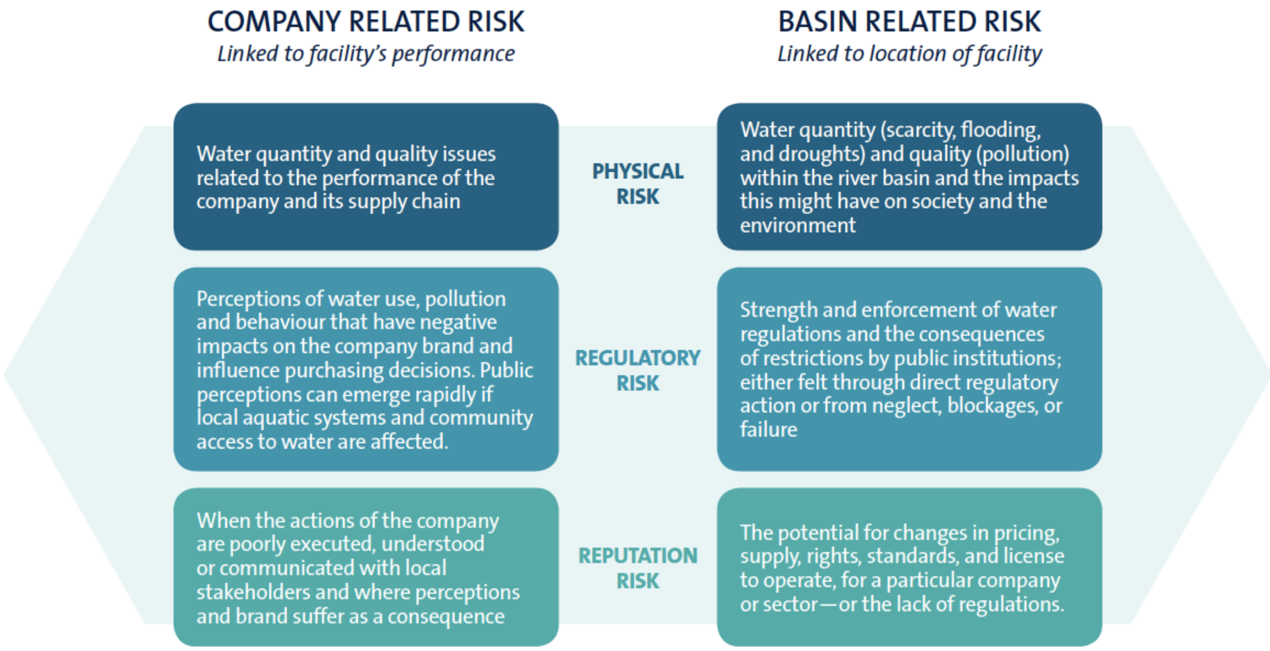

Figure 1.16 *Different types of companies' water related risks (Morgan et al., 2015).*

Addressing at the same time all the different dimension is highly recommended in order to perform a proper water risk management. However, companies often fail in doing that, focusing mainly on the evaluation of basin related risks, particularly the physical ones (e.g. water scarcity) that are easier to manage (Morgan and Orr, 2015).

A proper management of water risk can be reached by companies for sure tracking and monitoring their environmental impacts, in this case specifically those related to water consumption, resulting in the possibility to have some advantages according to different key aspects (Kaval, 2015):

1. *Reduce costs*: promotion of investments for environmental improvements, through efficiency and innovation in products and processes, may lead to cost savings as well as to the possibility to access to cheaper capital because of the better perception of the markets of a less risk.

2. *Respond to investor demands*: a better understand and management of environmental impacts may result in a better attraction of investors with more strategic opportunities.
3. *Facilitate regulatory approvals and mitigate operational risk:* avoiding negative environmental impacts companies may better access to project financing and regulatory approvals.
4. *Hire the best employees*: communication of consistent information about environmental performance of the company may be useful to attract employers.
5. *Meet customer demand for "green"*: since consumers in the last years are more oriented to pay for more responsibly produced goods.

To do that companies of all dimensions are asked to switch their way to elaborate plans and strategies into a more sustainable one, including water management within their policies (Koh et al., 2012; Nielsen, 2017).

To pursue the water sustainability, companies need to identify operative targets and strategic actions in a consistent manner. This is possible with the support of environmental management tools developed in the last decades by the scientific community, such as the Life Cycle Assessment (§ 1.2.1) and the Water Footprint (§ 1.2.2) that allow to perform environmental impact assessment.

However, when considering the economic dimensions, even if recently the importance of integration of environmental externalities into policy assessment and decision-making process has become more and more popular (Nguyen et al., 2016), the existing LCA methods almost fail in providing consistent economic information about environmental impacts (Pizzol et al., 2015). In the next paragraph the monetary valuation practice of environmental aspects is described, particularly focusing on the LCA context.

1.4 Environmental monetary valuation

Even if valuation of environmental impacts according to the monetization approach can be controversial, its diffusion in recent years is raising supported by the fact that this practice enables a better comprehension and comparison between direct economic costs and environmental costs (Nguyen et al., 2016; Morel et al., 2018).

In recent years the scientific community thus started investigating the possibility to perform assessment of environmental impacts and aspects into monetary terms, in order to make results from environmental assessments more comprehensible by stakeholder (Risz et al., 2012; Bruel et al., 2016; Nguyen et al., 2016).

The importance of the adoption of the monetization approach is highlighted by the current development of an ISO document aimed to provide a framework including principles, requirements and guidance for monetary valuation of environmental impacts and related environmental aspects (ISO/DIS 14008, under development).

Monetization of environmental impacts is one of the practices which can support organizations and policy makers in the development of sustainable strategies (Le Pochat, 2013). The existing approaches to perform monetary assessment of environmental aspects can be substantially grouped in three main classes (Le Pochat, 2013):

- *Economic valuation of biodiversity and ecosystem services*, which is based on the work of the Millennium Ecosystem Assessment (2005) and substantially addressed by TEEB (2010).
- *Monetization of environmental impacts*, which refers to LCA based methods for the assessment of environmental impacts.
- *Environmental accounting*, which is aimed to integrate the natural capital in the balance sheet of the companies (Natural Capital Coalition, 2014).

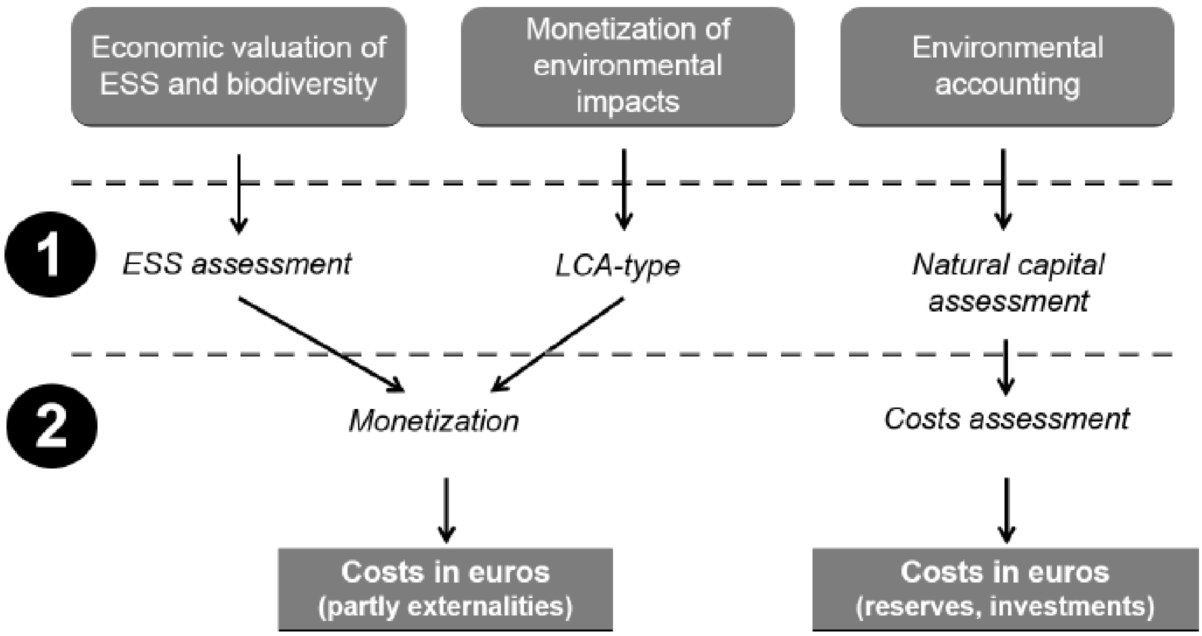

Figure 1.17 *Approach for the different classes of economic valuation of environmental aspects (Le Pochat, 2013).*

According to Figure 1.17, while a two-steps approach is commonly adopted to perform the monetary valuation whatever the class of economic valuation, only the techniques to assess the environmental impacts and the monetization factors are different. The two-steps generic approach can be defined according to: (i) a first stage where environmental assessment or valuation of the system investigated is performed, and (ii) a second stage where the environmental impacts are monetized (Le Pochat, 2013).

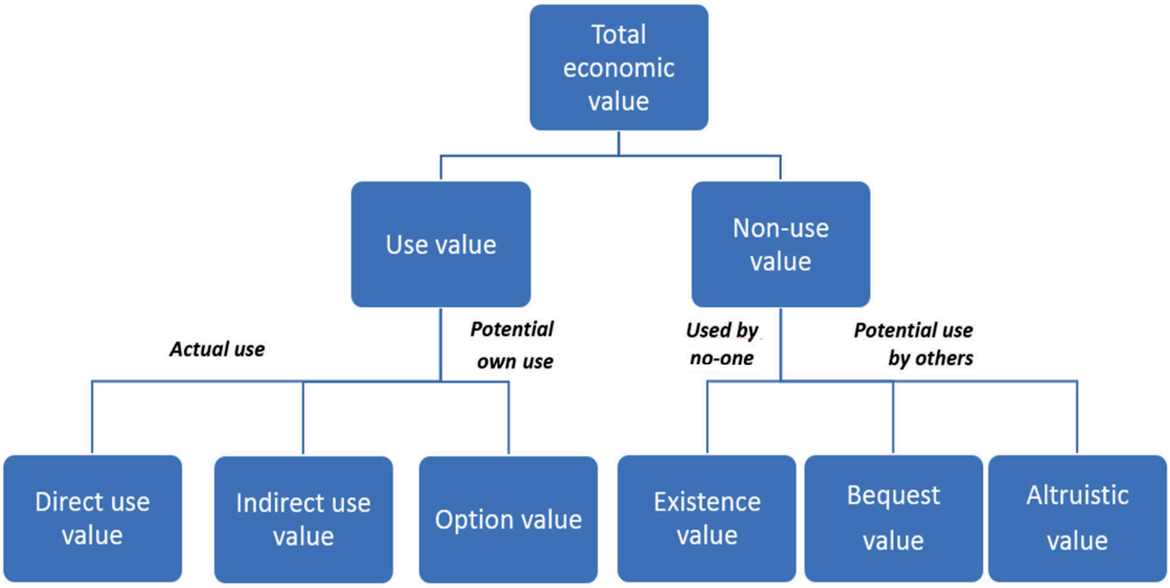

Figure 1.18 *Elements of the Total Economic Value (ISO/DIS 14008, under development).*

According to Figure 1.18, in monetary valuation the Total Economic Value (TEV) of a generic good is given by the sum of its use value, which refers to actual/potential consumptive/non-consumptive use, and non-use value, which refers to the value that a good may have regardless of its actual/future use (Turner et al., 1994). The first includes (ISO/DIS 14008, under development):

- Direct use value, which usually comes from the use of goods that typically has a market price.
- Indirect use value, which refers to benefits that humans derive from ecosystem services or health without direct intervention (e.g. the flood risk protection of a forest).
- Option use value, referring to values attached to potential future uses of a good even if not used at the present.

The second includes (ISO/DIS 14008, under development):

- Existence value, which is the value placed by individuals on knowing that a good will continue to exist, even if it will not be used (e.g. cultural and aesthetic aspects).

- Bequest value, which refers to the value placed by individuals on knowing that a good will continue to exist so that individuals yet to be born will be able to enjoy it in the future.
- Altruistic value, which is the value placed by individuals on knowing that a good exists, so that others alive today can enjoy it.

Monetary valuation can be performed according to many existing monetary valuation methods, according to the different capacity of each of them to evaluate environmental impacts and elements of the Total Economic Value, resulting in the possibility to be applied to different contexts and objectives (ISO/DIS 14008, under development).
Table 1.4 reports the different adopted monetary valuation methods, according to their classification and definition.

Table 1.4 *Classification and definitions of monetary valuation approaches and methods (Pizzol et al., 2015).*

Approach	Principle	Method	Definition
Observed Preferences	Determining willingness to pay in an existing market for a good	Market price	A monetary valuation method where the marginal value of a good is identified on the basis of its market price.
			A monetary valuation method where the marginal value of a non-market good is identified on the basis of the market price of a surrogate good, i.e. a market good whose price is indirectly affected by changes in availability of the non-market good
Revealed preferences	Determining willingness to pay in surrogate markets	Adverting behavior	A revealed preference valuation method where the marginal value of a non-market good is identified on the basis of the expenses actually made for market goods that are required to prevent or offset the change in availability of the non-market good
		Travel cost	A revealed preference valuation method where the marginal value of a site is identified on the basis of the expenses made by individuals to travel and visiting the site
		Hedonic pricing	A revealed preference valuation method where the availability of a non-market good is one of the multiple attributes reflected in the total price of a market good.
			A monetary valuation method where the marginal value of a non-market good is identified on the basis of the preferences expressed in response to hypothetical trade-off questions

Approach	Principle	Method	Definition
Stated preferences	Determining willingness to pay in hypothetical markets or trade-off situations	Contingent valuation	A stated preference valuation method where the marginal value of a non-market good is identified from the stated willingness to pay or accept compensation for a specified change in the availability of the good
		Conjoint analysis: Choice experiment	A stated preference valuation method where the marginal value of the individual attributes of a non-market good is identified on the basis of stated choices between alternative goods with different availability of the same attributes and different total price
Budget constraint	Determining willingness to pay for an additional Quality-Adjusted Life Year in a hypothetical situation without externalities	Budget constraint	A monetary valuation method where the marginal value of a Quality-Adjusted Life Year is identified on the basis of the potential economic production per capita per year
Abatement cost	Determining potential cost for the marginal abatement or replacement activity	Abatement cost	A cost estimation method where the change in availability of a non-market good is assessed in terms of the potential costs of the marginal counter-balancing change (replacement) or marginal measure that prevents the change

Monetary valuation can be strategic in supporting decision-making and is a very common practice in Cost Benefit Analysis performed by private and public actors performed according to the above describe methods in order to assess economic, environmental and social impacts of project (Pizzol et al., 2015).

However, monetary valuation to date is not widely applied to the universally recognized decision-supporting tool of Life Cycle Assessment (LCA) (Pizzol et al., 2015, Weidema, 2015).

Considering biodiversity and ecosystem services, Life Cycle Impacts Assessment (LCIA) methods implemented to date are affected by some gaps in the assessment of impacts caused by human activities on the environment (Zhang et al., 2010b; Curran et al., 2011; de Baan et al., 2013; Arbault et al., 2014).

These limitations affect the conduction of LCA based studies in sectors resulting strategic for the type of interconnected ecological services, as in the case of agri-food one (Arbault et al., 2014).

Some attempts have been undertaken in recent years to try to fill the existing gaps, as highlighted by studies focused on possibility to include environmental aspects of goods and services within the environmental impact assessment phase (Landers et al., 2012).

An example comes from the project launched by UNEP together with SETAC aimed to extend the scope of land use assessment in the LCIA phase including additional indicators representative of the soil related services generated by the ecosystem (Cao et al., 2015).
Considering monetization of environmental impacts according to the LCA based approach, some authors within the life cycle community have faced this topic performing different monetary valuation assessment in LCA. A review has been provided by Pizzol et al. (2015), considering the methods listed in Table 1.5.

Table 1.5 *LCA applications of monetary valuation methods (Adaptation from Pizzol et al., 2015).*

LCA Application	Reference	Approach	Method
STEPWISE2006	(Weidema, 2009; Weidema et al., 2007)	Budget constraint	Budget constraint
LIME 1-2	(Itsubo et al., 2012b; Itsubo et al., 2004)	Stated preferences	Choice experiment
ECOTAX2002	(Finnveden et al., 2006)	Revealed preferences	Averting Behavior
ECOVALUE08	(Ahlroth and Finnveden, 2011)	Mix	Contingent Valuation and market prices
MAC/RCA	(Davidson et al., 2005; Oka, 2005; Oka et al., 2005)	Abatement Cost	Abatement Cost
EPS2000	(Steen, 1999a, b)	Mix	Contingent valuation market prices and abatement cost
EVR	(Vogtlander and Bijma, 2000; Vogtlander et al., 2001)	Abatement Cost	Abatement Cost
ReCiPe	(Goedkoop et al., 2012)	Observed Preferences	Market prices
HEDONIC PRICING*	(Andersen et al., 2011; Riera et al., 2006; Sander and Haight, 2012)	Revealed preferences	Hedonic pricing
Travel Cost*	(Boardman et al., 2006)	Revealed preferences	Travel Cost
Contingent valuation of life expectancy loss*	(Desaigues et al., 2011; EC, 1999, 2005)	Stated preferences	Contingent Valuation
Contingent valuation of biodiversity loss*	(Nunes and van den Bergh, 2001; Veisten et al., 2004)	Stated preferences	Contingent Valuation
META-ANALYSIS*	(Costanza et al., 1997; de Groot et al., 2012; Nijkamp et al., 2008)	Mix	Contingent Valuation and market prices

In general, what emerges is that, even if monetary valuation has a great potential to be applied not only in CBA but also in LCA, existing methods are incomplete resulting in the impossibility to perform consistent monetary valuation of all impacts in LCA (e.g. across different LCA areas of protection). Moreover, monetary valuation in LCA to date still remains an approach potentially complex to be implemented because of the need for specific set of parameters correlated to a set of monetary values (Morel et al., 2018).

However, despite the need for a large improvement regarding the application of monetary valuation of environmental impacts in LCA, researchers agreed that this practice have to be considered in the future to support decision making process (Pizzol et al., 2015; Morel et al., 2018).

1.5 Opportunities, limits and research objectives

From the literature review reported in the previous paragraphs it emerges a general awareness about the health status of the planet, mostly because of anthropogenic pressures resulting in adverse effects on the environment like the depletion of natural resources, the constant degradation of ecosystems and the loss of biodiversity (Millennium Ecosystem Assessment, 2005; Global Footprint Network, 2016; WWF, 2016).

According to the different areas investigated by the scientific community to promote the protection of the environment and the sustainable development, one of high concern is represented by water scarcity (Vörösmarty et al., 2013; Davidson, 2014; Jiménez et al., 2014), especially considering the increasing competition between water users with a worrying expected situation for the next years where more than a half of the world population will live in areas affected by scarcity (World Economic Forum, 2016).

The necessity to tackle these emerging challenges, together with the possibility to better support organizations and policy makers in the development of more consistent sustainable strategies, has led in recently the scientific community to investigate the possibility to perform assessment of environmental impacts and aspects in monetary terms (Nguyen et al., 2016; Morel et al., 2018).

To do that the environmental management tool of LCA (§ 1.2.1), which is to date the widely adopted one to assess potential environmental impacts of a product/process/service along all the life cycle stages, has been identified as a valid supporting tool for the implementation of monetary assessments of environmental impacts (Weidema, 2009; Risz et al., 2012; Le Pochat 2013; Bruel et al., 2016; Nguyen et al., 2016, Morel et al., 2018).

Opportunities

Monetary valuation is the approach aimed to substantially convert biophysical impacts into monetary terms, resulting in a great potential for its application not only in Cost Benefit Analysis (CBA) but also in Life Cycle Assessment (LCA) (Pizzol et al., 2015).

The possibility to calculate the so-called externalities, that are the unaccounted costs and benefits arising from economic activities of one agent that impact on another (Ayres, 2008), represents an opportunity to link economic decisions and environmental assessment, providing results in a common unit for both of them and supporting decisional process at different levels (Morel et al., 2018).

Moreover, since private and public companies are facing risks and opportunities form the environmental management related to their activities, monetary valuation of environmental impacts and aspects may support them in definition of more sustainable business models and practices (ISO/DIS 14008, under development).

Monetization represents a powerful way to make results from life cycle impact assessment more intuitive and comprehensible for decision makers and stakeholder in general, allowing at the same time to reduce impacts, costs and risks (Risz et al., 2012).

Limits

Despite the general trend to the requirement for economic assessment of environment by decision-makers, many limits still persist in the existing monetary valuation methods within the LCA.

A first challenge in the adoption of monetary valuation in LCA is given by the need to provide monetary factors applicable broadly without any limitation to specific situations, since emissions and impacts in LCA from different processes and activities are aggregated over space and time (Pizzol et al., 2015).

Furthermore, because of LCA allows to perform impacts assessment at midpoint and endpoint level, the adoption of monetary valuation requires different approaches allowing to focus on potential impacts aggregated over a life cycle and at different points of the environmental mechanism (Pizzol et al., 2015). However, this results in the diffusion by some authors of few methods for the economic assessment of environment, with no general consensus in the scientific community about how the best way should be to develop consistent monetary valuation method for each impact category or damage category within the LCA (Nguyen et al., 2016).

All the existing monetary valuation methods are mainly oriented to the assessment of the TEV (§ 1.4) through the adoption of economic valuation techniques well recognized in the literature. However, just this dependence on the use of these techniques results in a very limited diffusion of consistent methods for the monetary valuation of environmental impacts in LCA.

From a review of these existing monetary valuation methods by Pizzol et al. (2015) aimed to investigate their potential use in the LCA context, it emerges that even if it possible to provide some suggestions on the adoption of one method over the other according to the specific purpose of the study intended to be performed, nevertheless each of them is affected by some limitations.

Considering monetary valuation methods developed based on observed and revealed preference approaches, as well as on the abatement cost one, it is possible to observe their limited applicability in LCA due to different degree of flexibility, with consequent variation in compatibility and relevance for LCA.

Revealed-preference methods are highly case-, space-, and time-specific and, in opposition to the LCA approach, have a very low level of abstraction.

Even if they can be adopted in non-specific contexts and they are usually characterized by a good level of abstraction, the stated-preference methods are strongly affected by subjectivity due to the survey design, the interview situation, the information provided by respondents, the behavior of the respondents and the size of the sample.

Abatement cost methods, despite the easier applicability due to a low complexity, are affected by a high degree of uncertainty since their estimations are based on hypothetical potential/expected situations (Pizzol et al., 2015).

Observed-preference methods, i.e. market-price, even if on the one hand the can be mostly applied to assess resources depletion (e.g. metals, land), on the other hand they are highly limited by the availability of appropriate market-price values linked directly with the environmental impacts in LCA (Pizzol et al., 2015).

Furthermore, considering the existing monetary valuation methods, it is possible to recognize an important difference in scale and geographical boundaries, with some methods developed for global level (e.g. Stepwise2006, EPS2000) and continental conditions (e.g. ExternE for the European context), and other methods only for specific countries, such as Sweden (e.g. Ecotax2002, Ecovalue08), Germany (e.g. EVR), Japan (e.g. LIME) (Tekie and Lindblad, 2013; Pizzol et al., 2015).

Finally, for all of the existing monetary valuation method within the LCA it is possible to observe a complete absence of approaches aimed to address only one single specific environmental issue, since each method try to provide monetary assessment of many environmental impacts at the same time, both at the midpoint and the endpoint level. In particular it was observed a total absence of monetary valuation methods to address specifically water scarcity related impacts.

Thus, according to the above described limits emerged from the literature review, the present research work is mainly aimed to try to fill the existing gaps in performing monetary assessment of water scarcity related impacts, providing a new method able to provide information useful for companies and decision makers to better understand LCA outputs in economic terms and to support them in developing more environmentally sustainable strategies.
Thus, the objectives of this research are:

i. Development of a new method to assess in monetary terms water scarcity impacts in Life Cycle Assessment (LCA), providing a new set of monetary characterization factors (MCF_i) able to convert water scarcity impacts into monetary impacts.
ii. Testing the new proposed method through its application to 4 different real case studies investigating the capacity to provide consistent hotspots analysis.

2. Materials and methods

In this chapter information about materials and methods adopted in the present research work are reported according to the research objectives.

Thus, assumptions and calculations made for the definition of the new proposed method are described, providing information about how the new specific monetary characterization factors were calculated. Moreover, this section also reports a description of the criteria adopted to perform a validation of the new proposed method.

Finally, information about the test of the new proposed method are given, describing the LCA framework adopted to perform the application in 4 real case studies whose results will be explained in the next chapter 3.

2.1 Research framework

According to the formulated objectives, the research has been performed on two main levels:

I. In the first stage the main research activities focused on the definition of a new method to convert in monetary terms water scarcity impacts in life cycle assessment. Particularly this was performed defining a new set of specific monetary characterization factors starting from the LCA based approach and considering the integration of some parameters reflecting the effects of water consumption on different aspects.
   Additionally, at this stage the research was aimed to perform a validation of the new proposed method through a sensitivity analysis at different levels.
II. In the second stage the research focused on the test of the new proposed method on different real production systems adopting the LCA structure, collecting primary data directly from companies involved in the research and secondary data from reliable sources (e.g. existing databases widely recognized by the LCA community, information contained in peer reviewed journals, etc.). Furthermore, the adoption of a dedicated LCA software allowed to perform the modeling phase and the extraction of results to be analyzed through a hotspots analysis.

To meet the research objectives of this research work information from methodologies, principles and recommendations consolidated at the international level were adopted, integrated with appropriate assumptions to perform the study that is described in detail in the next paragraphs.

2.2 Description of the new proposed set of monetary characterization factors

According to the above described first stage of research framework, the proposed new method is based on the definition of a new set of monetary characterization factors, named MCF_i, to convert water scarcity impacts into monetary impacts.

This was performed looking at the international agreed standardized LCA methodology (ISO 14040, 2006), particularly considering the life cycle impact assessment (LCIA) phase.

As previously described in this work (§ 1.2.1.3), the LCIA considers the environmental mechanism (or cause-effect chain) to convert emissions/resources into environmental impacts (Finnveden et al., 2009). Starting from an elementary flow at the life cycle inventory level (LCI), expressed as an amount of a certain quantity (e.g. m^3 of water), a characterization model allows to convert the elementary flow into a specific environmental impact (e.g. climate change, ozone depletion, acidification, biodiversity, water scarcity, etc.) (Bare et al., 2000) expresses by a score indicator (e.g. kg CO2eq for the impact category of climate change).

Most of to date available impact characterization models are based on the framework proposed by Udo de Haes et al. (2002), where characterization factors (CF) are calculated according to the following linear relationship:

$$CF = FF \cdot XF \cdot EF \qquad (2.1)$$

Where:

- FF is the fate factor, which gives information about where in the environment the emission ends up and its amount;
- XF is the exposure factor for the exposure of sensitive targets in the receiving environment;
- EF is the effects of the exposure on the targets for the impact category.

Considering Eq. 2.1, if on the one hand the adoption of this mechanistic approach to assess many types of environmental loads in different media (e.g. soil, air, etc.) has been a very common practice for the emission-related impact methods, such as toxicity models USES-LCA 2.0 by Van Zelm et al. (2009) and IMPACT 2002+ by Pennington et al. (2005), on the other hand it is possible to observe

that the existing methods to assess impacts from water consumption are to date typically based on the analytical approach, with elementary flows related to water consumptions characterized by CFs that make no distinction among both water compartments and water flows (Núñez et al., 2018).
Even if few water consumption LCIA models are present in the literature (Van Zelm et al., 2011; Verones et al., 2013; Núñez et al., 2018), there is no specific recommendations for adopting the mechanistic modeling principle for the assessment of water consumption related impacts (Núñez et al., 2018).
Thus, starting from the general principle of Eq. 2.1, the research proposal is to develop a new set of specific monetary characterization factors (MCF_i.) to perform, similarly to what is done when an elementary flow is characterized into an environmental impact, a monetary assessment converting water scarcity impact into monetary impact.
In the next pictures a schematic representation of the generic environmental impact pathway (Figure 2.1) and the new proposed monetary impact pathway (Figure 2.2) is provided, where:

- I_{env} represents a generic environmental impact (e.g. climate change, water scarcity, etc.) assessed through an existing method;
- I_{eco} represents the final monetary impact of the environmental impact I_{env} assessed through the new proposed method.

It is important to clarify that, according to the scope of this research, I_{env} is equal to the water scarcity impact assessed through existing methods diffused by many authors within the LCA scientific community (§ 1.2.2).

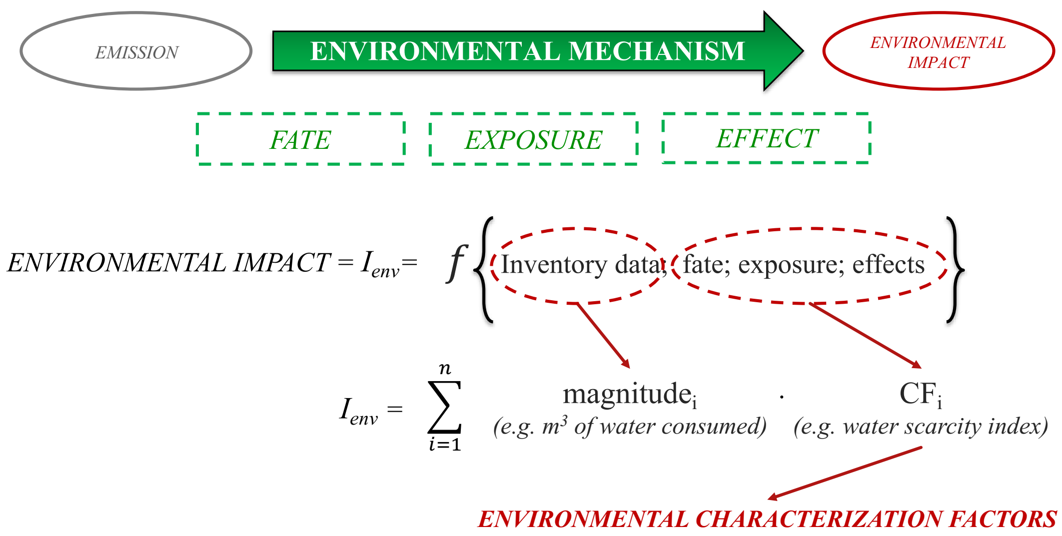

Figure 2.1 *Environmental life cycle impact assessment standard method.*

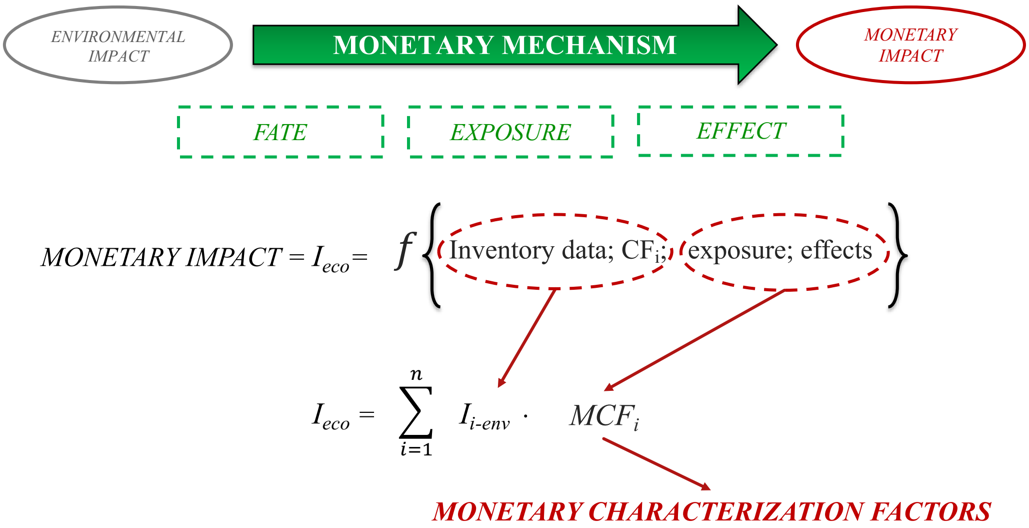

Figure 2.2 *New proposed monetary life cycle impact assessment method.*

According to the limits previously reported in this study about the diffusion of consistent methods for the monetary assessment of water scarcity impacts within the LCA (§ 1.5), the approach adopted to calculate the new set of MCF_i is based on the combination in a single linear equation, similar to Eq. 2.1, of different types of information:

- *Environmental*: principles from the LCA methodology have been considered to develop new environmental-related adimensional indexes, especially focusing on information collected from existing water impact assessment methods at midpoint and endpoint level according to the three common LCA areas of protection (AoP): human health, ecosystem quality, resources (Udo de Haes et al., 1999).
- *Economic*: new economic-related indexes have been calculated starting from information provided by existing parameters like Water Tariff, Gross National Income, and Water Productivity.

The adoption of this approach, which partially differs from those existing in the literature, is justified by the necessity to tackle some important limits of the already diffused monetary methods within the LCA, one above all the total absence of a specific monetary method specifically addressed to water scarcity impacts (Pizzol et al., 2015; Weidema et al., 2015). Moreover, the adoption of new economic-related indexes, derived from some existing parameters assumed as proxy for the effects of water consumption on some aspects rather than the application of one or more specific existing economic valuation techniques, is due to the fact that the latter are affected by strong limitations in their application within the LCA, with no recommended valuation method for the water impacts (Weidema et al., 2013). In particular, coherently to what emerged from the literature review, it is possible to observe a strong limitation in providing monetary factors widely applicable with no limitation to a specific context, in contrast with the fact that impacts in LCA are aggregated over space and time (Pizzol et al., 2015).

According to these observations and considering that to date there is no general consensus in the scientific community about which should be the best and unique way to develop a consistent monetary valuation method for all the existing impact categories within the LCA (Nguyen et al., 2016), therefore including also water scarcity impact, in this study a new method has been developed in order to be applied at global level (avoiding limitations of revealed-preference methods) without the necessity to perform any kind of surveys (avoiding limitations of stated-preference methods).

In order to calculate the new set of monetary characterization factors and bridge the gaps identified in the literature some criteria have been defined as follows:

- MCF_i have to be based on the general principle of the characterization pathway;
- MCF_i have to account for the effects of water consumption on the three LCA areas of protection;
- MCF_i have to be based on homogeneous information as much as possible, avoiding the risk of double counting;
- MCF_i have to account for the exposure (vulnerability) to the water consumption;
- MCF_i have to be applicable at global level for many different countries;
- MCF_i have to be expressed in a unit of measure compatible with the water scarcity impacts that have to be translated into monetary terms.

Considering the above defined criteria, the proposal of this research work is thus based on the calculation of the new set of MCF_i for each i-th country, according to the following equation:

$$MCF_i = MK \cdot EI_i = MK \cdot XF_i \cdot (HH_{i\text{-eff}} \cdot W_{HH} + ECO_{i\text{-eff}} \cdot W_{ECO} + R_{i\text{-eff}} \cdot W_R) \qquad (2.2)$$

Where:

- MK is a monetary constant ($\$/m^3$) representing a proxy parameter for the value of water which was assumed equal to the world average water supply tariff derived from the database of the International Benchmarking Network for Water and Sanitation Utilities (IBNET, 2017). Its principal utility is to give the right unit of measure ($\$/m^3$), as well as the proper order of magnitude, to the final monetary characterization factor. IBNET tariff database, which is a joint product of Global Water Intelligence (GWI) and International Benchmarking Network of the World Bank (IBNET), is aimed giving a global vision on water and wastewater services, providing information on 202 countries, 2.317 utilities and 10.207 tariffs (IBNET, 2017). The final value of this parameter represents the mean of the water supply tariffs of about 200 countries.

- EI_i is a new proposed dimensionless index, named Environmental Intensity Index. It was calculated considering the exposure (XF_i) and the effects ($HH_{i\text{-eff}}$, $ECO_{i\text{-eff}}$ and $R_{i\text{-eff}}$) from water consumption on each different area of protection human health (HH), ecosystem quality (ECO) and resources (R). This approach is in line with the assumption that impacts from water consumption can affect different areas of protection (Pfister et al. 2009; Bayart et al. 2010; Kounina et al. 2013). EI_i thus substantially provides an adimensional characterization of the variations of the status of different environmental compartments because of the water consumption. To account for these variations new adimensional indexes listed below have been proposed considering a combination of environmental and economic information.

- XF_i is a new index proposed to assess the population exposure to the water consumption. It has been calculated according to the introduction of two new dimensionless indexes multiplied together:

    1) I_i^{AC} , which is an index derived from the database of the World Bank Gross National Income (The World Bank, 2017a) adopted as proxy for country's adaptation capacity to the loss of water resource due to its consumption. Considering the adaptation capacity (AC), which focuses on economic strength, is a common practice in the literature in order to evaluate the ability to adapt to water supply restrictions (Boulay et al., 2011; Sullivan, 2011; Sonderegger et al., 2015). In this study I_i^{AC} has been calculated as follows:

$$I_i^{AC} = \frac{1}{GNI_i^{norm}} \tag{2.3}$$

    where $GNI_i^{norm} = f$ {per capita income threshold} is built on the approach adopted by some authors (Boulay et al., Cao et al., 2011) considering that the adaptation capacity is a function of GNI (gross national income), as demonstrated by its relationship with relevant socio-economic aspects like the access to improved drinking water resources and the access to sanitation (UN, 2009). Particularly, according to the classification of the World Bank where developing, advanced developing and developed countries are grouped according to different thresholds of income (Table 2.1), in this study GNI was fixed equal to 1 for the highest group (best adaptation when GNI is above threshold of high income), proportional to GNI normalized with the max value among those of the middle group, and equal to the minimum value among those of the middle group (worst adaptation when GNI is below threshold of low income). This last assumption was made in order to avoid zero values when calculating I_i^{AC}, since this last was assumed equal to the inverse of the GNI_i^{norm} according to the fact that the lower is the adaptation capacity of a country, the higher is its vulnerability to the consumption of water. In the next the GNI threshold adopted as reference are reported.

Table 2.1 *GNI per capita thresholds in US$ (Adaptation from The World Bank, 2017).*

GNI per capita thresholds	$
Low income	<= 1.005
Middle income	1006-12.234
High income	>= 12.235

2) I_i^{WS}, an index derived from the water scarcity impact assessment method proposed by Pfister et al. (2009) (see the next paragraph 2.2.1.3 for a description), it has been introduced to account for the effect of water resource consumption in terms of scarcity. Particularly, I_i^{WS} has been calculated dividing each i-th country water scarcity characterization factor developed by Pfister et al. (2009) by a normalization factor equal to the world water scarcity characterization factor. This allowed to obtain an adimensional index to express the magnitude of water consumption compared to a reference state assumed equal to the world one.

- $HH_{i\text{-}eff}$, called Human Health Index, is based on information from the characterization factors provided by Pfister et al. (2010) endpoint methodology (see the next paragraph 2.2.1.3 for a description) which expresses how the reduction in water availability potentially affects human health. According to the same approach adopted for I_i^{WS}, also this index has been calculated normalizing each i-th country human health characterization factor with a normalization factor equal to the world human health characterization factor, in order to obtain an adimensional index.

- $ECO_{i\text{-}eff}$, called Ecosystems Index, has been derived adopting information from the characterization factors provided by Pfister et.al (2010) endpoint methodology (see the next paragraph 2.2.1.3 for a description) which expresses how the reduction in water availability potentially affects biodiversity. As for the $HH_{i\text{-}eff}$ index, also for the $ECO_{i\text{-}eff}$ index it has been adopted a normalization reference value, applied to each i-th country ecosystems characterization factor, equal to the world ecosystems characterization factor, obtaining a final adimensional index.

- $R_{i\text{-}eff}$, called Resources Index, was introduced to express the effects on the resources area of protection according to the fact that water consumption may affect the resource itself. Such effects have been assumed proportional to how much economic output is produced per cubic meter of water consumed, and to the value of the resource itself. $R_{i\text{-}eff}$ was thus calculated through the combination (sum) of two new proposed indexes linked to economic information:

  1) $I_i^{Efficiency}$: it is an index derived from the database of the World Bank Water Productivity (The World Bank, 2017b) adopted as proxy for country's water use efficiency. Water productivity has been provided in constant US$ GDP per cubic meter of total freshwater withdrawal, according to the information of the Food and Agriculture Organization, AQUASTAT data and World Bank and OECD GDP estimates within the adopted databased (The World Bank, 2017b). According to what described previously for the other proposed indexes, a normalization was again applied referring to the global reference value of water productivity in order to have a final dimensionless index. The adoption of water productivity as proxy is aligned to assumptions made by other authors, according to the fact that high water use per GDP implies high importance (Sonderegger et al., 2015), resulting thus proportional to high effect on water resources.

2) I_i^{Supply}: it was derived from the database of the International Benchmarking Network for Water and Sanitation Utilities (IBNET, 2017) and it was adopted as proxy for the value of the resource itself. Adopting the water supply tariff as proxy market value is supported by similar assumption from the literature (Cao et al., 2011). According to the approach adopted in this study, also the calculation of I_i^{Supply} was performed applying a normalization, considering the global water supply tariff as reference value in order to obtain a final dimensionless index.

- W_{HH}, W_{ECO} and W_R represent the weighting factors for each effect on the different LCA area of protection, thus respectively $HH_{i\text{-}eff}$, $ECO_{i\text{-}eff}$, $R_{i\text{-}eff}$. The calculation of these factors, introduced to assess the severity of each AoP, will be explained in detail in the next paragraph 2.2.1.1.

Once obtained all the above described indexes, in order to convert water consumption related impacts (in terms of scarcity) into monetary terms, the new proposed MCF_i have to be finally applied according to the following equation:

$$I_{eco} = \sum (I_{env} \cdot MCF_i) \quad (2.4)$$

Eq. 2.4 allows substantially to calculate the total final monetary impact I_{eco} of a certain product system under study converting the environmental impact I_{env}, in this research work corresponding to water scarcity, through the application of the new proposed characterization factors MCF_i developed for each i-th country.

All the absolute values adopted for the development of the economic-related indexes I_i^{AC}, $I_i^{Efficiency}$ and I_i^{Supply} are listed in the Table A.1 of the annex A of this research work.

In order to provide a better comprehension of the assumption made for the development of the new proposed method, some additional details are provided here below:

- The choice to apply a normalization in order to calculate the above described adimensional indexes is justified by the fact that this is an approach commonly adopted within LCA, particularly to represent the severity of different interventions. According to the ISO standard, normalization is the procedure applied to understand the relative magnitude for each indicator result of the product system under study (ISO 14044, 2006). Each characterized impact indicator score is divided by a corresponding impact indicator score expressing the impact of the reference system (i.e. the normalization reference). This reference system can be a product, a service, the annual activities of a company, an industrial or societal sector, a nation, a larger region or the whole world (Hauschild and Huijbregts, 2015).

Similar to what performed when conducing an LCA, in this study a normalization has been applied adopting global reference values for the calculation of each of the proposed adimensional indexes in order to allow their aggregation in the Eq. 2.2 thanks to the final resulting common (adimensional) scale (Hauschild and Huijbregts, 2015). Moreover, the adoption of this approach was preparatory for the next weighting step performed through the application of the weighting factors W_{HH}, W_{ECO}, W_{R}.

- The choice made in developing the new MCF_i to refer, among all the existing methodologies for the assessment of water related impacts at midpoint and endpoint level, only to those provided by the same author, specifically by Pfister et al. (2009; 2010), is justified by the necessity to reduce as much as possible the risk of inconsistencies. This is in line to what suggested by Weidema (2009), observing that the combination of many assessment methods from different authors may results in a high level of uncertainty. Therefore, even if the latter cannot be totally eliminated, however the approach adopted may increase the consistency and transparency of the assumptions made (Weidema, 2009).

  Moreover, since assessment methods developed by different authors to address the same issues may adopt similar impact pathways with consequent overlapping effects, the approach adopted in this study of considering water impact assessment methods by a single author allows to avoid as much as possible the risk to have a double counting in the final MCF_i (Hauschild and Huijbregts, 2015).

  Finally, the method suggested by Pfister is the only one with global coverage and thus applicable for full LCA (Hauschild and Huijbregts, 2015).

- Unlike what was done in relation to $HH_{i\text{-}eff}$ and $ECO_{i\text{-}eff}$, $R_{i\text{-}eff}$ has been calculated introducing economic parameters rather than adopting information from the existing endpoint methodology by Pfister et al. (2010), which is aimed to assess impacts from water consumption on the area of protection of resources. This was because to date available endpoint impact assessment methods to cover the area of protection of resources are considered by the scientific community not mature enough (Kounina et al. 2013; Boulay et al

2015; Sonderegger et al., 2017). Moreover, this choice agrees with indications by other authors who stated that for the resources AoP it seems reasonable to adopt as common unit for the impact assessment an economic unit rather than a physical unit (Weidema, 2009).

2.2.1 Criteria adopted to perform the validation of the new proposed method

According to the framework of this study, the next step of the research work was to evaluate the consistency of the new proposed method through a validation. Aimed to demonstrate if the simulation model is a reasonable representation of the real context according to a specific purpose of the study (Law, 2006), the validation process may be difficult according to the complexity of the system modeled. When performing a validation, two main characteristics need to be taken into consideration (Chwif and Medina, 2007):

- there is no way to ensure the 100% validation of a model;
- there is no way to guarantee that a model is 100% free of bugs.

Since a model usually is developed to analyze a specific issue and thus it may represent different parts of the system with different levels of abstraction, the final model may be validated at different levels, usually according to three main tasks (Hillstone, 2016):

- assumptions;
- input parameter values;
- output values.

Achieving a full validation of a model according to the three above levels may result almost impossible, particularly when the modelled system does not yet exist, with a total absence of historical data (Hillstone, 2016). In general, the first attempt of validation focuses only on one single level, often the output of the model, considering the possibility to implement additional detailed assessment only if problems arise.
Considering the LCA, even if in the real system the effects on the environment are site and time dependent, because of the difficulties in collecting data about emissions and background concentrations from several processes including also those outside of the specific product system investigated, the interpretation of the outcomes from the LCIA stage have to be used to evaluate potential environmental impacts useful in comparing and optimizing the product system under study

(Hauschild, 2005a). Product systems are thus fictitious entities substantially impossible to fully monitor in the real world, and LCIA characterization models are very difficult to validate if not impossible (McKone and Hertwich, 2001; Hauschild, 2005a; Ciroth and Becker, 2006).
Despite the area of validation in LCA to date is not mature enough, needing further attention and development by the scientific community to bridge the gaps, in this research work an attempt to perform a validation has been however done, performing a sensitivity analysis which is one among all the validation techniques commonly used in model validation (Banks et al., 2010).
Particularly, the validation has been performed according to a sensitivity analysis at different levels:

i. First, different sets of weighting factors W_{HH}, W_{ECO} and W_R have been developed to investigating effects on final results. Two approaches were adopted: (a) equal weighting and (b) distance-to-target.
ii. Second, the parameter MK was reviewed in order to investigate the possibility to improve it.
iii. Third, the new proposed MCF_i were applied to different existing water scarcity impact assessment methods.

The next paragraphs reported a description of all the three different levels of the sensitivity analysis performed in this study.

2.2.1.1 Definition of the weighting sets

The weighting step in LCA still remains today a controversial procedure, mainly because it requires the inclusion of social, political, and ethical values (Finnveden, 1997). However, in the last decades weighting has been widely adopted in practice (Hansen, 1999), with several weighting sets developed in the LCA, based on different scientific approaches and often adopting proxies to bridge the gaps in explicit value choices and preference statements (Huppes et al., 2012).
According to Goedkoop and Spriensma (2000) weighting factors cannot be defined true or false in absolute terms, observing that their suitability can be evaluated only through their capacity to reflect in a consistent manner the point of view of the stakeholders. Thus, there is no specific and unique way to make weighting and therefore there is no consensus about a unique and correct set of ranks or weighting factors to be adopted (Finnveden et al., 2009; Sala et al., 2018).
According to the LCA literature, to date existing weighting approaches can be grouped as follows (Hauschild and Huijbregts, 2015; Pizzol et al. 2017):

- Single Item: methods of this group focus on physical properties or equivalents to characterize/weight the life cycle inventory (e.g. Carbon Footprint);
- Distance-to-Target: in this group the characterization/weighting of results are linked to targets which can be policy-based or carrying capacity-based (e.g. planetary boundaries);
- Panel-based: also called value-based or preference-based, this group of methods adopts a team of experts/stakeholders to derive the relative importance of damages/impacts categories/interventions through surveys and extrapolations;
- Monetary valuation: this kind of methods adopt monetary valuation techniques (e.g. willingness to pay) to derive the weighting factors;
- Meta-models: this group concerns the application of multiple weighting factors, resulting from the combination of other weighting sets, to weight damages and impacts.

To perform the first level of validation, according to the criteria defined in the previous paragraph 2.2.1, in this study different sets of weighting factors W_{HH}, W_{ECO} and W_R have been developed to investigating the effects on final results, particularly adopting two different approaches:

a) *equal weighting*: even if unpublished, this approach is instead widely applied in practice (Prado-Lopez et al., 2014; Pizzol et al., 2017). In this weighting procedure an equal weight (usually unitary) is assigned to each of the environmental impact category under study (Sala et al., 2018). This approach is thus aimed to give the same importance to each indicator. According to the equal weighting approach, the weighting factors W_{HH}, W_{ECO} and W_R, adopted in the Eq. 2.2 proposed in this study to assess the effects of water consumption on each area of protection, have been set in the ratio of 1:1:1 for the calculation of all the MCF_i.

b) *distance-to-target*: based on the concept of weighting impacts according to their proximity to a target (Sala et al., 2018), this approach is widely adopted in LCA as confirmed by several applications in the literature (Seppala and Hamalainen, 2001; Stranddorf et al., 2003; Hauschild and Potting, 2005b; Weiss et al., 2007; Frischknecht et al., 2009; Tuomisto et al., 2012; Castellani et al., 2016).
   The distance-to-target approach can refer to targets based on regulations (e.g. the CO_2 reduction target) for specific contexts (e.g. EU, global) reflecting thus a socio-political agreement on a category of impacts (Sala et al., 2018).

In a similar way, the calculation of the new weighting factors based on the distance-to-target approach has been performed in this part of the research assigning different values to the weighting factors W_{HH}, W_{ECO} and W_R taking account for existing indicators developed for Sustainable Development Goals (SDGs) introduced by the United Nations in 2015 (§ 1.1). This choice is justified by the fact that the 2030 Agenda and SDGs (UN General Assembly, 2015), among all the different challenges to tackle includes the address of water issues, as demonstrated by the Goal 6 specifically aimed to ensure availability and sustainable management of water and sanitation. Moreover, water issues are also addressed by other SDGs like those on health, poverty reduction, ecosystems and sustainable consumption and production, highlighting the strategic role of water in many different contexts in addition to the environmental one (UNESCO, 2015).
For this reason, in order to calculate the weighting factors W_{HH}, W_{ECO} and W_R different indicators linked to the SDGs were adopted as proxies for the effects arising from water consumption on each AoP, according to what described below:

- Human Health (W_{HH}): for this AoP the SDGs 3 (good health and wellbeing) and 6 (clean water and sanitation) have been considered, particularly focusing on one specific indicator for each of them: 3.9.2 (age standardized death rate attributable to unsafe water, sanitation, and hygiene) and 6.2.1 (total population with access to safe drinking-water) for human health.

  These two indicators were assumed to be consistent with the purpose of W_{HH} which is to give a certain degree of severity to the effects arising from the water consumption on the human health, represented in the new proposed method by $HH_{i\text{-}eff}$. In fact, the impact pathway considered by the existing endpoint methods, like the one by Pfister adopted in this research as reference for the calculation of $HH_{i\text{-}eff}$, includes data linked to hygiene and malnutrition as proxies for the effects on human health from water consumption.

  Indicator 3.9.2 provides information on age-standardized death rate attributable to unsafe water, sanitation, and hygiene (WaSH) per 100.000 people. Data for this indicator have been taken from the Global Health Data Exchange database (GHDx, 2017), the world's most comprehensive catalog of surveys, censuses, vital statistics, and other health-related data. Since the dataset allows to select values for several years in the past (before 2016), including also a projection for 2030 target year, the weighting factors W_{HH} has been derived by dividing the value referred to the year 2005 of the indicator of the i-th country by the value referred to the target year 2030 of the same i-th country. The choice of 2005 as reference year is justified by the fact that $HH_{i\text{-}eff}$ has been calculated according to the characterization factors provided by Pfister et al. (2010) which adopted in his impact method data from 2005 (Pfister et al., 2009). This assumption is intended to ensure homogeneity as much as possible between the effect index $HH_{i\text{-}eff}$ and the weighting factor W_{HH}.

Indicator 6.2.1, instead, refers to the total population with access to safe drinking-water expressed in percentage terms. Data for this indicator have been derived from the database of FAO named AQUASTAT (FAO, 2016) containing a collection of analysis and dissemination of information related to water resources, water uses and agricultural water management. In this case the weighting factor W_{HH} has been derived by dividing the value referred to the rage of years 2003-2007 (database doesn't provide information year by year) by the target value fixed equal to 100%. Since for this indicator a specific target value for 2030 is not available the assumption of a maximum target value of 100%, which implies that all the population can access to safe-drinking water, was made adopting a conservative approach.

- Ecosystems (W_{ECO}): for this AoP the SDG 15 (life on land) has been considered, focusing on the indicators 15.1.2 (average proportion of freshwater key biodiversity areas covered by protected areas) and 15.5.1 (red list index for change in aggregate global extinction risk of species).

  As for the human health, also for this AoP these two indicators have been assumed for their relevance with the W_{ECO} which is aimed to express a certain degree of severity to the effects caused by the water consumption on the ecosystem quality, represented in the new proposed method by $ECO_{i\text{-}eff}$. In fact, species richness has been often adopted in the LCA context as indicator for the biodiversity, assessing the reduction in species richness in terms of disappeared fraction of species (PDF) due to water consumption.

  Indicator 15.1.2 provides information about the average proportion of freshwater key biodiversity areas (KBAs) covered by protected areas in terms of percentage. Values were taken from the dissemination platform of the Global Sustainable Development Goals Indicators Database (UNDP, 2018), a platform allowing to access to data compiled through the UN System. In the calculation of the weighting factor W_{ECO}, because of in the literature no specific 2030 targets are recognizable for each country, two different assumption have been made resulting in two different final W_{ECO}.

The first concerns the assumption of a target equal to that resulting from the increase by 30% of the value of 2010, which represents the year of the adoption of the Strategic Plan for Biodiversity 2010-2020 and its 20 Aichi Biodiversity Targets (CBD, 2010), which were reconfirmed then in the 2030 Agenda for Sustainable Development and its Sustainable Development Goals (UN General Assembly, 2015). Since one of the commitments of the Strategic Plan for Biodiversity is to protected areas strategic for biodiversity conservation and sustainable development, thus it has been assumed a hypothetical flat increment equal to 30% to obtain a target to which relate the values of 2005 of each i-th country. The adoption of 2005 as reference year is consistent with the assumption made for the calculation of the previous W_{HH}.

The second concerns the adoption of the fixed percentage target of 17%, based on the Aichi Target 11 that promotes the need to reach a minimal level of Protected Key Biodiversity Areas by 2020. Even if highly debated, since the target is based mainly on political feasibility rather than scientific evidences making unclear if it will be sufficient to safeguard biodiversity (Larsen et al., 2014), this target has been assumed in this research as a good compromise considering also that to date no specific biodiversity targets in absolute terms exist for the 2030.

Indicator 15.5.1 refers to the global estimate of the extinction risk of all mammals, birds, amphibians, corals and cycads, derived from local and national data disaggregated to the national scale and weighted by the proportion of each species' distribution in the country or region (IUCN, 2013). As for the indicator 15.1.2, data were again derived from the platform of the Global Sustainable Development Goals Indicators Database (UNDP, 2018). The W_{ECO} for each i-th country has been calculated with the similar approach adopted for the other indicators, based on the ratio between the value referred to the year 2005 and the target value. The latter was assumed equal to 1, which corresponds to the best hypothetical status in which no species are threatened, adopting a conservative approach since no specific targets in absolute terms are available at both country and global level.

- Resources (W_R): for this AoP it was considered again the SDG 6 (clean water and sanitation), in this case focusing on the specific indicator 6.4.2 (level of water stress). This indicator refers substantially to the efficiency and sustainability of water usage, expressed by the ratio between the total freshwater withdrawn by the all economic activities and the total renewable freshwater resources, considering also the environmental flow requirements (GEMI, 2017).

  As for human health and ecosystems, also for this AoP the assumption made in this study to focus on this kind of indicator is justified by its capacity to reflect the effects caused by the water consumption on the water resource itself. The weighting factor W_R has been elaborated according to two approach.

  The first concerns the adoption of values from the platform of the Global Sustainable Development Goals Indicators Database (UNDP, 2018) elaborated by FAO adopting the total amount of freshwater withdrawn, which corresponds to the gross water abstraction, in calculating the indicator. W_R was obtained by dividing the water stress value of each i-th country for the most recent available year (in this case a mix of 2014 and 2015) by the target. The adoption of a baseline considering values referred to the most recent year rather than those of 2005 as assumed for the calculation of W_{HH} and W_{ECO} is due to the fact that $R_{i\text{-}eff}$ has been developed according to economic data from 2015. This assumption, as already stated for the calculation of the effect indexes $HH_{i\text{-}eff}$ and $ECO_{i\text{-}eff}$, is intended thus to ensure homogeneity as much as possible between the effect index $R_{i\text{-}eff}$ and the weighting factor W_R.

  According to FAO (2017), the target has been fixed for each i-th country equal to the suggested value of 70%, which is identified as the threshold for the occurrence of sever water stress conditions, applying a safety factor of additional 10% having a final more conservative threshold of 60%.

  The second refers to the adoption of values from the water scarcity method by Pfister et al. (2009) to calculate W_R, adopting in this case a target value equal to two different thresholds, respectively 0,5 and 0,1 over a maximum water stress level equal to 1, which are in the range usually assumed in the literature to identify different levels of water stress status (Vörösmarty et al. 2005; Rijsberman, 2006; Moore et al. 2015; Vanham et al., 2018).

According to the above information, with different options proposed in this research work to calculate the weighting factors W_{HH}, W_{ECO} and W_R, since they may have been several combinations a limited number (six in total) of weighting sets have been created and applied to understand the behavior of the final new proposed MCF_i, according to the information reported in the next Table 2.2.

The six sets have been created combining the weighting factors W_{HH}, W_{ECO} and W_R according to different assumptions based on criteria like the high target compliance or the fact that the indicators linked to the SDGs can be more or less target restrictive.

Moreover, the numerical values within the different datasets adopted to calculate all the weighting factors are reported in Table B.1, B.2, B.3, B.4 and B.5 of the annex B of this research work.

Table 2.2 *Criteria adopted for the definition of the weighting sets to be applied in the new proposed method.*

Weighting sets	Criteria	Weighting factors							
		W_{HH}			W_{ECO}			W_R	
		#1	#2	#3	#4	#5	#6	#7	#8
		Indicator 3.9.2	Indicator 6.2.1	Indicator 15.1.2 (option 1)	Indicator 15.1.2 (option 2)	Indicator 15.5.1	Indicator 6.4.2	Indicator 6.4.2 (option 1)	Indicator 6.4.2 (option 1)
SET 1	First option (high target compliance)	X			X		X		
SET 2	Most target restrictive		X			X		X	
SET 3	Less target restrictive	X		X					X
SET 4	Average (all weighting factors)	X	X	X	X	X	X	X	X
SET 5	Second option		X		X		X		
SET 6	Average (6 weighting factors)	X	X		X	X	X	X	

2.2.1.2 Review of the monetary base constant

In the second step of the validation performed in this research work, the monetary base constant MK has been reviewed in order to investigate the possibility to improve it.

According to the definition given in the previous part of this work (§ 2.2), MK represents a proxy for the market value of water that has been assumed equal to the average of the water supply tariffs of about 200 countries, resulting in a final absolute value of 1,23 $/m^3$. Moreover, as already stated, the main function of this parameter is to give the right unit of measure ($/m^3$) and, at the same time, the proper order of magnitude to the final monetary characterization factor MCF_i which is mainly dependent on the new proposed dimensionless index EI_i (§ 2.2.1)

Considering the definition of MK provided in this study and taking into account the three different LCA areas of protection (§ 1.2.1.3), it could be observed that MK substantially accounts for only the component of resources. Thus, in order to verify the possibility to improve the accuracy of this constant, it was investigated the presence in the literature of additional information to be used as proxies to account also for the other two AoP, human health and ecosystems.

What emerged was that, considering the existing LCIA methods aimed to provide final economic values of the two AoP human health and ecosystems, none of them is developed to specifically address water impacts (Weidema, 2015; Pizzol et al., 2017).

However, to meet the need of this stage of research, the Stepwise2006 method from Weidema (2009) has been assumed as reference for the review of MK. This is justified by the fact this method is the only one among all able to provides economic values that are valid globally (Pizzol et at., 2017), resulting in various applications (Bulle et al., 2014; Weidema, 2015; Huysegoms et al., 2018).

The Stepwise2006 method is based on a procedure for the endpoint impact assessment in monetary terms, starting from the physical indicator results for the three AoP human health, ecosystem quality and resources, according to the LCIA method EcoIndicator99 (Goedkoop and Spriensma, 2000).

According to the information from the Stepwise2006 method, the review of the monetary base constant has been performed through the addition (sum) of the global monetary values of the two areas of protection human health and ecosystem.

Particularly, the Stepwise2006 weighting factors used to put endpoint results on a comparable scale in monetary terms, correspond to 74.000 €/DALY for human health and 0,14 €/PDF·m^2 for ecosystem quality (Weidema, 2009).

Considering the measurement units for human health and ecosystem quality, they are by far the most investigated and adopted ones in the scientific community. The term DALY, introduced by the World Health Organization (WHO), represents the disability adjusted life years, which is equal to the sum of years of life lost due to premature mortality (YLL) and years of life lost due to disability (YLD) (Murray and Lopez, 1996). The term PDF, instead, refers to the potentially disappeared fraction of species on a given surface or volume during a given time (PDF per m^2 per year or PDF per m^3 per year) (van Zelm et al. 2011; Hanafiah et al. 2011).

Since the Stepwise2006 method provides a monetary assessment of the two AoP taking into account for the whole effect of several impact categories, thus in order to have final monetary values in a format compatible to MK ($\$/m^3$ of water consumed) allowing their sum, the weighting factors from Stepwise2006 method have been multiplied by the world characterization factors from Pfister et al. (2010) endpoint method, respectively equal to 7,930E-07 DALY/m^3 for the human health, and equal to 6,580E-10 for the ecosystem quality.

Once added together, the contribute from the three AoP lead to a final value of MK equal to 1,29 $\$/m^3$, showing thus a very low variation if compared to the initial one. The effects of the adoption of this reviewed value on the final results will be discussed later in this work.

2.2.1.3 Description of the existing water impact methods adopted as reference

Following the validation framework introduced in the paragraph 2.2.1, with a sensitivity analysis performed at three different levels, in the third step the new proposed MCF_i have been applied to different existing water scarcity impact assessment methods.

In this paragraph a brief description of the existing midpoint impact methods (4 in total) adopted as reference to perform the sensitivity analysis are provided, together with the description of the endpoint impact assessment method adopted as reference for the development of $HH_{i\text{-}eff}$ and $ECO_{i\text{-}eff}$ (§ 2.2). Results from the sensitivity analysis will be provided in the next chapter 3 within each case study.

Midpoint water impact methods

Considering the methods for the assessment of water scarcity impacts (§ 1.2.2) developed by the scientific community in the last decades, they are many and different in the way they address the water assessment (Bayart et al. 2010; Kounina et al, 2013; Pfister et.al, 2014; Quinteiro et al., 2017). Particularly, each of them is based on different assumption in the calculation of the water stress index (WSI) adopted to characterized water impacts in terms of scarcity (Scherer and Pfister, 2016; Xu and Wu, 2017).

Thus, according to the aim of this third step of the sensitivity analysis performed in this study, 4 existing water scarcity impact assessment methods have been considered for the application of the new proposed method in order to evaluate the effects on final results. The selection of the methods has been done according mainly to two criteria as follows:

i. The adoption of methods based on different approach in the way they develop the water scarcity index (WSI) that represents the characterization factor to be applied in performing the assessment.
ii. The availability of the methods within the LCA software SimaPro that was used to perform the modeling of each real case study.

According to the above described criteria, the following 4 methods have been selected:

- Pfister et al. (2009): this method adopted a WSI based on a withdrawal-to-availability (WTA) ratio, with final characterization values in the range between 0,01 and 1 m^3 deprived/m^3 consumed. According to the assumptions made by the authors, the resulting water stress thresholds are defined respectively moderate for the 20% of withdrawals, and severe for 50% of withdrawals. Furthermore, the indicator assesses only consumptive water use.
  The model adopts data from the WaterGap model, while the regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute. The WSI of Pfister et al. (2009) is defined according to the following equation:

$$WTA_i = \sum_j \frac{W_{i,j}}{A_i} \quad (2.5)$$

  Where $W_{i,j}$ represents the annual freshwater withdrawal for human uses in a specific region and A_i represents the annually renewable water supply in the region (Pfister et al., 2009).
  Because of the seasonal variations the authors have also introduced a variation factor (VF) to take climatic variability into consideration, obtaining a modified WTA (WTA*) to be adopted in the final equation for the calculation of WSI as follows:

$$WSI = \frac{1}{1 + e^{-6,4 \cdot WTA^*} \cdot \left(1/0,01-1\right)} \quad (2.6)$$

- Hoekstra et al. (2012): this method is based on the development of a water scarcity indicator (WSI) according to the consumption-to-availability ratio (CTA), which is calculated by dividing the fraction of water consumed (referred to as blue water footprint) by the available water. Results are available for the main watersheds worldwide, but many outlying regions are not covered. The indicator assesses only consumptive water use. As for Pfister et al. (2009)

method, the regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute. The Blue Water Scarcity Index of Hoekstra et al. (2012) is calculated according to the following equations:

$$WS_{blue}\,[x, t] = \frac{\sum WF_{blue}\,[x, t]}{WA_{blue}\,[x, t]} \tag{2.7}$$

$$WA_{blue}\,[x, t] = R_{nat}\,[x, t] - EFR\,[x, t] \tag{2.8}$$

Where WF_{blue} represents the blue water footprint, while WA_{blue} represents the available blue water resource. The latter is equal to the difference between natural runoff (R_{nat}) and EFR (environmental flow requirement), which is suggested by the authors to account for 80% of the mean annual natural flow. The characterization values of 1,0 and 2,0 are used as the thresholds respectively of low and high water stress areas.

- Berger et al. (2014): this method, called WAVE (water accounting and vulnerability evaluation), considers the vulnerability of basins to freshwater depletion, accounting for the local blue water scarcity. The method is based on the water depletion index (WDI), which refers to the risk that water consumption can lead to the depletion of freshwater resources.
  This risk of freshwater depletion (RFD) is calculated by multiplying the effective water consumption in each basin with its corresponding water depletion index (WDI), according to the following equation:

$$RDF = \sum_j \left(WC_{eff,n} \cdot WDI_n\right) \tag{2.9}$$

Where WDI, which is based on the consumption-to-availability (CTA) ratio, is calculated similar to the WSI from Pfister et al. (2009), according to the following equation:

$$WDI = \frac{1}{1 + e^{-40 \cdot CTA^{*} \cdot \left(1/0{,}01-1\right)}} \tag{2.10}$$

Where CTA^* accounts for the annual water consumption and availability, as well as for the usable surface water stocks in order to consider lakes, wetlands and dams in the scarcity index. The WAVE method assesses water scarcity by relating the annual water consumption to availability in more than 11.000 basins. The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute.

- Boulay et al. (2016): this method, called AWARE (Available WAter REmaining), is the one recommended by WULCA working group to assess water consumption impact assessment in LCA. It is based on a midpoint indicator representing the relative Available WAter REmaining per area in a watershed after the demand of humans and aquatic ecosystems has been met. The method provides an assessment of the potential of water deprivation, considering that a reduction in water availability per a specific area implies a deprivation for another user. Thus, differently from the previously described methods, AWARE is based on demand-to-availability ratio (DTA).

  The characterization factors in the AWARE method are calculated according to the following equations:

$$CF_{AWARE} = \frac{AMD_{world\ avg}}{AMD_i} \tag{2.11}$$

$$AMD_i = \frac{\text{Availability - HWC - EWR}}{\text{Area}} \tag{2.12}$$

  The method determines the characterization factors (CF_{AWARE}) as the inverse of the unused water remaining normalized to the reference flow of the worldwide weighted value. Unused water remaining refers to the difference between blue water availability and human (HWC) and ecosystem (EWR) demand for a given area.

  The result represents the relative value in comparison with the average m^3 consumed in the world. The indicator is limited to a range from 0.1 to 100, with a value of 1 corresponding to the world average, and a value of 10, for example, representing a region where there is 10 times less available water remaining per area than the world average.

All the water scarcity methods above described are available in the SimaPro software, except for AWARE. However, since the set of characterization factors of this last is available in CVS format on the website of WULCA, thus it was possible to upload manually the method in the software allowing its application in the case studies.

Endpoint water impact methods

According to this category, the endpoint impact assessment methods provide specific indicators for potential damages on the three areas of protection of human health, ecosystem quality and resources (Kounina et al., 2013) arising from water consumption.

Among all, the one adopted as reference in this study was the one from Pfister et al. (2010), in order to support the development of $HH_{i\text{-}eff}$ and $ECO_{i\text{-}eff}$ (§ 2.2). Since each of them refers specifically to an area of protection, respectively human health and ecosystem, thus only the correlated characterization factors were considered for the calculation of the adimensional effect indexes.
Considering the area of protection of human health, the method from Pfister et al. (2010) addresses water impacts adopting an approach based on water consumption as a function of water scarcity and socioeconomic conditions.
In particular, impacts form water use are obtained by first modeling the cause-effect chain of water deprivation for agricultural users, referring to the lack of irrigation water for the agriculture on a watershed level (more than 11.000 units) based on the WSI (Pfister et al, 2009). In a second step, the lack of water in agriculture is calculated assessing the consequent effects of malnutrition due to the lack of water for food by a regression analysis of socio-economic conditions of countries together with per capita water use requirements. Finally, the damages are quantified in terms of DALY (§ 2.2.1.2) lost based on the relationship between DALY from malnutrition and malnourished people, according to the following equation:

$$\Delta H_{malnutrition,i} = \underbrace{WSI_i \cdot WU_{\%agricolture,i} \cdot HDF_{malnutrition,i} \cdot WR_{malnutrition,i} \cdot DF_{malnutrition,i}}_{CF_i} \cdot WU_{consumptive,i} \qquad (2.13)$$

Where $CF_{malnutrition,i}$ ($DALY/m^3$ consumed) represents the expected specific damage per unit of water consumed, with the level of economic development based on the parameter Human Development Index. The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute.
Considering the area of protection of ecosystems, the method from Pfister et al. (2010) modelling the cause-effect chain of freshwater consumption on terrestrial ecosystem quality following the ReCiPe method (Goedkoop, 2012), evaluating the decrease of terrestrial biodiversity due to freshwater consumption in terms of PDF (§ 2.2.1.2). The latter, assumed proportional to the local limitation of plant growth by water availability, is obtained in the Pfister et al. (2010) method according to the following equation:

$$\Delta EQ = CF_{eq} \cdot WU_{consumptive} = \underbrace{NPP_{wat\text{-}lim}}_{PDF} \cdot \frac{WU_{consumptive}}{P} \qquad (2.13)$$

where CF_{eq} is the ecosystem damage factor ($m^2 \cdot yr/m^3$), $NPP_{wat\text{-}lim}$ represents the water-shortage vulnerability of an ecosystem, P is the mean annual precipitation (m/yr). The regional factors are weighted averages based on the freshwater withdrawal by country data from the Pacific Institute.

2.3 Criteria adopted to test the new proposed method

According to the structure explained in the previous paragraphs (§ 2.1), in the second part of this research work a test of the new proposed method on different real production systems has been performed in order to investigate its capacity to provide consistent hotspots analysis.
In particular, this was done following the structure of the life cycle approach (ISO 14040, 2006) and the LCA based Water Footprint approach (ISO 14046, 2014) according to the purpose of the study that is to provide an assessment of water scarcity impacts in monetary terms.
The test of the new proposed method has been performed through the application to different real case studies observing how results from different production contexts may change.
The selection of the case studies was done considering the possibility to investigate production systems characterized by critical water related processes, like agri-food systems and service systems highly dependent on water consumption (Aivazidou et al., 2016; Hoekstra et al., 2017; Weber and Hogberg, 2018).
A total of 4 real case studies (three concerning products, one concerning a service) placed in different parts of the national context were selected according to the information reported in Table 2.3.

Table 2.3 *Case studies selected for the test of the new proposed method.*

CASE STUDY	SECTOR	OBJECT	LOCATION
#1	Agri-food industry	Food product	Middle Italy
#2	Agri-food industry	Food product	Northwest Italy
#3	Agri-food industry	Food product	Northeast Italy
#4	Industry	Laundry service	Southern Italy

Starting from the above considerations, a general framework for the test of the new proposed method in each case study has been designed based on the life cycle approach, as well as tools and methods typically adopted when performing an LCA study. The proposed framework accounts for 5 main steps, according to the structure of Figure 2.3.

Principle and requirements from the Water Footprint (§ 1.2.2), and therefore from the Life Cycle Assessment (§ 1.2.1) have been adopted to be compliant to the existent ISO standardize framework (ISO 14040, 2006; ISO 14046, 2014), resulting in the following steps:

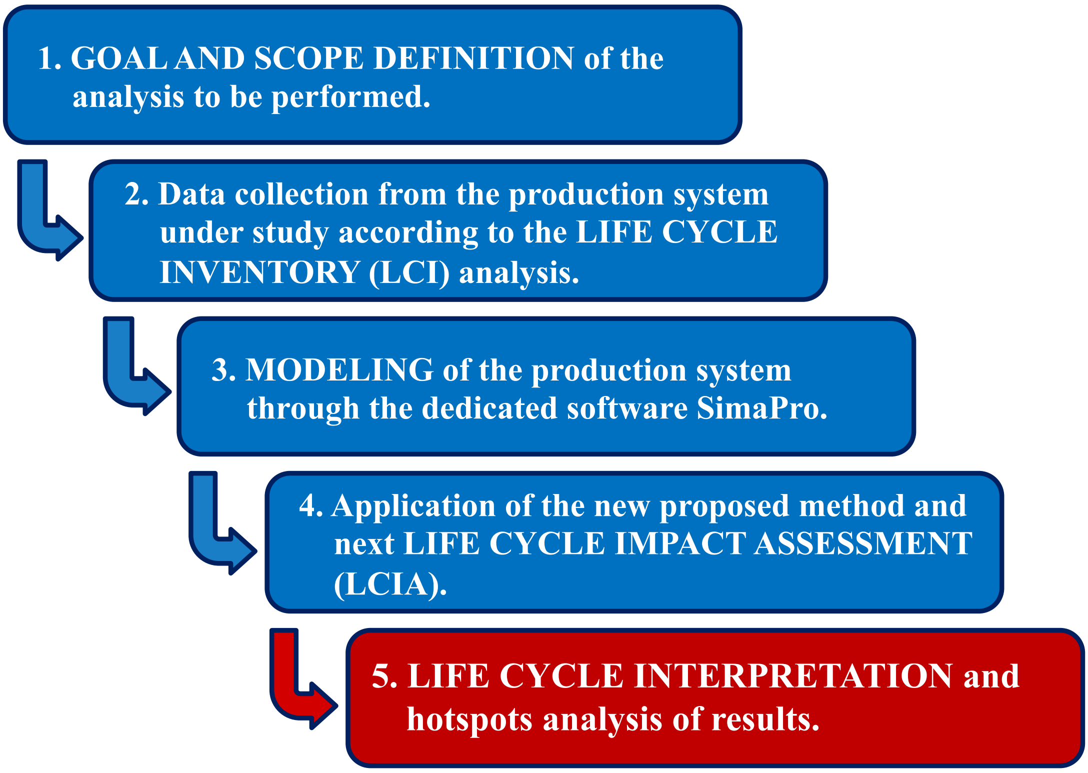

Figure 2.3 *Proposed framework for the test of the new developed method.*

1) According to the first phase of an LCA in this step the goal has to be unambiguously declared, clarifying the reasons for carrying out the study, the intended application as well as the intended audience.

   In defining the scope of the study, it is necessary to provide information about the product system investigated, setting the functional unit, the reporting flow, the selection of impact assessment methods to be applied, the data quality requirements and the data to be collected. Furthermore, the system boundaries, thus the processes included in the study, have to be identified according to the chosen life cycle perspective, which can differ according to the different approach adopted: cradle to grave, considering all input and output and elementary flows from the extraction of raw materials till the end of life management; cradle to gate, considering all input and output and elementary flows from the extraction of raw materials to one specific life cycle stage (e.g. industry gate); gate to gate, considering only one or few life cycle stages (e.g. specific processes of a company).

2) In the second step the life cycle inventory analysis is performed through a data collection of the unit processes under study, where according to the LCA theory a unit process can be defined as a black box in which inputs are elaborated into outputs (Heijungs and Guineè, 2012). In this phase all inputs and outputs related to water fluxes involved in the processes within the system boundaries are collected in order to have a comprehensive set of information for the next modeling and impact assessment steps. According to the requirements of the reference standard ISO 104046 (2014), the inventory analysis has to be done following the procedures described in ISO 14044 (2006) (§ 1.2.1.2):

    - All the assumption made in data collection have to be documented and clearly explained.
    - A check on data validity has to be done in order to provide evidence that the data quality requirements for the intended application have been fulfilled. The validation may be performed in many ways, e.g. mass and energy balances and/or comparative analyses of release factors in water.
    - Data collected have to be related to unit processes, reference flows and functional units The quantitative input and output data of each unit process shall be calculated in relation to an appropriate flow. Based on the flow chart and the flows between unit processes, the flows of all unit processes are related to the reference flow. The calculation should result in all system input and output data being referenced to the functional unit.
    - Data aggregation may be performed by ensuring a high level of consistency with the goal of the study.
    - Because of the iterative nature of water footprint assessment, and more in general of LCA, the system boundary can be refined according to the cut-off rule established in the definition of the scope of the study, thus including/excluding new data to be collected.

During data collection in the inventory analysis phase, allocation is also allowed when systems or processes produce multiple products or services (co-products) and when other options (e.g. system boundaries expansion) are not possible. The allocation is adopted to assign the inputs and outputs of a process to the function under study, adopting clearly stated procedures that need to be documented and explained.

Furthermore, data collected can be refereed to two main groups: primary data, which refers to direct measures of the product system under study; secondary data, which refers to information from databases or estimation made according to published data.

3) In the third step all the data collected according to the step 2 of the adopted framework are used to build the model, particularly adopting the dedicated software SimaPro which will be briefly described in the next paragraph 2.4.

   In this phase the real product system under study is modeled within the dedicated LCA software, adopting the most recognized databases included into the software itself.

   Moreover, in this phase all the new sets of characterization factors calculated according to the procedures described in the previous chapters of this research (§ 2.2), once applied to the selected water scarcity impact assessment methods (§ 2.2.1.3) have been imported into the LCA software allowing to perform the next life cycle impact assessment.

4) The fourth step refers to the impact assessment, where inventory data are converted into impacts related to water according to the goal and scope definition declared in the step 1 of the proposed framework (ISO 14046, 2014).

   According to the objective of this research work, in this phase impacts from water consumption are then assessed in monetary terms through the application of the new proposed monetary characterization factors.

5) Finally, in the fifth step the analysis of results from the life cycle impact assessment is performed, investigating the different contribution of the processes to each life cycle stage in order to identify hotspots useful for a consistent interpretation of results.

Results obtained from the application of the new proposed method in the four different real case studies will be reported in the next chapter 3, detailing each step of the above described framework and the related outcome.

2.4 Modeling software

The LCA software adopted in this research work in order to model each product system investigated was the SimaPro version 8.5.2.0 developed by the company PRé (PRé Consultants, 2018),which is one of the most diffused tools for the assessment of the environmental performance of company's products and services. The software can be used for a variety of applications, such as sustainability reporting, carbon and water footprint, environmental product declarations and many others, allowing to process all the input and output flows associated to the system under study.

A key feature of the SimaPro software is that is contains some different international databases (e.g. Ecoinvent and Agri-footprint), with thousands of datasets concerning the areas of agriculture, energy supply, transport, biofuels and biomaterials, chemicals, construction materials, packaging materials, metals, material processing, waste treatment.

The SimaPro software is characterized by a high flexibility since it allows to enter new processes, materials and analysis methods in order to perform environmental impacts assessment, as well as to modify or integrate the existing ones and to adapt them to each specific case study. Moreover, its interface is based on the framework defined by the LCA international standard ISO 14040 (2006).

Finally, it allows also to perform sensitive analysis, uncertainty analysis and evaluation of alternative scenarios for the product system investigated.

3. Results

According to the objectives of the present research work, in this chapter results from the analysis performed are reported.
Considering the research framework defined in the previous chapter 2 (§ 2.1), in the first part the new sets of monetary characterization factors to be used in the new proposed method are reported.
Results from the validation, performed through a sensitivity analysis according to 3 different levels (§ 2.2.1), are also reported. In particular, the outcome from the third level of sensitivity analysis are described in the second part of the chapter together with the results obtained from the test of the new proposed method, resulting in 4 different sections according to each real case study considered in this research work: (i) a jar packaged ice cream (§ 3.4.1); (ii) a fresh mozzarella cheese packaged (§ 3.4.2); (iii) a Parma ham with bone seasoned for 12 months (§ 3.4.3); (iv) a hospital laundry service (§ 3.4.4).

3.1 The new proposed monetary characterization factors

According to the criteria described in the previous chapter materials and methods (§ 2.2.1), the proposed new method is based on the definition of a new set of monetary characterization factors, named MCF_i, to convert water scarcity impacts into monetary impacts.
Since different sets of weighting factors W_{HH}, W_{ECO} and W_R to be used in the proposed Eq. 2.2 (§ 2.2) have been developed in order to investigate the effects on final results (§ 2.2.1.1), so in this paragraph the different sets of MCF_i resulting from the adoption of all the proposed sets of weights are reported, according to the following:

- $MCF_{i\text{ - SET EQ}}$: this set of monetary characterization factors refers to the adoption of the equal weighting approach, with W_{HH}, W_{ECO} and W_R assumed all equal to 1 (§ 2.2.1.1).
- $MCF_{i\text{ - SET }j}$: this set of monetary characterization factors refers to the adoption of the distance-to-target approach, with W_{HH}, W_{ECO} and W_R calculated according to the criteria described in 2.2.1.1 and j ranging from 1 to 6 according to the different combinations listed in Table 2.2 (§ 2.2.1.1).

The next Table 3.1 reported all the 7 resulting sets of monetary characterization factors to be applied in order to perform the monetary assessment of water scarcity impacts.

Table 3.1 *Data on the new proposed sets of MCFi resulting from the application of different weighting sets.*

Country	$MCF_{i\text{ - SET EQ}}$ (US$/m³)	$MCF_{i\text{ - SET 1}}$ (US$/m³)	$MCF_{i\text{ - SET 2}}$ (US$/m³)	$MCF_{i\text{ - SET 3}}$ (US$/m³)	$MCF_{i\text{ - SET 4}}$ (US$/m³)	$MCF_{i\text{ - SET 5}}$ (US$/m³)	$MCF_{i\text{ - SET 6}}$ (US$/m³)
Albania*	20,50	21,79	22,93	34,58	26,28	20,87	22,36
Algeria	29,32	48,76	72,71	90,94	68,24	33,38	60,73
Argentina	7,86	8,82	10,63	13,33	10,77	7,88	9,72
Armenia	39,15	116,80	68,09	150,43	98,94	39,83	92,44
Australia	7,46	7,81	21,90	8,60	12,71	7,46	14,85
Austria	4,30	4,38	4,59	5,11	4,68	4,30	4,48
Azerbaijan	179,72	245,90	214,55	313,09	247,16	181,77	230,22
Bangladesh	69,62	207,77	98,52	217,37	152,84	77,49	153,14
Belarus*	15,68	16,33	18,09	26,43	20,22	15,95	17,21
Belgium	15,35	15,97	73,26	75,16	54,70	15,35	44,62
Benin*	3,39	4,21	7,30	7,63	6,30	3,72	5,76
Bolivia	13,71	41,57	22,82	43,45	31,44	14,56	32,19
Bosnia and Herzegovina	6,46	7,09	6,97	14,58	9,44	6,47	7,03
Botswana*	37,15	48,51	70,68	78,55	64,71	41,27	59,59
Brazil	1,45	2,26	1,54	2,44	1,98	1,64	1,90
Bulgaria	28,01	30,46	34,60	70,69	44,84	28,02	32,53
Burkina Faso	2,47	2,81	2,62	3,85	3,06	2,60	2,71
Cambodia*	7,94	14,51	13,85	19,46	14,90	8,25	14,18
Cameroon*	2,46	2,89	3,93	4,48	3,72	2,62	3,41
Canada	1,59	1,68	1,62	1,84	1,70	1,59	1,65
Chile*	9,80	16,92	14,86	21,10	16,57	10,57	15,89
China	8,95	26,06	16,14	27,72	20,50	9,21	21,10
Colombia	1,42	2,47	1,74	2,90	2,26	1,84	2,10
Costa Rica	0,17	0,25	0,19	0,29	0,23	0,18	0,22
Croatia	1,10	1,22	1,13	1,30	1,19	1,10	1,17
Cyprus*	19,05	21,20	38,60	36,94	31,91	19,18	29,90
Czech Republic	4,60	4,73	5,77	5,43	5,29	4,60	5,25
Denmark*	19,43	19,87	27,85	33,97	27,20	19,71	23,86
Dominican Republic*	2,84	4,22	3,44	5,06	4,02	2,89	3,83
Ecuador	13,78	18,07	18,68	21,71	18,80	13,97	18,37
Estonia	0,35	0,45	0,35	0,50	0,42	0,35	0,40
Finland	10,39	12,63	19,83	14,61	15,32	10,39	16,23
France	9,46	9,57	12,16	12,65	11,44	9,46	10,87
Gabon	0,46	0,51	0,47	0,56	0,50	0,46	0,49
Germany	3,41	3,51	3,83	4,01	3,77	3,41	3,67
Ghana*	6,28	8,46	14,23	15,02	12,34	7,11	11,34
Greece	8,51	8,63	30,00	31,70	23,42	8,52	19,31
Guatemala	0,59	0,89	0,75	1,02	0,84	0,60	0,82
Honduras	0,64	1,06	0,77	1,23	0,96	0,67	0,92
Hungary	1,44	1,52	1,50	1,80	1,59	1,44	1,51
Iceland*	0,64	0,68	0,76	1,09	0,84	0,65	0,72
India	258,73	409,16	367,98	472,44	396,75	290,48	388,57
Indonesia	13,50	16,67	16,95	19,98	17,39	13,84	16,81
Iran	124,15	139,27	150,64	189,39	157,40	125,07	144,96
Israel*	27,86	36,47	110,20	99,36	80,77	29,01	73,34

Country	MCF$_{i\text{ - SET EQ}}$ (US$/m³)	MCF$_{i\text{ - SET 1}}$ (US$/m³)	MCF$_{i\text{ - SET 2}}$ (US$/m³)	MCF$_{i\text{ - SET 3}}$ (US$/m³)	MCF$_{i\text{ - SET 4}}$ (US$/m³)	MCF$_{i\text{ - SET 5}}$ (US$/m³)	MCF$_{i\text{ - SET 6}}$ (US$/m³)
Italy	3,72	3,85	7,05	4,32	5,05	3,72	5,45
Jamaica*	47,18	68,97	55,78	80,84	65,04	48,05	62,37
Japan	0,35	0,37	0,38	0,41	0,38	0,35	0,37
Jordan*	94,99	102,82	136,37	145,46	127,12	96,24	119,60
Kazakhstan*	89,34	97,85	114,30	127,77	112,07	90,44	106,07
Kenya	407,36	439,91	713,27	855,48	668,54	433,81	576,59
Kuwait*	26,76	34,49	108,40	96,78	78,79	27,86	71,45
Lebanon	19,65	30,93	56,64	69,79	50,62	19,93	43,79
Liberia	1,17	1,54	1,36	1,75	1,51	1,28	1,45
Lithuania*	1,42	1,52	2,07	2,52	2,02	1,43	1,79
Macedonia	25,72	47,55	41,95	68,88	49,16	25,74	44,75
Madagascar	6,71	7,09	8,75	8,87	8,32	7,61	7,92
Malawi	1,28	1,61	1,56	1,85	1,64	1,37	1,59
Malaysia	2,08	2,17	2,57	2,70	2,47	2,08	2,37
Mali	63,70	88,38	82,30	101,04	88,35	75,06	85,34
Mexico	27,70	57,70	53,74	60,67	56,19	50,65	55,72
Morocco	186,02	302,16	270,09	462,78	326,59	191,64	286,13
Mozambique	20,56	30,88	35,12	33,38	32,77	28,73	33,00
Namibia*	1,62	1,81	2,70	2,98	2,48	1,70	2,26
Nepal*	211,62	560,27	353,94	669,78	472,14	225,12	457,10
Netherlands	6,12	6,38	14,46	6,83	9,18	6,12	10,42
New Zealand	0,50	0,52	0,65	0,72	0,63	0,50	0,59
Niger*	37,00	49,86	82,37	87,51	71,91	41,84	66,12
Norway	2,82	2,86	2,87	3,15	2,95	2,82	2,86
Oman*	16,78	27,13	52,49	54,63	43,15	17,52	39,81
Panama*	1,09	1,16	1,38	1,60	1,37	1,10	1,27
Paraguay	0,60	0,91	0,63	1,04	0,81	0,61	0,77
Peru	14,75	28,31	36,67	50,00	36,25	15,83	32,49
Philippines	9,83	13,54	17,43	14,99	14,77	10,23	15,48
Poland	6,51	6,52	6,78	10,14	7,81	6,52	6,65
Portugal	31,93	32,10	51,15	59,47	47,55	31,94	41,63
Romania	2,97	4,90	3,11	15,68	7,74	3,99	4,00
Russia	5,12	5,70	5,37	6,99	5,93	5,13	5,54
Rwanda*	4,00	5,00	7,89	8,52	7,03	4,38	6,45
Senegal	10,83	12,61	12,43	15,63	13,43	11,85	12,52
Slovakia	3,54	3,68	3,60	4,07	3,76	3,54	3,64
Slovenia	1,59	1,79	1,64	2,03	1,79	1,59	1,72
South Africa	351,70	370,66	474,92	515,62	450,72	352,58	422,79
Spain	97,84	98,43	141,45	153,88	131,16	97,84	119,94
Sudan	14,96	30,60	23,56	29,28	25,96	19,50	27,08
Suriname*	2,89	3,32	3,54	4,47	3,75	3,15	3,43
Swaziland	5,74	6,02	6,14	8,70	6,93	5,87	6,08
Sweden	3,25	3,28	3,26	3,94	3,49	3,25	3,27
Switzerland*	4,18	4,41	10,06	8,40	7,59	4,19	7,24
Tajikistan*	153,50	349,89	189,05	384,06	276,18	160,97	269,47
Tanzania	1,16	1,59	1,61	1,92	1,68	1,41	1,60
Thailand	17,48	20,60	27,96	32,27	26,45	17,62	24,28
Tunisia*	170,05	192,69	208,44	261,75	218,40	177,35	200,57
Turkey*	42,69	46,67	51,15	73,45	56,54	43,39	48,91
Turkmenistan*	15,07	41,38	18,69	44,37	30,59	16,03	30,04
Uganda*	5,58	6,56	9,36	10,49	8,70	5,95	7,96
UK, England and Wales	18,34	18,79	63,86	19,48	33,97	18,34	41,32

Country	$MCF_{i - SET\ EQ}$ (US$/m³)	$MCF_{i - SET\ 1}$ (US$/m³)	$MCF_{i - SET\ 2}$ (US$/m³)	$MCF_{i - SET\ 3}$ (US$/m³)	$MCF_{i - SET\ 4}$ (US$/m³)	$MCF_{i - SET\ 5}$ (US$/m³)	$MCF_{i - SET\ 6}$ (US$/m³)
Ukraine	32,42	41,14	38,99	48,91	41,60	32,64	40,07
United States	40,93	41,37	60,32	52,37	51,28	40,94	50,84
Uruguay*	0,26	0,36	0,36	0,47	0,38	0,28	0,36
Uzbekistan*	47,97	135,28	59,91	144,86	99,32	51,12	97,59
Vietnam	22,28	47,25	30,82	51,60	39,21	23,19	39,04
Zambia	7,19	7,98	8,27	10,54	8,82	7,35	8,12
Zimbabwe*	57,15	68,06	76,65	94,56	78,54	60,76	72,36

* MCF_i calculated according to continental proxy value.

According to Table 3.1, a total of 104 countries have been characterized. In particular, for 70 of them it was possible to adopt specific data for the development of each indicator (§ 2.2) and weighting factor (§ 2.2.1.1) to be applied in the proposed Eq. 2.2 (§ 2.2.1).

For the remaining 34 countries, since not all the data at specific country level needed for the development of the MCF_i were available, so they were adopted proxy values referred at the continental level, particularly Africa, Asia, Europe, Northern America, Latin America and the Caribbean, South America, Oceania.

This allowed to expand the new proposed sets of monetary characterization factors covering a higher number of countries.

As highlighted in Table 3.1, MCF_i ranges from an average of 0,22 $/m^3, among all the minimum values, to an average of about 602 $/m^3, among all the maximum values.

Moreover, all the minimum values among the different sets refer to the same country of Costa Rica, while all the maximum values refer to the country of Kenya, with the only exception in $MCF_{i - SET\ 1}$ where the maximum value is referred to Nepal, with Kenya however characterized by the second higher value among all of the same set.

Results substantially confirm the same trend for each set of monetary characterization factors, with very little deviations among the values associated to each country as demonstrated in the next Figure 3.1 where a graphical comparison of all the calculated MCF_i sets is provided.

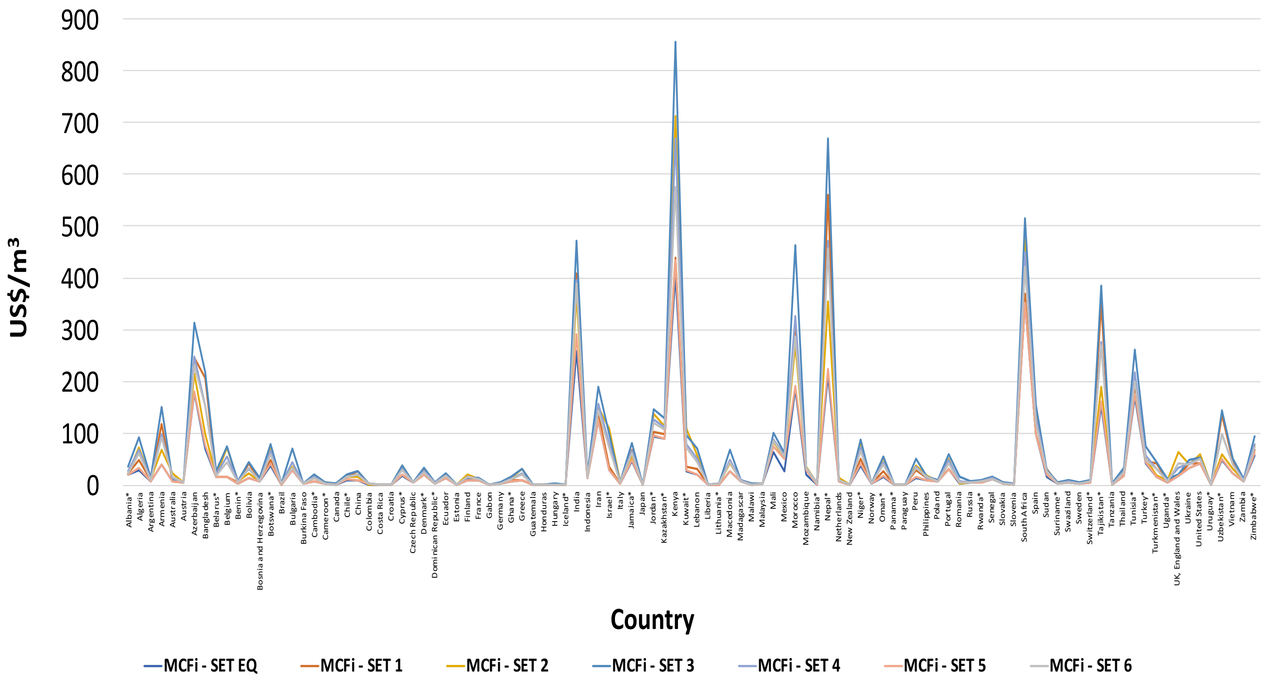

Figure 3.1 *Graphical comparison of all the proposed sets of monetary characterization factors.*

According to Figure 3.1, it is possible to observe that all the proposed sets have a very similar behavior, with peak points placed more or less in the same position among all the countries.

The most relevant variation when adopting a different set is thus related to the different absolute value of the specific monetary characterization factor of each country.

Observing each set individually, according to the graphical comparison reported in the next Figure 3.2, it is possible to observe that the trend of each resulting curve when all the values are ranked from the smallest to the largest is very close to each other, with a behavior more or less exponential for all the different sets.

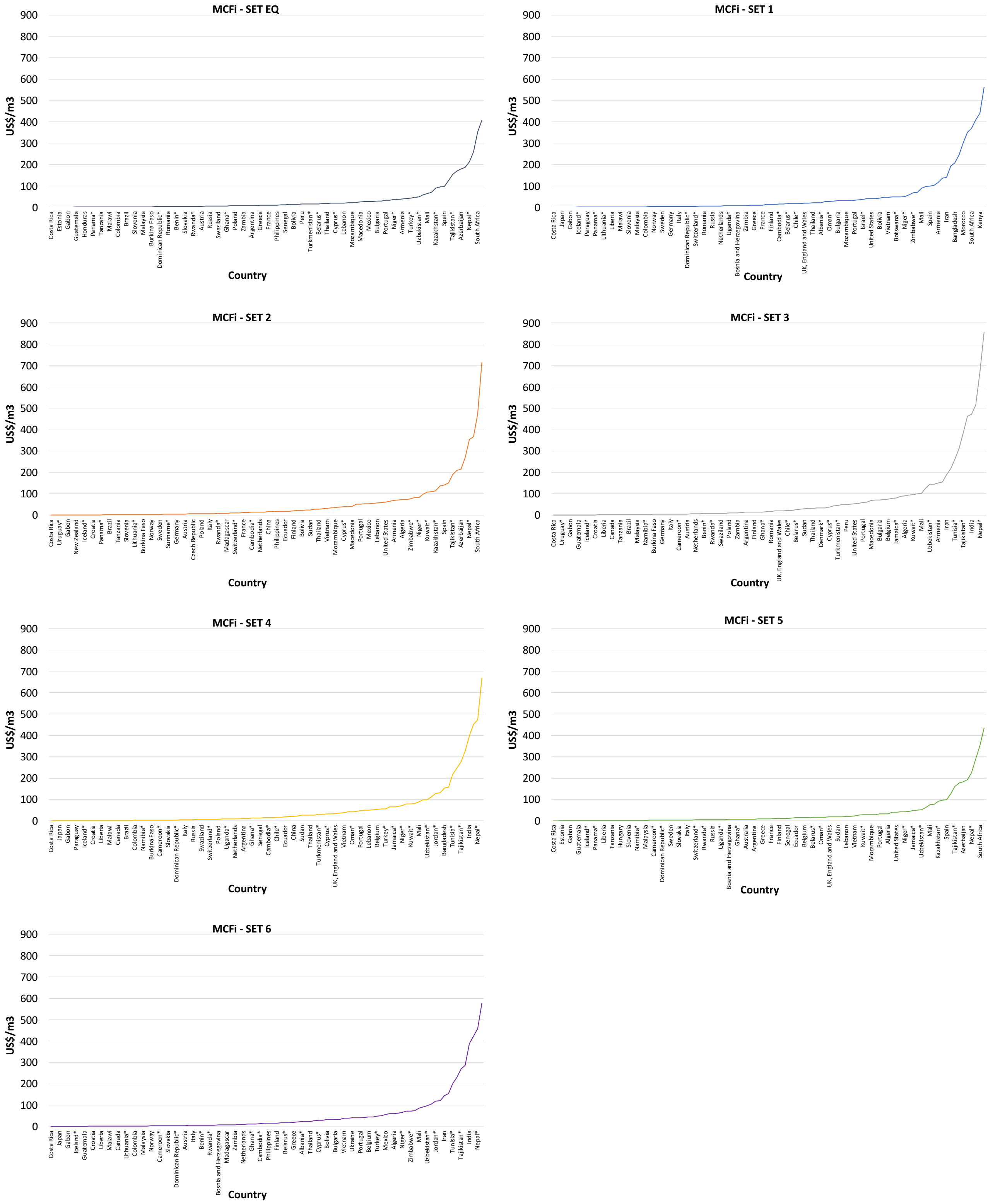

Figure 3.2 *Graphical comparison of the trend of each proposed set of monetary characterization factors, with values from the smallest to the largest.*

To provide a better comprehension about how the new proposed characterization factors may change across the different countries, in this research work it was also adopted a GIS software (QGIS Development Team, 2018) to create a specific thematic map in order to have a graphical view of the intensity of the proposed MCF_i according to the geographical position.
More in detail, since the different proposed sets are characterized by a very similar behavior as discussed above in this paragraph, with the only exception of differences of values in absolute terms, thus it was decided to include in this work the thematic map of only one set of MCF_i among all the seven developed.
This is justified by the fact that the maps resulting from the modeling though the GIS software were very similar each to other, with variations in color intensities not significant between each map.
According to what explained in the previous part of this research (§ 2.2.1.1), because of there is no consensus in the LCA community about how should be the best solution for the development and application of a set of weighting factors (Goedkoop and Spriensma, 2000; Finnveden et al., 2009; Sala et al., 2018), thus it was decided to adopt the $MCF_{i\text{ - SET 1}}$ as reference for the creation of the map through the GIS software, which is reported below in Figure 3.3.
Moreover, it was also created a thematic map of the existing water supply tariffs (IBNET, 2017) in order to have a comparison between the new proposed characterization factors to be applied in order to assess in monetary terms water scarcity impacts.

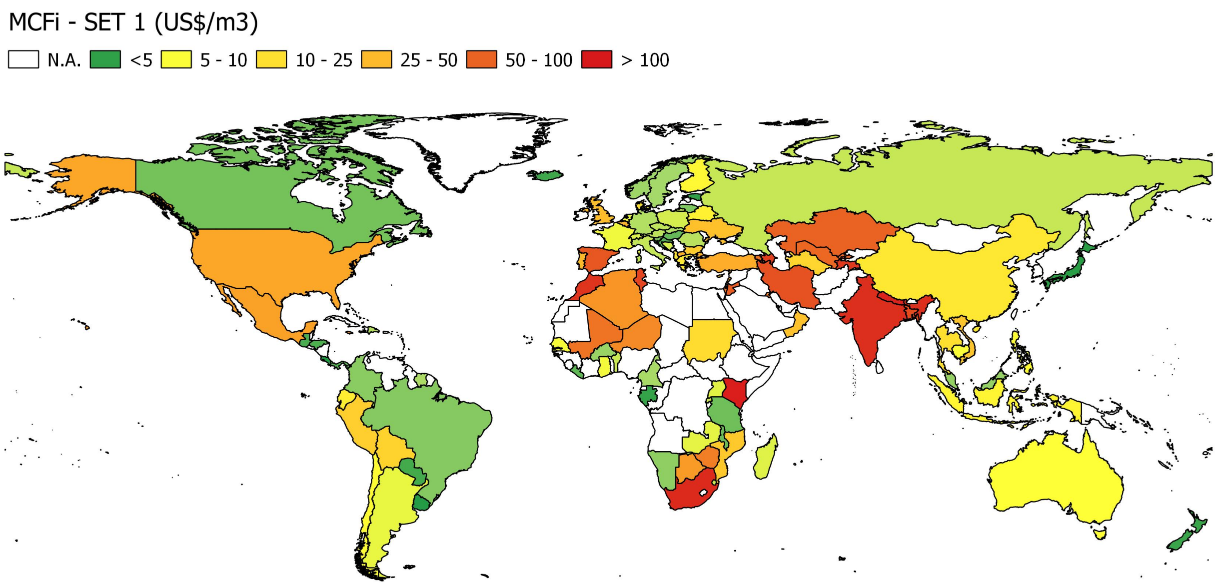

Figure 3.3 *Thematic GIS map representing the intensity of the monetary characterization factors (MCFi - SET 1 was chosen as reference).*

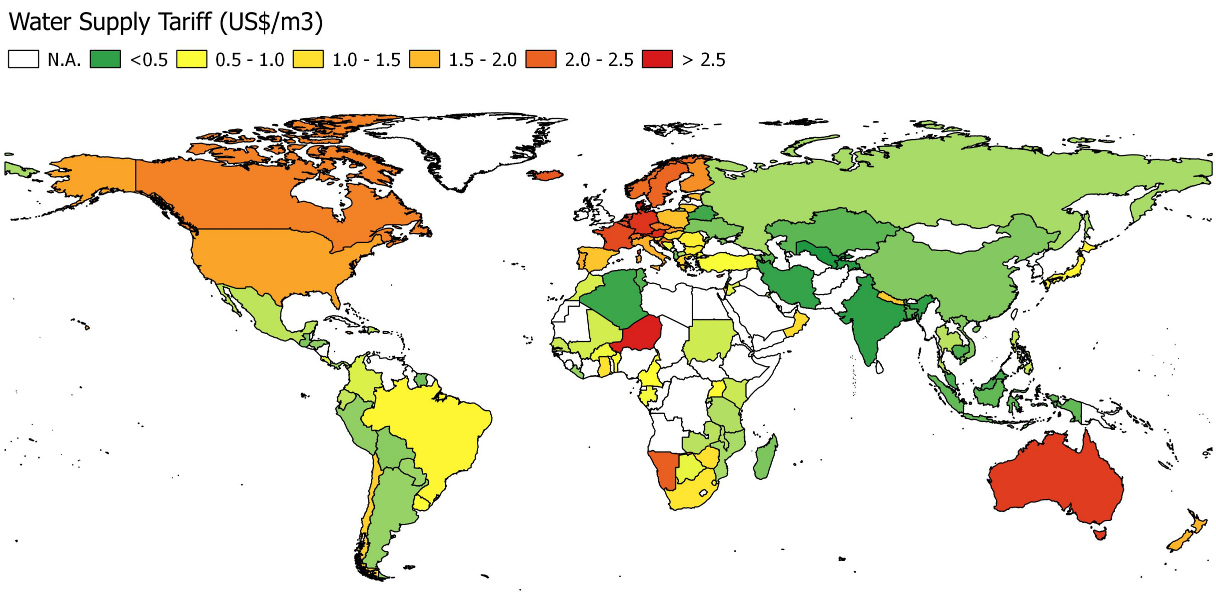

Figure 3.4 *Thematic GIS map representing the intensity of the water supply tariffs.*

Considering the two above thematic GIS maps, it is possible to observe in Figure 3.3 a trend characterized by the higher values, which are those above the world average monetary characterization factor value of 50 US$/m^3, located more or less in the central area of the world.

On the contrary, when comparing the MCF_i with the resulting thematic map of the water supply tariff in Figure 3.4, it is possible to observe that the countries more or less in the central area of the word are those characterized by the lower values, which are assumed below the world average water supply tariff value of 1,23 US$/m^3.

3.2 The resulting weighting sets

According to the criteria described in the previous chapter 2 (§ 2.2.1.1) for the calculation of the weighting factors W_{HH}, W_{ECO} and W_R to be used in the Eq. 2.2 (§ 2.2.1) in order to obtain the final new proposed monetary characterization factor MCF_i, in this paragraph the different developed weighting sets are reported.

Beyond the results from the adoption of the equal weighting approach, which refers to the adoption of the same weighting value of 1 for all the three parameters W_{HH}, W_{ECO} and W_R, in the next Table 3.2 all the results obtained from the adoption of the distance-to-target approach are listed.

Moreover, Table 3.3 provides a heat map of all the six weighting sets developed according to the criteria fixed in the Table 2.2 of the previous chapter 2 (§ 2.2.1.1).

Table 3.2 *Data on weighting factors developed for the definition of the six different combination of weighting sets.*

Country	Weighting factors							
	W_{HH}			W_{ECO}			W_R	
	#1	#2	#3	#4	#5	#6	#7	#8
	Indicator 3.9.2	Indicator 6.2.1	Indicator 15.1.2 (option 1)	Indicator 15.1.2 (option 2)	Indicator 15.5.1	Indicator 6.4.2	Indicator 6.4.2 (option 1)	Indicator 6.4.2 (option 1)
Albania	2,89	1,15	1,30	1,00	1,10	1,47	7,90	7,90
Algeria	2,26	1,02	1,70	1,00	1,16	1,00	3,52	1,00
Argentina	7,56	1,03	1,39	1,00	1,18	1,10	9,83	9,83
Armenia	1,43	1,00	1,40	1,00	1,16	1,00	4,02	1,00
Australia	1,36	1,00	1,30	1,00	1,12	1,00	1,00	1,00
Austria	8,95	1,25	1,30	1,00	1,10	1,00	9,03	9,03
Azerbaijan	5,04	1,23	1,30	1,00	1,23	1,00	4,99	1,00
Bangladesh	1,43	1,00	1,30	1,00	1,02	1,00	7,15	7,15
Belarus	6,92	1,18	1,30	1,00	1,14	1,00	3,69	1,00
Belgium	2,61	1,01	2,60	1,00	1,11	1,00	1,00	1,00
Benin	4,34	1,04	1,44	1,21	1,10	1,00	1,00	1,00
Bolivia	2,73	1,00	2,62	1,00	1,06	1,00	3,89	1,00
Bosnia and Herzegovina	1,94	1,37	1,63	1,00	1,01	1,00	1,00	1,00
Botswana	1,43	1,00	1,30	1,00	1,03	1,00	1,02	1,00
Brazil	9,61	1,13	1,30	1,00	1,26	1,00	4,78	1,00
Bulgaria	5,32	1,10	1,86	1,42	1,31	1,00	1,00	1,00
Burkina Faso	2,94	1,04	1,51	1,00	1,19	1,00	1,00	1,00
Cambodia	2,05	1,01	1,30	1,00	1,11	1,00	1,00	1,00
Cameroon	1,43	1,00	1,39	1,00	1,03	1,00	1,44	1,00
Canada	5,51	1,20	1,30	1,00	1,34	1,00	1,80	1,00
Chile	2,73	1,01	1,30	1,00	1,01	1,00	1,00	1,00
China	3,66	1,00	1,30	1,00	1,01	1,00	4,16	1,00
Colombia	1,30	1,00	1,47	1,00	1,10	1,00	1,81	1,00
Costa Rica	2,59	1,12	1,30	1,00	1,04	1,00	1,00	1,00
Croatia	1,43	1,00	1,43	1,00	1,02	1,00	1,20	1,00
Cyprus	1,08	1,00	1,62	1,00	1,18	1,00	7,11	7,11
Czech Republic	4,59	1,13	1,30	1,00	1,35	1,00	1,00	1,00
Denmark	3,66	1,16	1,51	1,00	1,31	1,00	1,00	1,00
Dominican Republic	1,43	1,00	1,35	1,00	1,08	1,00	1,00	1,00
Ecuador	3,33	1,14	1,30	1,12	1,37	1,00	9,67	9,67
Estonia	2,94	1,21	1,30	1,00	1,22	1,00	1,80	1,00
Finland	3,21	1,05	1,35	1,00	1,14	1,50	9,12	9,12
France	1,24	1,00	1,36	1,00	1,09	1,00	2,73	1,00
Gabon	1,42	1,00	1,31	1,00	1,22	1,00	1,00	1,00
Germany	1,90	1,73	1,59	1,00	1,19	1,00	9,97	9,97
Ghana	3,50	1,06	1,30	1,00	1,09	1,00	8,30	8,30
Greece	2,55	1,46	1,30	1,00	1,12	1,00	1,00	1,00

Country	Weighting factors							
	W_{HH}			W_{ECO}			W_R	
	#1	#2	#3	#4	#5	#6	#7	#8
	Indicator 3.9.2	Indicator 6.2.1	Indicator 15.1.2 (option 1)	Indicator 15.1.2 (option 2)	Indicator 15.5.1	Indicator 6.4.2	Indicator 6.4.2 (option 1)	Indicator 6.4.2 (option 1)
Guatemala	7,58	1,01	1,30	1,00	1,03	1,00	5,26	5,26
Honduras	1,53	2,27	1,30	1,00	1,20	1,00	1,00	1,00
Hungary	2,17	1,32	1,30	1,00	1,24	1,00	1,00	1,00
Iceland	1,83	1,04	1,30	1,00	1,27	1,00	1,00	1,00
India	2,40	1,64	1,30	1,00	1,02	1,00	2,69	1,00
Indonesia	3,91	1,08	1,40	2,00	1,41	1,00	7,56	7,56
Iran	5,57	1,22	1,66	1,00	1,12	1,00	8,44	8,44
Israel	2,46	2,16	1,30	1,00	1,16	1,00	1,97	1,00
Italy	1,43	1,00	1,30	1,00	1,04	1,00	3,06	1,00
Jamaica	1,43	1,00	1,61	1,00	1,46	1,00	1,00	1,00
Japan	1,25	1,00	1,30	1,00	1,05	1,00	1,00	1,00
Jordan	4,99	1,17	1,30	1,00	1,05	1,00	1,00	1,00
Kazakhstan	3,51	1,20	1,51	1,00	1,37	1,00	7,16	7,16
Kenya	2,14	1,12	1,30	1,00	1,42	1,00	3,96	1,00
Kuwait	1,08	1,03	1,62	1,00	1,05	1,00	1,00	1,00
Lebanon	1,15	1,01	1,46	1,00	1,16	1,00	5,73	5,73
Liberia	4,56	1,07	6,60	1,48	1,06	1,00	1,00	1,00
Lithuania	2,95	1,04	1,30	1,00	1,04	1,00	1,11	1,00
Macedonia	1,66	1,38	1,51	1,00	1,05	1,00	1,13	1,00
Madagascar	1,71	1,00	1,30	1,00	1,04	1,00	1,00	1,00
Malawi	2,05	1,00	1,30	1,00	1,07	1,00	1,00	1,00
Malaysia	3,46	1,11	1,31	1,00	1,24	1,00	6,87	6,87
Mali	1,40	1,00	1,31	1,00	1,18	1,00	7,15	7,15
Mexico	3,42	1,54	1,00	1,00	1,04	1,56	3,18	1,00
Morocco	2,16	1,54	1,51	1,00	1,05	1,00	1,00	1,00
Mozambique	1,43	1,00	1,30	1,00	1,01	1,00	1,00	1,00
Namibia	2,37	1,82	1,6	1,0	1,32	1,00	1,00	1,00
Nepal	2,11	1,05	1,30	1,00	1,20	1,00	5,34	5,34
Netherlands	1,56	1,00	1,30	1,00	1,20	1,00	3,95	1,00
New Zealand	3,28	1,03	1,30	1,00	1,06	1,00	3,00	1,00
Niger	1,43	1,01	1,30	1,00	1,18	1,00	4,99	1,00
Norway	4,99	1,15	1,30	1,00	1,26	1,00	3,50	1,00
Oman	4,38	1,69	1,38	1,00	1,14	1,00	1,00	1,00
Panama	2,15	1,01	1,66	1,02	1,07	1,00	2,68	2,05
Paraguay	2,15	1,01	1,66	1,02	1,07	1,00	2,68	2,05
Peru	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82
Philippines	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82
Poland	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Portugal	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82

Country	Weighting factors							
	W_{HH}			W_{ECO}			W_R	
	#1	#2	#3	#4	#5	#6	#7	#8
	Indicator 3.9.2	Indicator 6.2.1	Indicator 15.1.2 (option 1)	Indicator 15.1.2 (option 2)	Indicator 15.5.1	Indicator 6.4.2	Indicator 6.4.2 (option 1)	Indicator 6.4.2 (option 1)
Romania	4,69	1,13	1,49	1,09	1,21	1,00	2,74	1,88
Russia	2,15	1,01	1,66	1,02	1,07	1,00	2,68	2,05
Rwanda	2,15	1,01	1,66	1,02	1,07	1,00	2,68	2,05
Senegal	3,73	1,11	1,44	1,00	1,28	1,00	1,00	1,00
Slovakia	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82
Slovenia	2,15	1,01	1,66	1,02	1,07	1,00	2,68	2,05
South Africa	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Spain	3,73	1,11	1,44	1,00	1,28	1,00	1,00	1,00
Sudan	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Suriname	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Swaziland	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Sweden	2,15	1,01	1,66	1,02	1,07	1,00	2,68	2,05
Switzerland	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82
Tajikistan	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Tanzania	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82
Thailand	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Tunisia	3,73	1,11	1,44	1,00	1,28	1,00	1,00	1,00
Turkey	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82
Turkmenistan	4,69	1,13	1,49	1,09	1,21	1,00	2,74	1,88
Uganda	2,15	1,01	1,66	1,02	1,07	1,00	2,68	2,05
UK, England and Wales	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Ukraine	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82
United States	2,15	1,01	1,66	1,02	1,07	1,00	2,68	2,05
Uruguay	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Uzbekistan	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82
Vietnam	4,69	1,13	1,49	1,09	1,21	1,00	2,74	1,88
Zambia	4,36	1,11	1,31	1,01	1,23	1,05	5,56	4,48
Zimbabwe	2,72	1,53	1,39	1,00	1,13	1,06	3,13	2,82

Table 3.3 *Heat map showing the relative importance of the weighting factors W_{HH}, W_{ECO}, W_R according to the different proposed weighting sets.*

Country	Weighting sets																	
	SET 1			SET 2			SET 3			SET 4			SET 5			SET 6		
	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R
Albania	52	24	24	21	23	56	37	28	35	33	26	40	33	34	33	35	23	41
Algeria	54	19	27	11	11	78	24	11	65	23	13	65	32	28	41	26	14	60
Argentina	53	23	23	18	20	62	46	34	20	34	27	39	34	33	33	33	22	45
Armenia	78	10	11	9	10	82	40	7	52	35	10	56	33	32	35	40	10	50
Australia	42	29	29	16	19	65	37	37	26	28	27	46	33	33	33	25	22	52
Austria	41	30	30	32	36	32	37	35	27	36	34	30	33	33	33	36	33	31
Azerbaijan	82	9	9	11	10	79	46	7	47	41	9	50	38	31	31	46	9	45
Bangladesh	72	14	14	17	17	67	69	18	14	47	18	35	38	31	31	43	15	41
Belarus	52	24	24	21	23	56	37	28	35	33	26	40	33	34	33	35	23	41
Belgium	42	29	29	11	11	78	14	13	72	16	15	69	33	33	33	19	16	65
Benin	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
Bolivia	78	11	11	20	19	61	75	14	11	57	16	27	37	31	31	54	14	31
Bosnia	57	22	22	32	35	32	42	42	16	41	36	23	34	33	33	47	27	26
Botswana	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
Brazil	66	19	15	33	35	32	64	21	15	54	25	20	32	37	31	56	24	21
Bulgaria	58	21	21	17	18	65	43	41	16	35	29	36	33	33	33	35	19	46
Burkina Faso	49	25	25	41	30	30	42	36	22	43	31	26	41	30	30	45	27	27
Cambodia	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Cameroon	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
Canada	42	29	29	33	34	34	38	35	27	36	33	30	33	33	33	38	31	31
Chile	69	16	15	22	24	54	58	18	23	48	21	31	35	34	31	49	19	32
China	83	9	9	16	18	67	81	11	8	61	13	26	36	32	32	57	12	31
Colombia	69	18	13	32	38	29	65	23	12	56	27	17	31	40	28	58	24	18
Costa Rica	59	20	20	32	37	31	54	28	18	47	29	24	34	33	33	49	27	24
Croatia	51	25	25	32	36	32	47	30	23	42	31	27	34	33	33	43	29	28
Cyprus	52	24	24	21	23	56	37	28	35	33	26	40	33	34	33	35	23	41
Czech Republic	42	29	29	29	30	41	37	36	26	35	33	33	33	33	33	35	29	35
Denmark	52	24	24	21	23	56	37	28	35	33	26	40	33	34	33	35	23	41
Dominican Rep.	65	17	17	33	38	29	60	23	16	52	27	21	36	32	32	53	25	22
Ecuador	73	13	13	28	31	41	71	17	13	58	21	22	38	31	31	57	20	24
Estonia	58	21	21	33	34	33	54	26	20	47	28	25	33	33	33	48	26	26
Finland	65	18	18	16	16	67	61	22	17	42	20	37	33	33	33	39	17	44
France	39	30	30	26	28	46	34	39	27	32	33	35	33	33	33	32	29	39
Gabon	56	22	22	35	33	32	53	27	20	47	28	25	36	32	32	48	26	26

Country	SET 1			SET 2			SET 3			SET 4			SET 5			SET 6		
	Weighting sets																	
	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R
Germany	42	29	29	31	32	37	37	37	26	35	33	31	33	33	33	37	30	33
Ghana	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
Greece	35	33	33	11	13	77	11	17	72	14	17	69	33	33	33	17	18	66
Guatemala	70	15	15	32	39	29	67	19	15	56	24	20	36	32	32	57	23	20
Honduras	65	18	18	34	38	29	59	24	16	51	27	21	37	32	32	53	25	22
Hungary	42	29	29	33	35	32	38	36	26	36	34	30	33	33	33	37	32	31
Iceland	52	24	24	21	23	56	37	28	35	33	26	40	33	34	33	35	23	41
India	61	21	18	9	11	79	23	9	68	22	12	66	35	34	31	25	14	61
Indonesia	60	20	20	29	29	43	56	25	19	46	26	28	38	31	31	45	24	31
Iran	56	18	26	9	10	81	23	10	67	22	12	67	30	28	42	25	13	62
Israel	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Italy	38	31	31	21	23	57	35	38	28	29	30	41	33	33	33	28	26	46
Jamaica	65	17	17	33	38	29	60	23	16	52	27	21	36	32	32	53	25	22
Japan	42	29	29	31	38	31	38	35	27	36	35	30	33	33	33	36	33	30
Jordan	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Kazakhstan	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Kenya	49	26	26	13	9	77	14	12	74	18	13	69	46	27	27	22	13	65
Kuwait	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Lebanon	64	18	18	10	10	79	27	10	63	25	12	63	35	33	33	29	13	58
Liberia	56	22	22	41	31	28	53	27	21	48	27	24	42	29	29	49	26	25
Lithuania	52	24	24	21	23	56	37	28	35	33	26	40	33	34	33	35	23	41
Macedonia	79	10	10	14	14	72	54	9	37	46	12	42	33	33	33	51	12	37
Madagascar	43	28	28	51	27	22	40	34	26	47	29	25	53	23	23	48	27	25
Malawi	52	24	24	37	35	28	49	29	22	45	30	25	40	30	30	45	29	26
Malaysia	48	26	26	31	38	30	44	31	24	40	33	28	34	33	33	40	32	28
Mali	55	23	23	31	19	50	51	28	21	43	24	33	45	27	27	42	21	38
Mexico	57	29	14	11	14	75	30	11	59	26	17	57	26	49	24	29	20	50
Morocco	74	13	13	11	10	78	36	11	54	32	12	56	38	31	31	37	12	51
Mozambique	55	22	22	41	22	37	52	27	21	48	24	28	52	24	24	47	22	30
Namibia	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
Nepal	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Netherlands	42	29	29	20	20	60	38	35	27	30	28	42	33	33	33	28	24	48
New Zealand	42	29	29	29	42	29	35	40	25	34	38	28	33	33	33	35	36	29
Niger	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
Norway	39	31	31	33	35	33	35	37	28	35	34	31	33	33	33	36	33	32
Oman	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46

Country	Weighting sets																	
	SET 1			SET 2			SET 3			SET 4			SET 5			SET 6		
	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R	W_{HH}	W_{ECO}	W_R
Panama	65	17	17	33	38	29	60	23	16	52	27	21	36	32	32	53	25	22
Paraguay	71	14	14	36	33	31	68	18	14	59	22	19	37	32	32	60	20	20
Peru	64	18	18	12	14	74	29	12	59	27	15	58	38	31	31	31	16	54
Philippines	52	24	24	17	22	61	48	29	23	34	26	41	36	32	32	31	23	47
Poland	35	32	32	33	34	33	29	44	27	32	37	31	34	33	33	34	33	32
Portugal	37	32	32	13	15	73	14	17	69	17	19	64	34	33	33	20	20	61
Romania	65	21	14	34	34	32	37	54	8	41	44	15	30	42	28	55	25	20
Russia	60	20	20	33	33	35	56	25	19	48	27	25	34	33	33	49	25	26
Rwanda	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
Senegal	45	27	27	39	30	32	40	36	24	40	32	28	41	30	30	42	28	30
Slovakia	46	27	27	33	34	33	43	32	25	39	32	29	33	33	33	40	30	30
Slovenia	51	25	25	33	35	33	47	30	23	42	31	27	33	33	33	43	29	28
South Africa	63	18	18	12	13	74	30	11	59	27	14	59	36	32	32	31	15	54
Spain	41	29	29	11	13	77	14	13	73	16	16	68	33	33	33	19	17	64
Sudan	57	17	26	27	18	55	63	18	18	46	19	35	38	24	38	42	17	40
Suriname	69	16	15	22	24	54	58	18	23	48	21	31	35	34	31	49	19	32
Swaziland	52	24	24	43	29	28	46	32	21	46	29	25	44	28	28	48	26	26
Sweden	42	29	29	33	33	33	38	35	27	37	33	30	33	33	33	38	31	31
Switzerland	52	24	24	21	23	56	37	28	35	33	26	40	33	34	33	35	23	41
Tajikistan	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Tanzania	54	23	23	44	32	24	48	32	20	48	29	23	48	26	26	49	27	23
Thailand	51	24	24	14	16	70	24	15	61	24	18	59	34	33	33	27	19	54
Tunisia	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
Turkey	52	24	24	21	23	56	37	28	35	33	26	40	33	34	33	35	23	41
Turkmenistan	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Uganda	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40
UK	44	28	28	16	20	64	40	34	26	29	26	45	33	33	33	26	23	51
Ukraine	62	19	19	20	21	59	59	23	18	44	23	34	34	33	33	42	20	39
United States	42	29	29	14	16	70	38	35	27	26	25	49	34	33	33	23	21	56
Uruguay	69	16	15	22	24	54	58	18	23	48	21	31	35	34	31	49	19	32
Uzbekistan	68	16	16	14	16	70	43	13	44	36	16	49	35	32	33	38	16	46
Vietnam	71	14	14	19	21	59	68	18	14	50	20	30	36	32	32	48	18	35
Zambia	69	16	16	44	30	26	65	20	15	58	23	19	46	27	27	59	21	20
Zimbabwe	57	21	22	26	19	54	39	20	41	38	21	42	43	28	30	40	20	40

Table 3.3 shows the resulting relative importance of each weighting factor W_{HH}, W_{ECO}, W_R listed in Table 3.2 according to the different approach adopted to develop the six proposed weighting sets.
Darker shades of red color (higher numbers) represent higher relative incidence of the weighting factor, while darker shades of green color (lower numbers) represents lower relative incidence of the weighting factor.
According to the results obtained, it is possible to observe that the set 1 is the one characterized by an average higher incidence of the area of protection human health (about 60%), in opposition to the set 2 that is the one characterized by the higher incidence of the area of protection resources (about 60%).
Set 3 shows a flat distribution among the 3 AoP, with a slightly higher incidence of the AoP human health and ecosystem (about 40% for both), as well as set 4 and set 6.
Finally, set 5 is characterized by a more or less equal repartition of the relative importance among the 3 AoP.
For a better comprehension of the relative importance of the developed weighting factors among the 3 different AoP, in the next Figure 3.5 a graphical representation through the adoption of ternary triangles is reported for each proposed weighting set.
This kind of representation, also known as mixing triangles, which is typically adopted in areas such as chemistry, geology, and metallurgy (Hofstetter et al., 1999) has been adopted so far also within the LCA community for the graphical display of choices with respect to weighting (Hosseinijou et al., 2014; Dal Pozzo et al., 2017; Santos et al., 2017; Gear et al., 2018; Tarne et al., 2018).
Each mixing triangle reported in Figure 3.5 represents the combinations of the relative weights for the three areas of protection human health, ecosystems and resources according to the specific weighting set of reference (6 in total).
For each point in the mixing triangle, which refers to a single country, the relative weights always add up to 100%. Observing the graphics, each corner represents a weight of 100% for a specific area of protection: the top corner refers to the combination where AoP ecosystems is weighted 100%, giving 0% of weight to the other AoP; the left and the right bottom corner refer to the combination where respectively AoP human health and AoP resources are weighted 100%, giving 0% of weight to the other AoP.

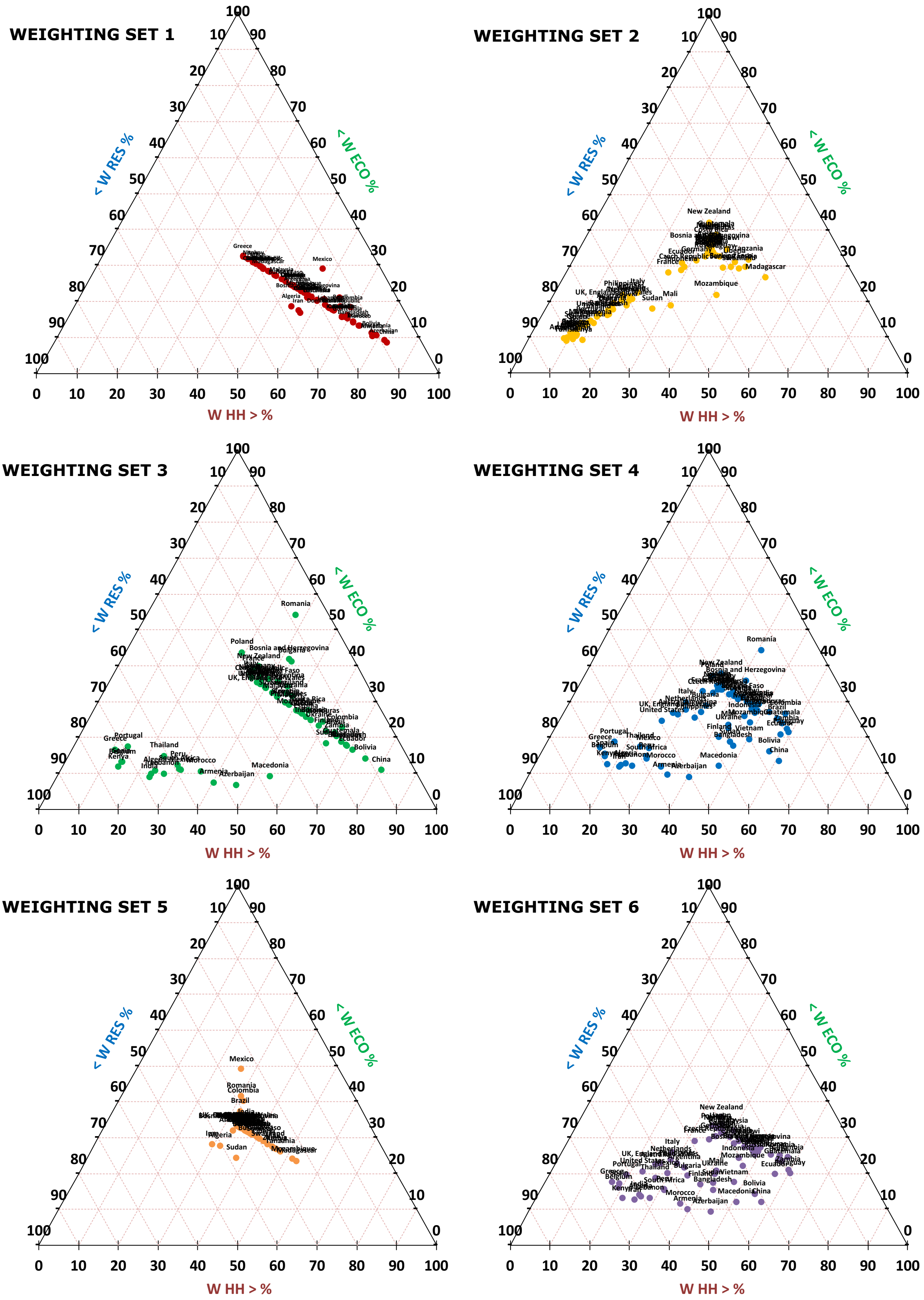

Figure 3.5 *Graphical representation of the weighting sets according to the mixing triangles.*

Each mixing triangle in Figure 3.5 highlights the different distribution of the weights according to each proposed weighting combination, with set 1 characterized by the most uniform distribution of the points, followed by set 2, set 5 and set 6 characterized by a less homogeneous distribution. Set 3 and 4, instead, show an uneven distribution with a split of the cloud of points into two main parts.

3.3 Results from the review of the monetary base constant

According to the step of the sensitivity analysis proposed in this research that refers to the possibility to improve the monetary base constant MK (§ 2.2), according to the assumptions described in the previous chapter 2 (§ 2.2.1.2), in this paragraph the results from the assessment are reported.
Starting from the value of 1,23 $/m^3 initially assumed for MK, it was observed the possibility to integrate this value obtaining a revised one able to account for all the three LCA areas of protection. To do that, additional information assumed as proxy for the AoP human health and ecosystems have been taken from the Stepwise2006 method from Weidema (2009), integrating thus the AoP resources already accounted by MK since the value of 1,23 $/m^3 has been derived from the average world water supply tariff.
After an adaptation of the data from the Stepwise2006 method, in order to allow their sum all together accounting finally for all the three AoP, the new value of MK resulted to be equal to 1,29 $/m^3, with a very low variation if compared to the initial one.
According to the developed Eq. 2.2 (§ 2.2.1), MK has to be multiplied by the dimensionless index EI_i (§ 2.2.1) in order to obtain the final new proposed monetary characterization factor MCF_i of each i-th country.
Because of the linearity between MK and EI_i, thus also the variation in the final results from the application of the MCF_i modified according to the new value of MK will be very low, particularly less than 5% according to the difference between MK pre and post review.
Moreover, the aim of this research work is to assess only the effects due to water consumption, thus to consider only the single impact category of water scarcity, whereas the monetary values from Stepwise method have been obtained by the author accounting for many different impact categories, generating a consequent overestimation in the final value of MK.
For these reasons it was concluded that at this stage no further implementation of the parameter could be significant for the scope of this research work.
However, the results from the application of the modified MK to one set of monetary characterization factors as an example, in particular the one calculated according to the distance-to-target approach

($MCF_{i - SET 1}$), will be provided in the next paragraph 3.4 together with the results from the application of the new proposed method in the 4 real case studies, in order to confirm the negligible effects on final results from the adoption of the reviewed value of MK.

3.4 Results from the application of the new proposed method in real case studies

According to the objective of this research work to test the new proposed method described in the chapter 2 (§ 2.2), 4 real case study (three concerning products, one concerning a service) selected in the national context have been chosen as follows:

i. A jar packaged ice cream.
ii. A fresh mozzarella cheese packaged.
iii. A Parma ham with bone seasoned for 12 months.
iv. A hospital laundry service.

In order to meet the aim of the test, which is to apply the new proposed method adopting an LCA approach (§ 2.3), the next paragraphs provide a deep description of the modelled product systems, in particular providing detailed information about the life cycle phases of goal and scope definition and life cycle inventory that are preparatory for the next impact assessment where final results are reported. The research is based on primary data collected directly from the involved companies, and secondary data coming from databases widely recognized by the LCA scientific community, statistical data from institutions (e.g. the Italian Institute for Environmental Protection and Research – ISPRA, for data about waste treatment) and data published in peer review papers. During the description of each case studied the origin of data used to perform the study will be provided.

3.4.1 Case study #1: Ice cream

The first case study investigated to test the applicability and effectiveness of the new proposed method for the assessment in monetary terms of water scarcity impacts concerns a jar packaged ice cream produced by a company in the middle Italy.
The company in recent years has started implementing an internal policy aimed to address the environmental sustainability in ice cream production, performing studies to investigate the key features of its processes.

This product system was thus chosen according to the company needs to deeply investigate the water topic, according to the increasing awareness on the importance that a proper management of water resource may have for a company operating in the food sector.
For confidentiality reason any reference to the company and its suppliers has been omitted in the description, as well as any sensitive data that was described only in qualitative terms.

3.4.1.1 Goal and scope definition

The goal of this case study application is to test the new proposed method for the assessment of water scarcity impacts in monetary terms applying the new developed sets of monetary characterization factors, performing a hotspots analysis of the results throughout the life cycle stages of the jar packaged ice cream under study.
Moreover, according to the criteria described in the previous chapter 2 (§ 2.2.1), a sensitivity analysis is also performed applying the new proposed method to 4 existing water scarcity impact assessment methods selected according to the criteria defined in the previous chapter 2 (§ 2.2.1.3).
The analysis was aimed on the one hand to provide a description of water scarcity impacts in monetary terms identifying the processes of the whole product supply chain characterized by the most significant contribution to the total impact, on the other hand to understand if this may change according to different water scarcity impact assessment methods.

The product under study belong to a famous brand of the company realized in Italy since the '50, characterized by a net weight of 500g contained in a plastic jar packaging (Figure 3.6).

Figure 3.6 *Jar packaged ice cream product.*

The product under study consists in a single mixture of ice cream composed mainly of water, which is the most incident ingredient in quantitative terms, and glucose syrup, skimmed milk powder, egg yolk, cream and butter.

Function, functional unit and reference flow

The function of the product under study is to satisfy a human food need that can be usually linked to the energy and nutrient requirements but more often to the need to feed.

The functional unit (FU) and the reference flow in this study match each other, corresponding to 1 kg of ice cream packaged in plastic jar, produced by an Italian company located in the middle Italy and distributed and consumed in the Italian market.

System boundary

The system boundary has been defined including all the processes attributable to the product in its whole life cycle according to the adopted reference year of 2017. All the elementary flows entering /leaving the system have been accounted for all the product life cycle stages, according to the schematic flow chart of Figure 3.7, adopting a cradle to grave approach. Each life cycle stage has been analyzed to identify all the process units responsible for water resource consumption, according to the following description:

- Raw materials: starting from their production, including also the mid-term processing and the transport to the company plant.
- Packaging: considering production and transport to the plant of all the elements adopted for the primary packaging, including also the secondary and tertiary packaging need for the final distribution in the market.
- Production: considering all the processing involved in the production of the ice cream, focusing on inputs and outputs flows of the production plant (e.g. water consumption, energy consumptions, auxiliary materials, wastes, etc.).
- Distribution: considering the refrigerated transport of the final product from the plant to the different stores placed in the Italian market, including also the final disposal of wastes generated by the secondary and tertiary packaging.
- Use: considering processes linked to the consumption of the product by the final user.
- End of life: corresponding to the final dismission of the primary packaging of the product.

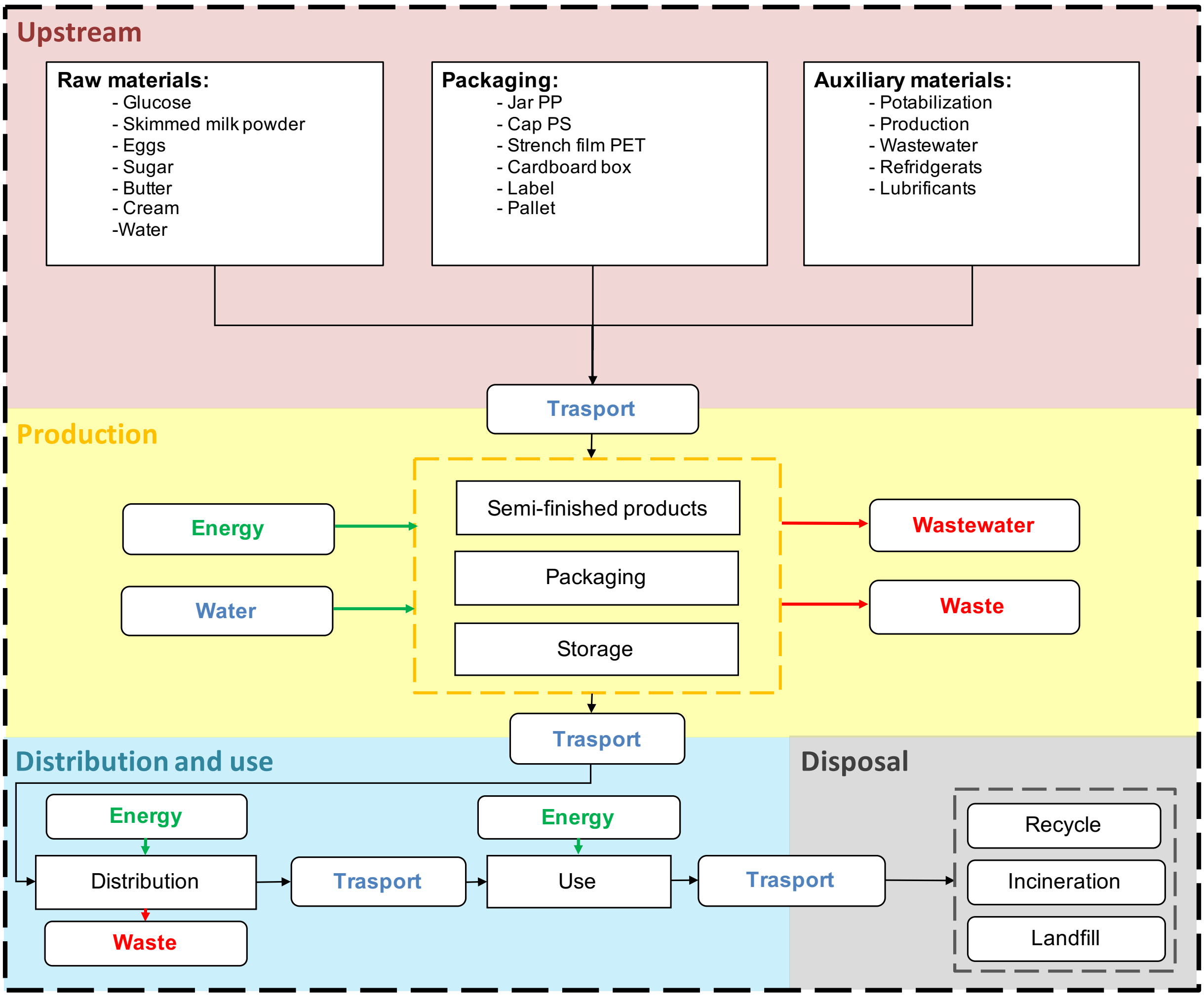

Figure 3.7 *Schematic representation of the system boundaries of the jar packaged ice cream according to the different life cycle stages.*

Cut-off and allocation rules

In this study a cut-off rule of 1% by mass was used, avoiding thus the collection of data representing a percentage of the total flows less than 1%. Flows within this threshold are typically those characterized by a not significant mass with respect to the total or those for which it was impossible to collect specific data.

However, all processes for which data were available although their contribution was less than 1%, were included in the analysis. This choice is confirmed by several LCA studies in the literature (Humbert et al., 2009).

Furthermore, in modeling the recycling operations within the end of life stage it was applied the cut-off approach that gives null impacts to these kind of processes (Frischknecht, 2010), associating the

100% of impacts from recycling operations to the next product system in which the recycled material will be used.

According to the standard requirements (ISO 14044, 2006) in this study some allocations were performed considering the physical properties (mass, volume) of the fluxes to be allocated. Table 3.4 contains all the allocation criteria applied in this study.

Table 3.4 *Allocation rules applied according to the different kind of data collected for the modeling of the jar packaged ice cream.*

Elementary flow	Cause	Allocation rule
Chemicals for water pre-treatment	Data were available according to the total amount consumed by the plant	Total volume of water withdrawn from groundwater wells
Chemicals for wastewater treatment	Data were available according to the total amount consumed by the plant	Total volume of wastewater processed by the treatment plant
Chemicals for equipment maintenance	Data were available according to the total amount consumed by the plant	Total mass of ice cream mixture produced in the plant
Refrigerant gas	Data were available according to the total amount consumed by the plant	Total mass of ice cream mixture produced in the plant
Electricity energy for raw material processing of sugar, butter and cream	Data were available for these raw materials according to the total amount processed in the plant	Total mass of each raw material processed in the plant
Electricity energy of auxiliary services	Data were available according to the total amount consumed by the plant	Total mass of ice cream mixture produced in the plant
Electricity energy internal wastewater treatment plant	Data were available according to the total amount consumed by the treatment plant	Total volume of wastewater processed by the treatment plant
Thermal energy	Data were available according to the total amount consumed by the plant	Total mass of ice cream mixture produced in the plant
Wastes	Data were available according to the total amount produced by the plant	Total mass of ice cream mixture produced in the plant

<u>*Data quality*</u>

In this study data collection has been performed giving priority to primary information collected on site, particularly those related to production processes and packaging that are directly under control of the company, and when this was not feasible secondary data from reliable sources.

Considering the production life cycle stage, the main data collected have been energy and water consumptions, wastes, input and output of water resources, total amount of final products, chemicals consumption and specific product recipe.

Considering the packaging life cycle stage, the main data collected concern all the elements involved in the final product distribution, including also the packaging of the raw materials entering the plant.

According to the distribution life cycle stage, all the logistic fluxes have been characterized considering distance and type of vehicle involved in the distribution of the final product to the store.

Data collected about agricultural process involved in raw materials production, as well as packaging production, use and end of life stages have been collected from a mix of secondary sources, adopting widely accepted database and technical report from national institutions.

The whole data quality level has been assessed by a critical review according to the following requirements fixed by the reference standard (ISO 14044, 2006):

- Time-related coverage: this requirement has been met adopting primary data from the most recent representative period, with the 2017 adopted as reference year in this study. When only secondary data were available, the most recent and representative ones have been selected for the collection. Furthermore, the reference datasets adopted were those referred to the most recent version available at the time of the modeling.
- Geographical coverage: to meet this requirement all primary data collected are site specific and, when this was not possible, the reference datasets adopted have been selected considering the average production from the country of origin or the most representative market as proxy (e.g. European context).
- Technology coverage: data collected in this study concerns technologies representative as much as possible of the real production system under study.
- Completeness: according to this requirement the percentage of primary data collected is good, having the possibility to integrate to the information under the direct control of the company also data about the suppliers and the raw materials produced in other plants extracted from the available technical data sheets, which refer to materials composition and place of production. For all the secondary data collected, assumptions were made according to benchmark analysis and industry practices. Finally, the cut-off rule which is usually fixed at 5% by weight of the product materials, in this study has been fixed at 1% with and expected no effect on the outcome of the final results.

- Consistency: this requirement has been met by a consistent and uniform implementation of the new method proposed in this research work to all the components of the product under study, in terms of modeling and assumptions made.
- Reproducibility: to meet this requirement the modeling has been performed allowing its implementation also in another similar study.
- Uncertainty: primary data are characterized by an almost total absence of uncertainty, while the most part of the secondary data concern datasets containing uncertainty information.

To model the product system under study the LCA software SimaPro version 8.5.2.0 has been used (PRé Consultants, 2018), adopting the databases Ecoinvent v3.1 (Ecoinvent, 2014) and Agri-footprint v1.0 (Agri-footprint, 2014).

3.4.1.2 Life cycle inventory

The life cycle inventory includes a mix of foreground and background inventories. The first is based on primary data collected directly from the producer company concerning direct resources consumption ad emissions, including all the water withdrawals and releases as well as all the other kind of information not directly related to water (e.g. energy consumption and raw materials), the second is based mainly on inventory databases where the inventory data have been determined and processed according to ISO 14046 (2014) to account for all the water flows involved.
In this paragraph all the data collected are reported, according to the different life cycle stages investigated.

Raw materials

This stage concerns all the processes involved in the extraction and processing of raw materials needed for the production of the jar packaged ice cream under study.
The ice cream production has been modeled according to the specific recipe provided by the company, which is omitted in this study for confidentiality reasons.
For almost all the elements involved in the ice cream production it has been possible to use existent datasets, accounting for all the cultivation phases and the related agricultural processes (e.g. irrigation, fertilization, harrowing, harvesting, etc.), for the next processing in the final raw material (e.g. sugar) and finally for the transport to the plant. For some ingredients of less importance for the final

assessment, such as flavorings that are characterized by an incidence by mass of less than 1% over the total final product, it has been adopted a generic dataset available in the software.
Information on the raw materials included in the analysis are reported as follows:

- Water: primary withdrawn from groundwater wells, and in less amount from the national supply network, this material flow has been modeled through the dataset "Water, well, in ground, IT" and "Tap water {Europe without Switzerland}| market for | Alloc Rec, U".
- Butter: this primary ingredient of the recipe has been modeled adopting the dataset "Butter, from cow milk {GLO}| butter production, from cream, from cow milk | Alloc Rec, U", which was modified to account for the specific source of water consumption in the country of origin of each supplier, placed in Germany, Netherlands and Italy.
- Skimmed powder milk: this material has been modeled adopting several datasets. For the fresh skimmed milk it was adopted the dataset "Skimmed milk, from cow milk {GLO}| market for | Alloc Rec, U", while for the next evaporation process required for the first water extraction from milk it was used the dataset "Evaporation of milk {RoW}| milk evaporation | Alloc Rec, U". Finally, the process required for the final drying obtaining the powder milk it was adopted the dataset "Spray-drying of milk {RoW}| milk spray-drying | Alloc Rec, U".

  The mass balance has been satisfied adopting a mix of primary and secondary information, leading to a final value of 11,68 kg of fresh milk necessary for the production of 1 kg of skimmed powder milk. When it was possible, each dataset has been modified to account for the different country of origin of each supplier, placed in Germany, Belgium Poland and France.

  Panna: this material has been modeled according to the dataset "Cream, from cow milk {RoW}| yogurt production, from cow milk | Alloc Rec, U", modified to account for the country of origin of the suppliers that are all Italians.

  Glucose syrup: the modeling of this element was performed starting from the dataset "Maize starch {DE}| production | Alloc Rec, U", modified to account for the country of origin of the suppliers placed in Italy, Austria and France, integrating also secondary information about the process necessary to convert the maize starch into final glucose syrup.
- Sugared egg yolk: this material has been modeled starting from the Agri-footprint dataset "Consumption eggs, laying hens >17 weeks, at farm/NL Economic", modifying all the inventory and adopting Ecoinvent 3.1 as reference in order to account for all the agricultural phases involved upstream from the eggs production. Moreover, it was considered also the

contribute for the sugar component according to the dataset “Sugar, from sugar beet {CH}| beet sugar production | Alloc Rec, U” modified according to the country of origin of the suppliers that are all Italian. In modeling the sugared egg yolk it was taken into account also that during the production the two by-products albumen and eggshell are obtained.

- Sugar: it has been modeled through the dataset “Sugar, from sugar beet {CH}| beet sugar production | Alloc Rec, U”, modified according to the country of origin of the different suppliers, which are Italy, United Kingdom and Serbia.

For all the above described raw materials it has been considered also the transport from the suppliers to the company plant, adopting the dataset “Transport, freight, lorry 16-32 metric ton, EURO 4 {RER} | transport, freight, lorry 16-32 metric ton, EURO 4 | Alloc Rec, U”. This emission class is justified by the literature that highlight in Italy a vehicle flat characterized by this kind of emission class.

Packaging

In this stage all the packaging to be used by the company in relation to the product under study have been modeled, in particular focusing on the primary packaging (i.e. PE plastic jar, PET/PE plastic film, PS plastic cap), the secondary packaging (i.e. cardboard box and paper label) and tertiary packaging (i.e. stretch plastic film and wood pallet).

For all the packaging it was considered the production process and next transport to the company plant according to the cradle to industry gate approach. For the plastic jar, plastic cap and cardboard box it was also included in the modeling the different packaging elements necessary for their transport to the company plant, thus cardboard boxes, plastic bags, plastic stretch film and top covers, wood pallets. Information about the packaging included in the analysis are reported as follows:

- PP jar: characterized by a mass of 35,5 grams of polypropylene, it was modeled through the dataset “Polypropylene, granulate {GLO}| market for | Alloc Rec, U” and the reference production process “Injection molding {RER}| processing | Alloc Rec, U”, modified according to the country of origin of the supplier that is Italian.
- PET/PE stretch film: characterized by a mass of 1,46 grams and made of a multilayer of polyethylene terephthalate and polyethylene, it was modeled with the dataset “Polyethylene terephthalate, granulate, amorphous {GLO}| market for | Alloc Rec, U”, and “Polyethylene, linear low density, granulate {GLO}| market for | Alloc Rec, U”. The adhesive material used

to keep together the two layers was modeled trough the dataset “Urea formaldehyde resin {GLO}| market for | Alloc Rec, U”. Finally, the production process has been modeled considering the dataset “Extrusion, plastic film {RER}| production | Alloc Rec, U”.

- PS cap: characterized by a mass of 17 grams of polystyrene, it was modeled though the dataset “Polystyrene, high impact {GLO}| market for | Alloc Rec, U” and the reference production process “Injection molding {RER}| processing | Alloc Rec, U” modified according to the country of origin of the supplier that is Italian.
- Cardboard box: used to transport the final product in a set of 6 pieces, it was modeled using the dataset “Corrugated board box {RER}| production | Alloc Rec, U”.
- Paper label: applied to the cardboard box, it was modeled though the dataset “Paper, wood free, coated {RER}| market for | Alloc Rec, U”.
- Glue: used to attach the paper label to the cardboard box, it has been modeled through the dataset “Urea formaldehyde resin {GLO}| market for | Alloc Rec, U”.
- Stretch film: adopted to wrap the final products placed on the pallet to be distributed, it was modeled with the dataset “Polyethylene, linear low density, granulate {GLO}| market for | Alloc Rec, U” including also the production process “Extrusion, plastic film {RER}| production | Alloc Rec, U”.
- Pallet: made according to the standard format EU, it was modeled considering a reuse factor equal to 20 with the dataset “EUR-flat pallet {RER}| production | Alloc Rec, U” including also the production process “Wood chipping, industrial residual wood, stationary electric chipper {RER}| processing | Alloc Rec, U”.

For all the previously described packaging the transport process has been modeled through the dataset “Transport, freight, lorry 16-32 metric ton, EURO 4 {RER} | transport, freight, lorry 16-32 metric ton, EURO 4 | Alloc Rec, U”.

<u>*Production*</u>

The ice cream production is made basically of 3 steps: semi-finished product processing, mixture processing and final hardened stage.

In the very first phase of production all the raw materials are pre-processed all together in order to obtain a pre-finished ice cream mixture. Powder ingredients are subjected to a dissolution process, while liquid ingredients are mixed. Solid materials such as butter, instead, are melted in order to make them better workable.

Once mixed all together according to the quantities within the recipe, the resulting mixture is subjected to the pasteurization and then placed in special tanks for the maturation.
After a specific maturation time, the mixture is transferred to the production line where the ice cream is realized thanks to the adoption of different equipment, like the cooling tunnels where the mixture is subjected to a first hardening within its primary packaging.
The product is then sent to the refrigeration cell where the final product undergoes to a change from a liquid phase to a solid phase thanks to the chilling that occurs in the range between -26°C and -30°C.

The main sources of energy involved in the process are electricity and methane gas for the production of heat. The first has been modeled through the dataset "Electricity, medium voltage {IT} | market for | Alloc Rec, U" for the consumption of energy coming from the national supply network in medium voltage, and through the dataset "Electricity, low voltage {IT}| market for | Alloc Rec, U" for the consumption of energy from the national supply network in low voltage (e.g. for offices and illumination). Moreover, the dataset "Electricity, low voltage {IT}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Alloc Rec, U" has been considered for the amount of energy produced by the photovoltaic system installed by the company.
The second has been modeled according to the dataset "Heat, district or industrial, other than natural gas {Europe without Switzerland}| market for heat, district or industrial, other than natural gas | Alloc Rec, U" modified when possible according to the country of origin of the company that is Italian.

Considering chemicals involved in the ice cream production, they were modeled according to primary information from company and adopting datasets as reported in Table 3.5. For each chemical it was considered the production process and the transport to the company plant.

Table 3.5 *Data on chemicals and related datasets adopted in the modeling of the jar packaged ice cream.*

Function	Type of chemical	Dataset
Water pre-treatment	Sodium hypochlorite	Sodium hypochlorite, without water, in 15% solution state {RER}| sodium hypochlorite production, product in 15% solution state | Alloc Rec, U
Production process	Breltak	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Alloc Rec, U
		Ethoxylated alcohol (AE3) {GLO}| market for | Alloc Rec, U
		Water, unspecified natural origin, IT

Function	Type of chemical	Dataset
	Divoflow NTC	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Alloc Rec, U EDTA, ethylenediaminetetraacetic acid {RER}| EDTA production | Alloc Rec, U Water, unspecified natural origin, IT
	Lubricants	Lubricating oil {RER}| production | Alloc Rec, U
	PE 4M	Chemical, inorganic {GLO}| production | Alloc Rec, U
	Profile	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Alloc Rec, U Sodium hypochlorite, without water, in 15% solution state {RER}| sodium hypochlorite production, product in 15% solution state | Alloc Rec, U Potassium hydroxide {RER}| production | Alloc Rec, U Water, unspecified natural origin, IT
	Suma Sol	Chemical, inorganic {GLO}| production | Alloc Rec, U
	Topax 686	Sodium hypochlorite, without water, in 15% solution state {RER}| sodium hypochlorite production, product in 15% solution state | Alloc Rec, U Potassium hydroxide {RER}| production | Alloc Rec, U Water, unspecified natural origin, IT
Wastewater treatment	Bioease 4245	Chemical, organic {GLO}| production | Alloc Rec, U
	Biofoam 282	Chemical, inorganic {GLO}| production | Alloc Rec, U
	Bioremove 5600	Chemical, organic {GLO}| production | Alloc Rec, U
	Biotek base L	Chemical, organic {GLO}| production | Alloc Rec, U
	Biotrol 157	Chemical, inorganic {GLO}| production | Alloc Rec, U
	Catfloc C 187	Chemical, inorganic {GLO}| production | Alloc Rec, U
	EM 454	Chemical, inorganic {GLO}| production | Alloc Rec, U
	EM 494 N	Chemical, inorganic {GLO}| production | Alloc Rec, U
	Sodium hydroxide	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Alloc Rec, U Water, unspecified natural origin, IT
	Zetag 9048FS	Chemical, inorganic {GLO}| production | Alloc Rec, U

As for the raw materials, also for chemicals it has been considered the transport from the suppliers to the company plant, adopting the dataset “Transport, freight, lorry 16-32 metric ton, EURO 4 {RER} | transport, freight, lorry 16-32 metric ton, EURO 4 | Alloc Rec, U”.
Focusing on refrigerants used in the cooling equipment at the plant, particularly R507, R422d and ammonia, they were accounted for all the amount consumed during the operations of refill.

During the ice cream production some fluxes of wastes are generated because of the packaging used to transport the materials from the suppliers to the plant of the company, as well as because of the scraps arising from the packing stage of the final product. All the waste treatment has been modeled according to primary data from the company, with the exception of the wood waste for which it has been adopted secondary data from the literature (ISPRA 2017a), according to the information listed in the next Table 3.6.

Table 3.6 *Waste treatment scenario adopted in the modeling of the jar packaged ice cream.*

Type of waste	Recycling	Incineration	Landfill
Sludge	100%	0%	0%
Paper and carton	100%	0%	0%
Plastic	100%	0%	0%
Wood	85,2%	12,3%	2,5%
Mix materials	100%	0%	0%
Metals	100%	0%	0%

Information about how the different fluxes of waste were modeled are reported as follows:

- Treatment of sludge (CER 020502): the 100% of this waste is recycled and has been modeled through the dataset “Refinery sludge {CH}| treatment of, landfarming | Alloc Rec, U”.
- Treatment of paper and carton (CER 150101): the 100% of this waste is recycled and has been modeled through the dataset “Paper (waste treatment) {GLO}| recycling of paper | Alloc Rec, U”.

- Treatment of plastic (CER 150102): the 100% of this waste is recycled and has been modeled through the dataset “Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Alloc Rec, U”.
- Treatment of wood (CER 150103): this waste, which is subjected to the treatment according to the information of Table 2.6, was modeled with the dataset “Waste wood, untreated {CH}| treatment of, municipal incineration | Alloc Rec, U”, the dataset “Waste wood, untreated {CH}| treatment of, sanitary landfill | Alloc Rec, U” and the dataset “Waste wood, untreated {CH}| treatment of, recycling | Alloc Rec, U”.
- Treatment of mix materials (CER 150106): the 100% of this waste is recycled and has been modeled through a generic dataset for the recycling.
- Treatment of metals (CER 170405): the 100% of this waste is recycled and has been modeled through the dataset “Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Alloc Rec, U”.

For all the above described waste treatment it was also included the transport process from the company plant to the final destination, modeled through the dataset “Municipal waste collection service by 21 metric ton lorry {CH}| processing | Cut-off, U”, considering the specific distances according to primary information given by the company and contained into the waste register.

Distribution

This life cycle stage has been modeled accounting for the different positions of the market stores, which are all within the national context, where the final product has to be delivered.

The transport, which occurs mainly by refrigerated trucks with a weighted average distance of 230 km, has been modeled through a mix of datasets according to the different type of vehicle used by the company (29% EURO3, 7% EURO4, 64% EURO5), thus “Transport, freight, lorry 16-32 metric ton, EURO3 {RER}| transport, freight, lorry 16-32 metric ton, EURO3 | Alloc Rec, U”, “Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Alloc Rec, U”, “Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| transport, freight, lorry 16-32 metric ton, EURO5 | Alloc Rec, U”, all modified in order to account for the high fuel consumption and for the refrigerant leaks due to the presence of the cooling equipment according to information from the literature (Tassou et al., 2009).

Furthermore, even if in a smaller part, the transport occurs also by ship with a weighted average distance of 2 km. This has been modeled through the dataset "Transport, freight, sea, transoceanic ship {GLO}| processing | Alloc Rec, U".

The life cycle stage of distribution also accounts for the treatment of wastes arising from the secondary and tertiary packaging, which were modeled according to the following information:

- Treatment of paper and carton: this flux of waste is made of a fraction to be incinerated which was modeled with the dataset "Waste paperboard {CH}| treatment of, municipal incineration | Alloc Rec, U", a fraction to be landfilled modeled with the dataset "Waste paperboard {CH}| treatment of, sanitary landfill | Alloc Rec, U", and a fraction to be recycled modeled through the dataset "Paper (waste treatment) {GLO}| recycling of paper | Alloc Rec, U".
- Treatment of plastic: this flux of waste considering a mix of datasets, according to the different treatment processes, equal to "Waste polyethylene {CH}| treatment of, municipal incineration | Alloc Rec, U", "Waste polyethylene {CH}| treatment of, sanitary landfill | Alloc Rec, U", "PE (waste treatment) {GLO}| recycling of PE | Alloc Rec, U".
- Treatment of wood: this waste has been modeled through the datasets "Waste wood, untreated {CH}| treatment of, municipal incineration | Alloc Rec, U", "Waste wood, untreated {CH}| treatment of, sanitary landfill | Alloc Rec, U", "Waste wood, untreated {CH}| treatment of, recycling | Alloc Rec, U" according to the different treatment processes.

Table 3.7 contains information from the literature (ISPRAa, 2017) about the values applied to account for the different treatment processes of the wastes generated in the distribution life cycle stage.

Table 3.7 *Waste treatment scenario adopted in the modeling of the distribution stage of the jar packaged ice cream.*

Type of waste	Recycling	Incineration	Landfill
Paper and carton	79,6%	8,6%	11,8%
Plastic	38,0%	44,5%	17,5%
Wood	59,7%	3,4%	36,9%

In this life cycle stage, they were also included the energy and refrigerant consumptions that occur at the market stores, which were assumed with a precautionary approach equal to those observed in the

company storehouse were the final products stay for few days before to be delivered to the market stores.
Moreover, assuming a shelf life of a week, it was also possible to account for the energy consumption at the retailer, adopting literature data (Cecchinato et al., 2010), as well as for the energetic consumption due to the storage in a freezer modeled trough secondary data.

Use

In this stage, both the transport of the product from the retailer to the house of the final user and the energy consumption for the store of the product in a domestic freezer have been considered in the analysis.
The first has been modeled through the dataset "Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Alloc Rec, U", which is comparable to a mid-size family car, assuming an average distance equal to 5 km according to literature data (Point et al., 2012).
The amount of energy consumed by the domestic freezer, modeled through the dataset "Electricity, low voltage {IT}| market for | Alloc Rec, U", has been assumed on the basis of a residence time of a week, considering an annual consumption of electricity equal to 180 kWh for a volume of 20 liters (BigEE, 2016). The specific energy consumption has been then calculated considering the volume occupied by the product in the freezer.

End of life

In the last life cycle stage all the elements of the primary packaging of the product, thus plastic jar, film and cap, are subjected to the final disposal. According to the different type of material, a different treatment has been applied according to secondary data (ISPRAb, 2017).
Since all the 3 packaging components are made of plastic material, thus the same percentage of treatment have been applied to all of them, particularly 40,7% for recycling, 43,7% for incineration and 15,6% for disposal in landfill. In this life cycle stage, it was also included the transport of the waste to the final destination, assuming a distance of 30 km.
Finally, it is important to highlight that the contribution given by the ice cream itself in terms of human digestion was not assessed because of the difficulties in performing accurate estimations and, in any case, it is very likely that it could be not significant for the purpose of the study.

Starting from the whole inventory data described above and adopting the LCA software SimaPro to process all the information, the water inventory results for the system product under study in terms of input (raw materials) and outputs (water, air, soil) listed in the Table 3.8.

Table 3.8 *Water inventory data of the whole life cycle of the jar packaged ice cream.*

Substance	Compartment	Unit	Value
Water, cooling, unspecified natural origin, AT	Raw material	m3	2,18E-04
Water, cooling, unspecified natural origin, AU	Raw material	m3	3,19E-04
Water, cooling, unspecified natural origin, BA	Raw material	m3	1,36E-05
Water, cooling, unspecified natural origin, BE	Raw material	m3	3,09E-04
Water, cooling, unspecified natural origin, BG	Raw material	m3	9,89E-05
Water, cooling, unspecified natural origin, BR	Raw material	m3	1,16E-04
Water, cooling, unspecified natural origin, CA	Raw material	m3	5,62E-04
Water, cooling, unspecified natural origin, CH	Raw material	m3	3,65E-03
Water, cooling, unspecified natural origin, CL	Raw material	m3	5,06E-05
Water, cooling, unspecified natural origin, CN	Raw material	m3	2,87E-03
Water, cooling, unspecified natural origin, CZ	Raw material	m3	2,85E-04
Water, cooling, unspecified natural origin, DE	Raw material	m3	5,21E-03
Water, cooling, unspecified natural origin, DK	Raw material	m3	7,85E-05
Water, cooling, unspecified natural origin, ES	Raw material	m3	5,48E-04
Water, cooling, unspecified natural origin, Europe without Switzerland	Raw material	m3	5,26E-04
Water, cooling, unspecified natural origin, FI	Raw material	m3	1,10E-04
Water, cooling, unspecified natural origin, FR	Raw material	m3	7,13E-03
Water, cooling, unspecified natural origin, GB	Raw material	m3	8,82E-04
Water, cooling, unspecified natural origin, GLO	Raw material	m3	6,13E-05
Water, cooling, unspecified natural origin, GR	Raw material	m3	1,50E-04
Water, cooling, unspecified natural origin, HR	Raw material	m3	7,61E-05
Water, cooling, unspecified natural origin, HU	Raw material	m3	1,81E-04
Water, cooling, unspecified natural origin, ID	Raw material	m3	1,78E-04
Water, cooling, unspecified natural origin, IE	Raw material	m3	5,94E-05
Water, cooling, unspecified natural origin, IN	Raw material	m3	1,07E-03
Water, cooling, unspecified natural origin, IR	Raw material	m3	6,33E-04
Water, cooling, unspecified natural origin, IT	Raw material	m3	6,36E-02
Water, cooling, unspecified natural origin, JP	Raw material	m3	1,10E-03
Water, cooling, unspecified natural origin, KR	Raw material	m3	5,47E-04
Water, cooling, unspecified natural origin, LU	Raw material	m3	6,04E-06
Water, cooling, unspecified natural origin, MA	Raw material	m3	4,05E-06
Water, cooling, unspecified natural origin, MK	Raw material	m3	1,41E-05
Water, cooling, unspecified natural origin, MX	Raw material	m3	2,57E-04
Water, cooling, unspecified natural origin, MY	Raw material	m3	1,29E-04
Water, cooling, unspecified natural origin, NL	Raw material	m3	1,07E-03
Water, cooling, unspecified natural origin, NO	Raw material	m3	1,93E-06
Water, cooling, unspecified natural origin, PE	Raw material	m3	1,55E-05
Water, cooling, unspecified natural origin, PH	Raw material	m3	1,12E-05
Water, cooling, unspecified natural origin, PL	Raw material	m3	3,53E-04
Water, cooling, unspecified natural origin, PT	Raw material	m3	6,85E-05
Water, cooling, unspecified natural origin, RER	Raw material	m3	4,74E-03
Water, cooling, unspecified natural origin, RNA	Raw material	m3	1,24E-06
Water, cooling, unspecified natural origin, RO	Raw material	m3	1,15E-04
Water, cooling, unspecified natural origin, RoW	Raw material	m3	1,64E-02
Water, cooling, unspecified natural origin, RS	Raw material	m3	6,62E-05
Water, cooling, unspecified natural origin, RU	Raw material	m3	6,63E-03
Water, cooling, unspecified natural origin, SA	Raw material	m3	2,82E-04
Water, cooling, unspecified natural origin, SE	Raw material	m3	1,88E-04
Water, cooling, unspecified natural origin, SI	Raw material	m3	7,47E-04
Water, cooling, unspecified natural origin, SK	Raw material	m3	4,72E-05
Water, cooling, unspecified natural origin, TH	Raw material	m3	1,57E-04
Water, cooling, unspecified natural origin, TR	Raw material	m3	2,08E-04
Water, cooling, unspecified natural origin, TW	Raw material	m3	2,58E-04

Substance	Compartment	Unit	Value
Water, cooling, unspecified natural origin, TZ	Raw material	m3	2,76E-06
Water, cooling, unspecified natural origin, UA	Raw material	m3	4,69E-03
Water, cooling, unspecified natural origin, US	Raw material	m3	4,05E-03
Water, cooling, unspecified natural origin, WEU	Raw material	m3	4,35E-07
Water, cooling, unspecified natural origin, ZA	Raw material	m3	2,87E-04
Water, lake	Raw material	m3	5,60E-06
Water, lake, AT	Raw material	m3	-2,74E-15
Water, lake, BE	Raw material	m3	-5,41E-15
Water, lake, BG	Raw material	m3	-5,89E-17
Water, lake, CA	Raw material	m3	6,20E-06
Water, lake, CH	Raw material	m3	1,43E-05
Water, lake, CN	Raw material	m3	4,36E-07
Water, lake, CZ	Raw material	m3	-7,97E-17
Water, lake, DE	Raw material	m3	-3,57E-14
Water, lake, DK	Raw material	m3	-7,38E-15
Water, lake, ES	Raw material	m3	-6,08E-15
Water, lake, Europe without Switzerland	Raw material	m3	2,13E-04
Water, lake, FI	Raw material	m3	-1,86E-15
Water, lake, FR	Raw material	m3	-1,42E-14
Water, lake, GB	Raw material	m3	-1,11E-14
Water, lake, GLO	Raw material	m3	2,63E-12
Water, lake, HU	Raw material	m3	-2,49E-15
Water, lake, IT	Raw material	m3	1,70E-04
Water, lake, JP	Raw material	m3	-1,40E-14
Water, lake, KR	Raw material	m3	-3,36E-16
Water, lake, LU	Raw material	m3	-1,81E-16
Water, lake, NL	Raw material	m3	-1,19E-14
Water, lake, NO	Raw material	m3	-5,44E-16
Water, lake, PL	Raw material	m3	-1,03E-15
Water, lake, PT	Raw material	m3	-2,26E-15
Water, lake, RER	Raw material	m3	9,94E-08
Water, lake, RNA	Raw material	m3	8,45E-08
Water, lake, RoW	Raw material	m3	5,09E-04
Water, lake, RU	Raw material	m3	-5,30E-15
Water, lake, SE	Raw material	m3	-1,30E-14
Water, lake, SK	Raw material	m3	-1,48E-16
Water, lake, TR	Raw material	m3	-1,49E-16
Water, lake, TW	Raw material	m3	-5,57E-15
Water, lake, US	Raw material	m3	7,31E-10
Water, river	Raw material	m3	-4,35E-06
Water, river, AT	Raw material	m3	-2,20E-11
Water, river, AU	Raw material	m3	2,39E-06
Water, river, BE	Raw material	m3	-1,58E-11
Water, river, BG	Raw material	m3	-7,27E-14
Water, river, BR	Raw material	m3	9,79E-03
Water, river, CA	Raw material	m3	8,56E-05
Water, river, CH	Raw material	m3	1,84E-02
Water, river, CN	Raw material	m3	5,92E-04
Water, river, CZ	Raw material	m3	-5,18E-12
Water, river, DE	Raw material	m3	1,51E-04
Water, river, DK	Raw material	m3	-1,41E-11
Water, river, ES	Raw material	m3	2,30E-04
Water, river, Europe without Switzerland	Raw material	m3	3,36E-03
Water, river, FI	Raw material	m3	-4,05E-12
Water, river, FR	Raw material	m3	3,90E-04
Water, river, GB	Raw material	m3	-1,18E-10
Water, river, GLO	Raw material	m3	3,86E-05
Water, river, GR	Raw material	m3	-3,59E-12
Water, river, HU	Raw material	m3	-4,33E-12
Water, river, IE	Raw material	m3	-2,54E-12
Water, river, IN	Raw material	m3	5,81E-04
Water, river, IT	Raw material	m3	2,61E-03

Substance	Compartment	Unit	Value
Water, river, JP	Raw material	m3	-1,74E-11
Water, river, KR	Raw material	m3	-4,44E-13
Water, river, LU	Raw material	m3	-8,43E-13
Water, river, MX	Raw material	m3	-4,27E-15
Water, river, MY	Raw material	m3	1,46E-04
Water, river, NL	Raw material	m3	4,89E-08
Water, river, NO	Raw material	m3	-8,01E-13
Water, river, PE	Raw material	m3	2,26E-09
Water, river, PH	Raw material	m3	1,42E-03
Water, river, PL	Raw material	m3	-5,81E-12
Water, river, PT	Raw material	m3	-4,22E-12
Water, river, RAS	Raw material	m3	4,18E-05
Water, river, RER	Raw material	m3	1,84E-03
Water, river, RLA	Raw material	m3	9,90E-06
Water, river, RNA	Raw material	m3	2,04E-05
Water, river, RoW	Raw material	m3	7,91E-03
Water, river, RU	Raw material	m3	1,39E-06
Water, river, SE	Raw material	m3	5,23E-08
Water, river, SI	Raw material	m3	-1,18E-12
Water, river, SK	Raw material	m3	-4,60E-13
Water, river, TH	Raw material	m3	-2,65E-15
Water, river, TR	Raw material	m3	-1,92E-13
Water, river, TW	Raw material	m3	-6,89E-12
Water, river, TZ	Raw material	m3	3,47E-08
Water, river, US	Raw material	m3	5,68E-04
Water, river, WEU	Raw material	m3	3,23E-11
Water, river, ZA	Raw material	m3	1,44E-07
Water, salt, ocean	Raw material	m3	8,93E-04
Water, salt, sole	Raw material	m3	1,68E-04
Water, turbine use, unspecified natural origin, AT	Raw material	m3	2,77E-01
Water, turbine use, unspecified natural origin, AU	Raw material	m3	1,40E-02
Water, turbine use, unspecified natural origin, BA	Raw material	m3	3,42E-03
Water, turbine use, unspecified natural origin, BE	Raw material	m3	1,88E-03
Water, turbine use, unspecified natural origin, BG	Raw material	m3	6,04E-03
Water, turbine use, unspecified natural origin, BR	Raw material	m3	8,49E-02
Water, turbine use, unspecified natural origin, CA	Raw material	m3	2,41E-01
Water, turbine use, unspecified natural origin, CH	Raw material	m3	7,71E-01
Water, turbine use, unspecified natural origin, CL	Raw material	m3	2,42E-02
Water, turbine use, unspecified natural origin, CN	Raw material	m3	2,47E-01
Water, turbine use, unspecified natural origin, CZ	Raw material	m3	4,61E-03
Water, turbine use, unspecified natural origin, DE	Raw material	m3	1,29E-01
Water, turbine use, unspecified natural origin, DK	Raw material	m3	7,55E-05
Water, turbine use, unspecified natural origin, ES	Raw material	m3	2,99E-02
Water, turbine use, unspecified natural origin, FI	Raw material	m3	2,29E-02
Water, turbine use, unspecified natural origin, FR	Raw material	m3	6,77E-01
Water, turbine use, unspecified natural origin, GB	Raw material	m3	1,10E-02
Water, turbine use, unspecified natural origin, GLO	Raw material	m3	2,00E-07
Water, turbine use, unspecified natural origin, GR	Raw material	m3	8,23E-03
Water, turbine use, unspecified natural origin, HR	Raw material	m3	2,11E-03
Water, turbine use, unspecified natural origin, HU	Raw material	m3	6,88E-04
Water, turbine use, unspecified natural origin, ID	Raw material	m3	2,28E-03
Water, turbine use, unspecified natural origin, IE	Raw material	m3	1,81E-03
Water, turbine use, unspecified natural origin, IN	Raw material	m3	1,51E-02
Water, turbine use, unspecified natural origin, IR	Raw material	m3	9,03E-03
Water, turbine use, unspecified natural origin, IT	Raw material	m3	2,94E+00
Water, turbine use, unspecified natural origin, JP	Raw material	m3	6,42E-02
Water, turbine use, unspecified natural origin, KR	Raw material	m3	2,65E-03
Water, turbine use, unspecified natural origin, LU	Raw material	m3	4,73E-04
Water, turbine use, unspecified natural origin, MK	Raw material	m3	3,45E-04
Water, turbine use, unspecified natural origin, MX	Raw material	m3	3,97E-02
Water, turbine use, unspecified natural origin, MY	Raw material	m3	1,53E-03
Water, turbine use, unspecified natural origin, NL	Raw material	m3	6,95E-04

Substance	Compartment	Unit	Value
Water, turbine use, unspecified natural origin, NO	Raw material	m3	6,26E-03
Water, turbine use, unspecified natural origin, PE	Raw material	m3	3,38E-04
Water, turbine use, unspecified natural origin, PL	Raw material	m3	5,06E-03
Water, turbine use, unspecified natural origin, PT	Raw material	m3	8,68E-03
Water, turbine use, unspecified natural origin, RER	Raw material	m3	1,43E-04
Water, turbine use, unspecified natural origin, RNA	Raw material	m3	1,02E-04
Water, turbine use, unspecified natural origin, RO	Raw material	m3	3,14E-02
Water, turbine use, unspecified natural origin, RoW	Raw material	m3	8,18E-01
Water, turbine use, unspecified natural origin, RS	Raw material	m3	1,59E-02
Water, turbine use, unspecified natural origin, RU	Raw material	m3	3,74E-01
Water, turbine use, unspecified natural origin, SE	Raw material	m3	1,03E-01
Water, turbine use, unspecified natural origin, SI	Raw material	m3	1,72E-01
Water, turbine use, unspecified natural origin, SK	Raw material	m3	4,47E-03
Water, turbine use, unspecified natural origin, TH	Raw material	m3	1,33E-03
Water, turbine use, unspecified natural origin, TR	Raw material	m3	2,02E-02
Water, turbine use, unspecified natural origin, TW	Raw material	m3	7,99E-03
Water, turbine use, unspecified natural origin, TZ	Raw material	m3	5,57E-04
Water, turbine use, unspecified natural origin, UA	Raw material	m3	2,08E-02
Water, turbine use, unspecified natural origin, US	Raw material	m3	2,08E-01
Water, turbine use, unspecified natural origin, ZA	Raw material	m3	3,21E-04
Water, unspecified natural origin, AR	Raw material	m3	3,99E-06
Water, unspecified natural origin, AT	Raw material	m3	-2,76E-11
Water, unspecified natural origin, AU	Raw material	m3	-1,48E-12
Water, unspecified natural origin, BA	Raw material	m3	-2,99E-14
Water, unspecified natural origin, BE	Raw material	m3	9,45E-11
Water, unspecified natural origin, BG	Raw material	m3	-5,95E-13
Water, unspecified natural origin, BR	Raw material	m3	6,28E-07
Water, unspecified natural origin, CA	Raw material	m3	4,61E-06
Water, unspecified natural origin, CH	Raw material	m3	1,46E-05
Water, unspecified natural origin, CL	Raw material	m3	2,21E-10
Water, unspecified natural origin, CN	Raw material	m3	3,83E-06
Water, unspecified natural origin, CZ	Raw material	m3	-1,77E-12
Water, unspecified natural origin, DE	Raw material	m3	2,42E-07
Water, unspecified natural origin, DK	Raw material	m3	-7,01E-11
Water, unspecified natural origin, ES	Raw material	m3	6,61E-09
Water, unspecified natural origin, Europe without Switzerland	Raw material	m3	5,17E-06
Water, unspecified natural origin, FI	Raw material	m3	-1,84E-11
Water, unspecified natural origin, FR	Raw material	m3	1,09E-05
Water, unspecified natural origin, GB	Raw material	m3	7,00E-09
Water, unspecified natural origin, GLO	Raw material	m3	1,13E-04
Water, unspecified natural origin, HR	Raw material	m3	-1,37E-14
Water, unspecified natural origin, HU	Raw material	m3	6,42E-08
Water, unspecified natural origin, IAI Area 1	Raw material	m3	2,06E-07
Water, unspecified natural origin, IAI Area 2, without Quebec	Raw material	m3	2,83E-07
Water, unspecified natural origin, IAI Area 3	Raw material	m3	2,57E-07
Water, unspecified natural origin, IAI Area 4&5 without China	Raw material	m3	3,81E-07
Water, unspecified natural origin, IAI Area 8	Raw material	m3	4,59E-07
Water, unspecified natural origin, IN	Raw material	m3	-9,35E-14
Water, unspecified natural origin, IR	Raw material	m3	-2,82E-13
Water, unspecified natural origin, IT	Raw material	m3	1,40E-02
Water, unspecified natural origin, JP	Raw material	m3	-1,51E-10
Water, unspecified natural origin, KR	Raw material	m3	-1,32E-11
Water, unspecified natural origin, LU	Raw material	m3	-1,72E-12
Water, unspecified natural origin, MX	Raw material	m3	-3,27E-13
Water, unspecified natural origin, NL	Raw material	m3	2,26E-06
Water, unspecified natural origin, NO	Raw material	m3	-5,34E-12
Water, unspecified natural origin, PG	Raw material	m3	2,74E-08
Water, unspecified natural origin, PH	Raw material	m3	2,79E-06
Water, unspecified natural origin, PL	Raw material	m3	4,05E-10
Water, unspecified natural origin, PT	Raw material	m3	-2,15E-11
Water, unspecified natural origin, RAF	Raw material	m3	2,87E-05
Water, unspecified natural origin, RER	Raw material	m3	3,77E-04

Substance	Compartment	Unit	Value
Water, unspecified natural origin, RME	Raw material	m3	2,82E-04
Water, unspecified natural origin, RNA	Raw material	m3	4,83E-06
Water, unspecified natural origin, RO	Raw material	m3	5,22E-11
Water, unspecified natural origin, RoW	Raw material	m3	2,37E-03
Water, unspecified natural origin, RS	Raw material	m3	-5,73E-14
Water, unspecified natural origin, RU	Raw material	m3	4,02E-05
Water, unspecified natural origin, SE	Raw material	m3	-8,43E-11
Water, unspecified natural origin, SK	Raw material	m3	-1,70E-12
Water, unspecified natural origin, TH	Raw material	m3	8,78E-08
Water, unspecified natural origin, TR	Raw material	m3	-2,04E-12
Water, unspecified natural origin, TW	Raw material	m3	-5,40E-11
Water, unspecified natural origin, UA	Raw material	m3	4,32E-08
Water, unspecified natural origin, UN-EUROPE	Raw material	m3	1,03E-06
Water, unspecified natural origin, UN-OCEANIA	Raw material	m3	2,74E-07
Water, unspecified natural origin, US	Raw material	m3	6,66E-05
Water, unspecified natural origin, WEU	Raw material	m3	3,91E-08
Water, unspecified natural origin/kg	Raw material	kg	8,76E-05
Water, well, in ground	Raw material	m3	1,22E-05
Water, well, in ground, AT	Raw material	m3	-3,15E-13
Water, well, in ground, AU	Raw material	m3	1,10E-05
Water, well, in ground, BE	Raw material	m3	-4,96E-13
Water, well, in ground, BG	Raw material	m3	-4,94E-15
Water, well, in ground, BR	Raw material	m3	2,26E-03
Water, well, in ground, CA	Raw material	m3	6,81E-06
Water, well, in ground, CH	Raw material	m3	5,14E-03
Water, well, in ground, CN	Raw material	m3	3,91E-04
Water, well, in ground, CZ	Raw material	m3	-2,99E-14
Water, well, in ground, DE	Raw material	m3	1,18E-04
Water, well, in ground, DK	Raw material	m3	-6,43E-13
Water, well, in ground, ES	Raw material	m3	1,36E-04
Water, well, in ground, Europe without Switzerland	Raw material	m3	7,68E-04
Water, well, in ground, FI	Raw material	m3	-1,64E-13
Water, well, in ground, FR	Raw material	m3	4,19E-05
Water, well, in ground, GB	Raw material	m3	-1,41E-12
Water, well, in ground, GLO	Raw material	m3	2,34E-05
Water, well, in ground, GR	Raw material	m3	-1,68E-14
Water, well, in ground, HU	Raw material	m3	-2,15E-13
Water, well, in ground, ID	Raw material	m3	3,49E-05
Water, well, in ground, IE	Raw material	m3	-1,17E-14
Water, well, in ground, IN	Raw material	m3	1,01E-03
Water, well, in ground, IT	Raw material	m3	5,64E-03
Water, well, in ground, JP	Raw material	m3	-1,18E-12
Water, well, in ground, KR	Raw material	m3	-3,38E-14
Water, well, in ground, LU	Raw material	m3	-1,79E-14
Water, well, in ground, MA	Raw material	m3	1,39E-06
Water, well, in ground, MX	Raw material	m3	-8,36E-16
Water, well, in ground, MY	Raw material	m3	1,27E-05
Water, well, in ground, NL	Raw material	m3	-1,10E-12
Water, well, in ground, NO	Raw material	m3	-4,63E-14
Water, well, in ground, NORDEL	Raw material	m3	6,92E-08
Water, well, in ground, PE	Raw material	m3	3,67E-09
Water, well, in ground, PG	Raw material	m3	2,36E-07
Water, well, in ground, PH	Raw material	m3	2,22E-04
Water, well, in ground, PL	Raw material	m3	9,81E-06
Water, well, in ground, PT	Raw material	m3	-1,96E-13
Water, well, in ground, RER	Raw material	m3	2,99E-04
Water, well, in ground, RLA	Raw material	m3	1,21E-06
Water, well, in ground, RNA	Raw material	m3	1,67E-05
Water, well, in ground, RoW	Raw material	m3	2,60E-03
Water, well, in ground, RU	Raw material	m3	1,00E-05
Water, well, in ground, SE	Raw material	m3	9,10E-09
Water, well, in ground, SI	Raw material	m3	-5,50E-15

Substance	Compartment	Unit	Value
Water, well, in ground, SK	Raw material	m3	-1,36E-14
Water, well, in ground, TH	Raw material	m3	-5,19E-16
Water, well, in ground, TR	Raw material	m3	6,75E-10
Water, well, in ground, TW	Raw material	m3	-4,68E-13
Water, well, in ground, US	Raw material	m3	9,00E-04
Water, well, in ground, WEU	Raw material	m3	1,87E-05
Water, well, in ground, ZA	Raw material	m3	2,34E-06
Water	Air	kg	1,02E-02
Water/m3	Air	m3	3,90E-02
Water, AT	Water	m3	2,77E-01
Water, AU	Water	m3	1,43E-02
Water, BA	Water	m3	3,43E-03
Water, BE	Water	m3	2,19E-03
Water, BG	Water	m3	6,14E-03
Water, BR	Water	m3	9,16E-02
Water, CA	Water	m3	2,41E-01
Water, CH	Water	m3	7,90E-01
Water, CL	Water	m3	2,43E-02
Water, CN	Water	m3	2,50E-01
Water, CO	Water	m3	7,58E-07
Water, CZ	Water	m3	4,90E-03
Water, DE	Water	m3	1,34E-01
Water, DK	Water	m3	1,55E-04
Water, ES	Water	m3	3,04E-02
Water, Europe without Switzerland	Water	m3	5,42E-04
Water, FI	Water	m3	2,30E-02
Water, FR	Water	m3	6,84E-01
Water, GB	Water	m3	1,19E-02
Water, GLO	Water	m3	8,09E-04
Water, GR	Water	m3	8,39E-03
Water, HR	Water	m3	2,17E-03
Water, HU	Water	m3	8,70E-04
Water, IAI Area 1	Water	m3	3,72E-07
Water, IAI Area 2, without Quebec	Water	m3	4,84E-07
Water, IAI Area 3	Water	m3	4,13E-07
Water, IAI Area 4&5 without China	Water	m3	6,84E-07
Water, IAI Area 8	Water	m3	8,30E-07
Water, ID	Water	m3	2,48E-03
Water, IE	Water	m3	1,87E-03
Water, IL	Water	m3	9,79E-11
Water, IN	Water	m3	1,62E-02
Water, IR	Water	m3	9,55E-03
Water, IT	Water	m3	3,00E+00
Water, JP	Water	m3	6,53E-02
Water, KR	Water	m3	3,20E-03
Water, LU	Water	m3	4,79E-04
Water, MA	Water	m3	3,40E-06
Water, MK	Water	m3	3,58E-04
Water, MX	Water	m3	4,00E-02
Water, MY	Water	m3	1,76E-03
Water, NL	Water	m3	1,67E-03
Water, NO	Water	m3	6,07E-03
Water, NORDEL	Water	m3	5,88E-08
Water, PE	Water	m3	3,41E-04
Water, PG	Water	m3	2,24E-07
Water, PH	Water	m3	9,42E-04
Water, PL	Water	m3	5,42E-03
Water, PT	Water	m3	8,74E-03
Water, RAF	Water	m3	2,44E-05
Water, RAS	Water	m3	2,05E-05
Water, RER	Water	m3	4,53E-03
Water, RLA	Water	m3	5,87E-06

Substance	Compartment	Unit	Value
Water, RME	Water	m3	2,40E-04
Water, RNA	Water	m3	1,37E-04
Water, RO	Water	m3	3,15E-02
Water, RoW	Water	m3	8,42E-01
Water, RS	Water	m3	1,60E-02
Water, RU	Water	m3	3,80E-01
Water, SA	Water	m3	2,84E-04
Water, SE	Water	m3	1,03E-01
Water, SI	Water	m3	1,73E-01
Water, SK	Water	m3	4,51E-03
Water, TH	Water	m3	1,48E-03
Water, TR	Water	m3	2,04E-02
Water, TW	Water	m3	8,25E-03
Water, TZ	Water	m3	5,58E-04
Water, UA	Water	m3	2,56E-02
Water, UCTE	Water	m3	6,06E-10
Water, UCTE without Germany	Water	m3	5,13E-10
Water, UN-EUROPE	Water	m3	1,63E-06
Water, UN-OCEANIA	Water	m3	4,96E-07
Water, US	Water	m3	2,13E-01
Water, WEU	Water	m3	2,10E-05
Water, ZA	Water	m3	6,13E-04

3.4.2 Life cycle impact assessment

Starting from the life cycle inventory above described, in this paragraph results of the life cycle impact assessment are reported, particularly referring to the monetary assessment of water scarcity impacts related to the product under study.

According to the Eq. 2.4 (§ 2.2), the monetary assessment is performed through the application of the new monetary characterization factors developed in this research work to existing water scarcity impact methods.

Since several methods are to date available in the literature for the assessment of water scarcity impacts, each of them resulting in a different way to address the effects from water consumption (Kounina et al, 2013; Pfister et.al, 2014; Boulay et al., 2015), thus it has been necessary to select one of them in order to perform the test.

The method proposed by Pfister et al. (2009) has been assumed as reference, since it is one of the most accepted within the LCA scientific community (Liu et al., 2017) and also because it is available for use within different LCA software like the SimaPro one that has been adopted in this research work.

Considering this assumption, it is important also to clarify that results of the sensitivity analysis performed through the application of the new proposed method to 4 existing water scarcity impact assessment methods, including the one developed by Pfister et al. (2009), will be explained in the next paragraph allowing to evaluate the effects of the adoption of different water scarcity impact assessment methods on the final results.

The next Table 3.9 reports the results from the application of the new proposed method in absolute terms according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.9 *Monetary impact assessment resulting from the application of the new proposed method to the jar packaged ice cream. Results are expressed in US$/FU and characterized according to the life cycle stages.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
$I_{eco\text{ - Pfister based}}$ (MCFi - SET EQ)	0,507	0,027	0,008	0,007	0,004	0,000	**0,553**
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 1)	0,756	0,043	0,011	0,010	0,006	0,000	**0,826**
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 2)	0,739	0,049	0,015	0,012	0,007	0,000	**0,822**
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 3)	0,899	0,059	0,014	0,013	0,008	0,000	**0,993**
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 4)	0,765	0,048	0,013	0,011	0,007	0,000	**0,843**
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 5)	0,557	0,030	0,008	0,007	0,004	0,000	**0,606**
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 6)	0,748	0,046	0,013	0,011	0,007	0,000	**0,824**

Results show a variability in the absolute values obtained from the application of the 7 different proposed set of characterization factors developed according to the weighting approaches described in the previous chapter 2 (§ 2.2.1.1).

The total value of the monetary assessment of water scarcity impacts of the jar packaged ice cream resulted to be in the range between 0,533 US$/FU of the monetary impact $I_{eco\text{ - Pfister based}}$ applying $MCF_{i\text{ - SET EQ}}$, and 0,993 US$/FU of the monetary impact $I_{eco\text{ - Pfister based}}$ applying $MCF_{i\text{ - SET 3}}$.

Beyond the results in absolute terms, since as already explain in this research work (§ 2.2.1.1) there is no consensus in the LCA community about a unique solution to be adopted for the development

and application of a set of weighting factors (Goedkoop and Spriensma, 2000; Finnveden et al., 2009; Sala et al., 2018), it is important to analyze the results in terms of incidence among the different life cycle stages in order to highlight which is the most incident one over the whole supply chain.
Thus, the values listed in the Table 3.9 in absolute terms are reported also in percentage terms in the next Table 3.10 and Figure 3.8 in order to allow a better understanding of the incidence of the results.

Table 3.10 *Monetary assessment of water scarcity impacts resulting from the application of the new proposed method to the jar packaged ice cream. Results are expressed in % and characterized according to the life cycle stages.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
I_{eco} - Pfister based (MCFi - SET EQ)	91,6	5,0	1,5	1,2	0,7	0,0
I_{eco} - Pfister based (MCFi - SET 1)	91,6	5,2	1,3	1,2	0,7	0,0
I_{eco} - Pfister based (MCFi - SET 2)	89,9	5,9	1,8	1,4	0,9	0,0
I_{eco} - Pfister based (MCFi - SET 3)	90,5	5,9	1,4	1,3	0,8	0,0
I_{eco} - Pfister based (MCFi - SET 4)	90,7	5,7	1,5	1,3	0,8	0,0
I_{eco} - Pfister based (MCFi - SET 5)	91,9	4,9	1,4	1,1	0,7	0,0
I_{eco} - Pfister based (MCFi - SET 6)	90,8	5,6	1,6	1,3	0,8	0,0

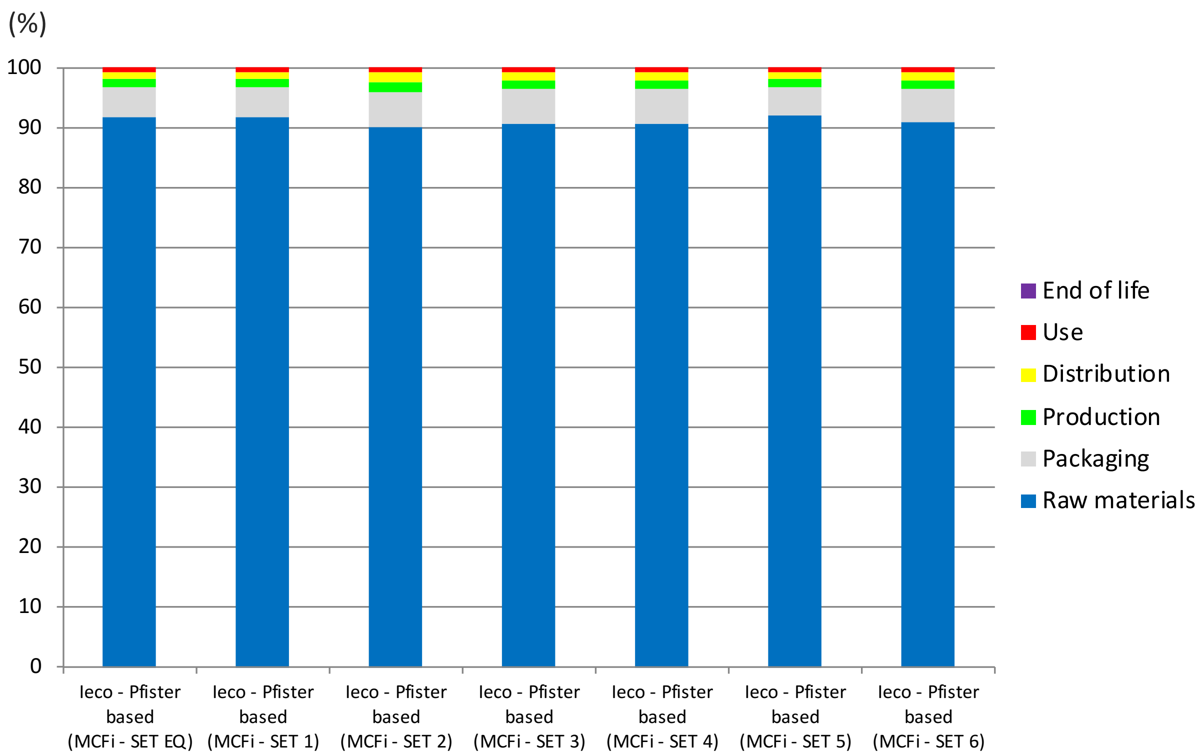

Figure 3.8 *Graphical representation of results from the application of the new proposed method to the jar packaged ice cream. Results are represented in % and characterized according to the life cycle stages.*

Observing the results in percentage terms along the whole supply chain it was possible to observe that the application of the 7 different proposed sets of characterization factors, developed according to different weighting approaches, resulted to have the same incidence on the different life cycle stages, with variation of less than 1% among the 7 proposed sets of characterization factors.

Moreover, all the applications of the different sets identified the raw materials as the most impactful life cycle stage with an average incidence of 91% on the overall impact, followed by packaging that was the second most important contribution to the overall impact with an average incidence of 5,5%.

3.4.3 Life cycle interpretation and hotspots analysis

In this stage results are analyzed in order to highlight the hotspots related to the impact assessment performed in this case study.

Furthermore, according to the research objectives, some sensitivity analysis have been also performed in order to investigate: (i) the effects on the final results from the application of the new proposed method to different existing water scarcity impact assessment methods, including the one from Pfister et al. (2009) adopted as reference in the previous stage; (ii) the effects on the final results from the adoption of the modified monetary base constant MK (§ 3.3) in the calculation of the new monetary characterization factors.

Results from the monetary assessment of water scarcity impacts of the jar packaged ice cream under study, performed applying different sets of proposed monetary characterization factors, confirmed that raw materials is the most impactful life cycle stage with an average incidence of 91% on the overall impact.

A deep analysis shown that the main reason of the high impact of this life cycle stage is due to the presence of dairy ingredients in the recipe, with butter, skimmed powder milk and cream that all together have an incidence on the total impact of raw materials higher than 60%.

These raw materials, in fact, are characterized by a high water consumption during the farm phase, particularly in relation to the production of the animal feeds.

Considering the life cycle stage of packaging, which is the second most important contribution to the overall impact with an average incidence of 5,5%, a more detailed analysis highlights that plastic jar and cap are the main causes of the total contribute to this life cycle stage, with an average incidence on the total impact of packaging higher than 40%.

According to the hotspots analysis, because of the high incidence of the dairy raw materials on the total impact, so it has been also performed an additional sensitivity analysis in order to investigate the potential effects on the results from the change of the datasets adopted to model these elements.

Sensitivity analysis 1: adoption of alternative water scarcity impact assessment methods

According to the research objectives this analysis concerns the assessment of how results may change when the new proposed method for the monetary assessment is applied to existing water scarcity impact assessment methods alternative to the one developed by Pfister et al. (2009) that was used as reference for the analysis performed in the life cycle impact assessment phase of this case study (§ 3.4.2).

The selection has been done adopting the criteria described in the chapter 2 (§ 2.2.1.3), resulting in the application of the new proposed method to 4 different existing water scarcity impact assessment methods.

According to the information obtained from the life cycle impact assessment phase of this case study (§ 3.4.2), it was possible to observe a very low variation in the incidence, in percentage terms, of the final results from the application of the 7 different proposed set of characterization factors developed according to the weighting approaches described in the previous chapter 2 (§ 2.2.1.1).

For this reason, since also the variation in the incidence on final results would be very low when applying all the 7 sets to different water scarcity impact assessment methods, thus in this sensitivity analysis it was assumed only one single set of monetary characterization factors, particularly $MCF_{i\text{ - SET 1}}$.

The next Table 3.11 contains results in absolute terms from the sensitivity analysis according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.11 *Results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are expressed in US$/FU and characterized according to the life cycle stages of the jar packaged ice cream.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
I_{eco} - Pfister based (MCFi - SET 1)	0,756	0,043	0,011	0,010	0,006	0,000	**0,826**
I_{eco} - Hoekstra based (MCFi - SET 1)	1,779	0,097	0,018	0,019	0,012	0,000	**1,925**
I_{eco} - Berger based (MCFi - SET 1)	0,648	0,042	0,016	0,011	0,007	0,000	**0,724**
I_{eco} - Boulay based (MCFi - SET 1)	30,072	2,860	1,087	0,751	0,475	0,016	**35,261**

Results in Table 3.11 show a high variability in the absolute values obtained from the application of the $MCF_{i\text{ - SET 1}}$ to different existing water scarcity impact assessment methods.

This is because the different approach adopted by each author in developing the relative water scarcity index (WSI) that represents the characterization factor to be applied to perform the water scarcity assessment (§ 2.2.1.3), resulting in different range of minimum and maximum values (e.g. for Pfister characterization factors range between 0,01 and 1, while for Boulay they range between 0,1 and 100).

In order to have a better comprehension about the variability of the incidence on final results when considering different existing water scarcity impact assessment methods, it was important to analyze values in percentage terms, as reported in the next Table 3.12 and Figure 3.9.

Table 3.12 *Results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are expressed in % and characterized according to the life cycle stages of the jar packaged ice cream*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
I_{eco} - Pfister based (MCFi - SET 1)	91,6	5,2	1,3	1,2	0,7	0,0
I_{eco} - Hoekstra based (MCFi - SET 1)	92,4	5,0	0,9	1,0	0,6	0,0
I_{eco} - Berger based (MCFi - SET 1)	89,5	5,8	2,2	1,5	0,9	0,0
I_{eco} - Boulay based (MCFi - SET 1)	85,3	8,1	3,1	2,1	1,3	0,0

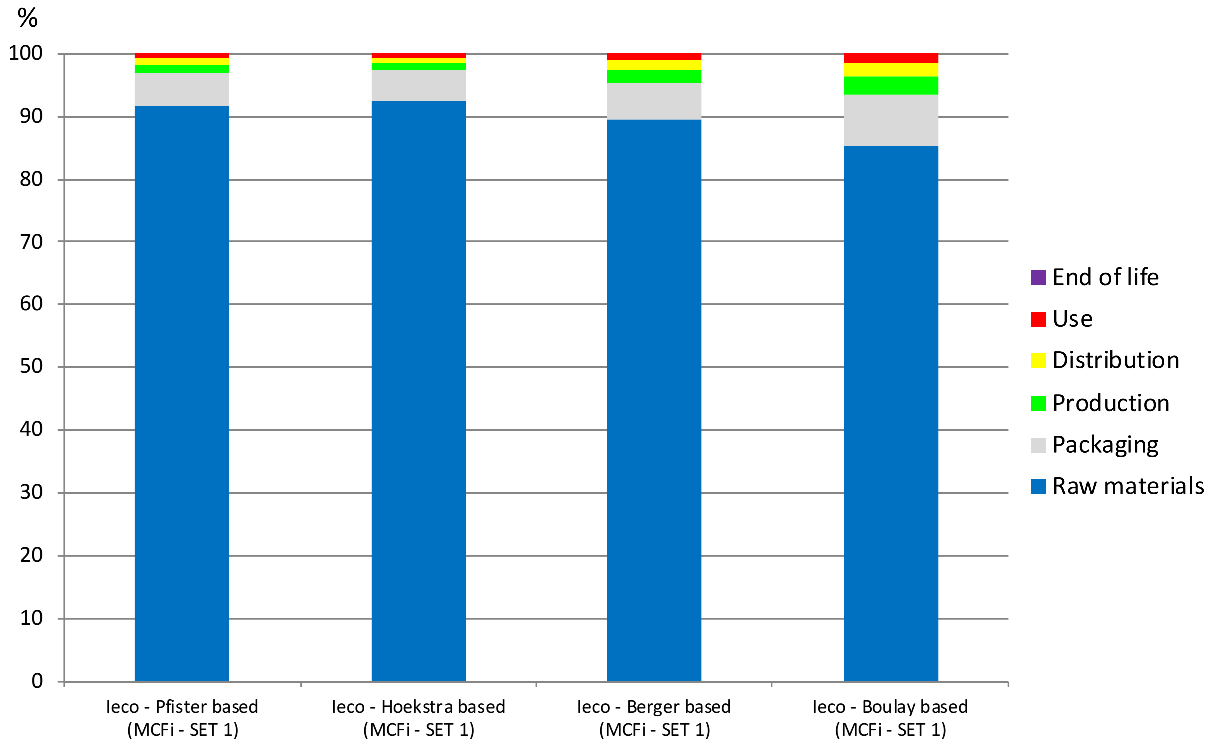

Figure 3.9 *Graphical representation of results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are represented in % and characterized according to the life cycle stages of the jar packaged ice cream.*

Results confirm that raw materials is the life cycle stage characterized by the most incidence on the overall impact, followed by packaging which is the second most important contribution. However, comparing results within the same life cycle stage from the application of the new proposed method to the different existing water scarcity impact assessment methods, it was observed that each method gives a different incidence to life cycle stage analyzed.

Considering raw materials, which is the most impactful life cycle stage, its incidence on the total may range from the minimum value of 85,3% according to Boulay et al. (2016) to the maximum value of 92,4% according to Hoekstra et al. (2012).

Even if in this case study the variation in the incidence observed among the different water scarcity impact assessment methods doesn't affect too much the final hotspots analysis, however it stresses the importance in the choice of the method to be applied to perform the assessment, with careful interpretation of results since different existing methods may lead to different interpretation of results.

Sensitivity analysis 2: adoption of the modified monetary base constant MK

According to the review of the monetary base constant MK (§ 2.2.1.2) performed in this research work, this sensitivity analysis is aimed to confirm the observations reported in the chapter 2 (§ 2.2.1.2) about the expected very low variation in final results when applying the new proposed monetary characterization factors calculated adopting the modified monetary base constant MK.

Considering the information obtained from the life cycle impact assessment phase of this case study (§ 3.4.2) that highlight a very low variation of the incidence in percentage terms of the final results from the application of the 7 different proposed set of characterization factors, thus it was assumed only one single set of monetary characterization factors, particularly $MCF_{i\ -\ SET\ 1}$, to perform the assessment adopting the same approach of the previous sensitivity analysis 1.

Figure 3.9 shows the results from the comparison between the application of $MCF_{i\ -\ SET\ 1}$ to Pfister et al. (2009) method and the application of $MCF_{i\ -\ SET\ 1*}$, which refers to the adoption of the monetary base constant MK modified to calculate the set of monetary characterization factors, to the same water scarcity impact assessment method adopted as reference.

As expected, the final impact in monetary terms showed a low variation, with resulting values equal to 0,826 US$/FU when applying $MCF_{i\ -\ SET\ 1}$ and 0,863 US$/FU when applying $MCF_{i\ -\ SET\ 1*}$.

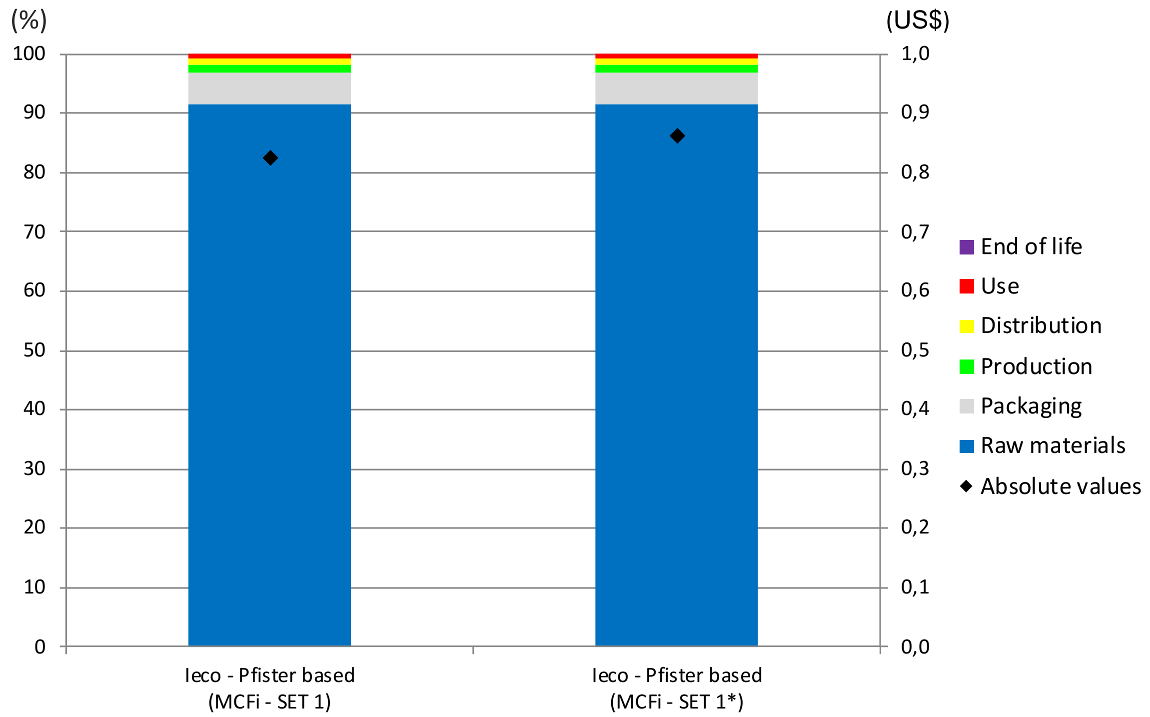

Figure 3.10 *Graphical representation of results from the sensitivity analysis performed to evaluate effects on final results from the application of the monetary base constant MK modified. Results are represented in % and characterized according to the life cycle stages of the jar packaged ice cream, with black squares in the middle of the columns representing total values in absolute terms.*

Sensitivity analysis 3: change of water related datasets adopted for the main dairy ingredients

According to the results of the hotspots analysis, which showed a high incidence of the dairy ingredients on the total impact, it has been performed an additional sensitivity analysis aimed to investigate the effects on final results from the change of the datasets adopted to model the production of the three main raw materials, thus butter, skimmed powder milk and cream.

In particular, the analysis has been done modifying when possible the datasets adopted in the modeling of production of raw materials, modifying also the farm processes, assuming where practicable Italy as country of reference for the processes of irrigation, water withdrawals and releases in water bodies and air.

It is important to clarify that, since for all the three raw materials object of this sensitivity analysis it was possible to collect primary data about the specific location of the suppliers, so the one adopted in this sensitivity analysis is only a hypothesis made to evaluate how could be the effects on the results assuming the production of butter, skimmed powder milk and cream totally in Italy.

Furthermore, the analysis has been performed applying the $MCF_{i\text{ - SET 1}}$ to 4 different existing water scarcity impact assessment methods as already done in the sensitivity 2 of this case study.

The next Table 3.13 contains results in absolute terms from the sensitivity analysis according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.13 *Results from the sensitivity analysis performed modifying the water related datasets adopted in the modeling of butter, skimmed powder milk, cream and applying the new prosed method to 4 different existing water scarcity impact assessment methods. Results are expressed in US$/FU and characterized according to the life cycle stages of the jar packaged ice cream.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
I_{eco} - Pfister based (MCFi - SET 1)	0,695	0,043	0,011	0,010	0,006	0,000	**0,764**
I_{eco} - Hoekstra based (MCFi - SET 1)	1,660	0,097	0,018	0,019	0,012	0,000	**1,805**
I_{eco} - Berger based (MCFi - SET 1)	0,597	0,042	0,016	0,011	0,007	0,000	**0,673**
I_{eco} - Boulay based (MCFi - SET 1)	27,688	2,860	1,087	0,751	0,475	0,016	**32,878**

As already observed in the sensitivity analysis 2 of this case study, the results show a high variability in the absolute values obtained from the application of the $MCF_{i\text{ - SET 1}}$ to different existing water scarcity impact assessment methods.

Again, the reason is the same that was already explained previously, thus the different approach adopted by the authors in developing the water scarcity index (WSI) of each method (§ 2.2.1.3).

Moreover, the most important result from this sensitivity analysis is that final impact is reduced of about 7%, for each method, if compared to the results from the business as usual scenario.

This is due to the changes applied to the water consumed in the production processes of the three raw materials and mostly to water irrigation processes that, for some type of crops, were associated by the database adopted during the modeling to the generic average European context, characterized by a higher value of the characterization factor than that of Italy.

In order to better understand how this variation may affect the hotspots analysis, results have been also analyzed in percentage terms, as reported in the next Table 3.14 and Figure 3.11.

The analysis of results expressed in percentage terms on the one hand confirmed that raw materials is the life cycle stage characterized by the most incidence on the total final impact, on the other hand highlighted a slight reduction in the incidence of the life cycle stage itself for all the different methods applied, with an average variation of about -1% among all the methods applied.

Table 3.14 *Results from the sensitivity analysis performed modifying the water related datasets adopted in the modeling of butter, skimmed powder milk, cream and applying the new prosed method to 4 different existing water scarcity impact assessment methods. Results are expressed in % and characterized according to the life cycle stages of the jar packaged ice cream.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
Ieco - Pfister based (MCFi - SET 1)	90,9	5,6	1,4	1,2	0,8	0,0
Ieco - Hoekstra based (MCFi - SET 1)	91,9	5,4	1,0	1,1	0,6	0,0
Ieco - Berger based (MCFi - SET 1)	88,8	6,2	2,3	1,6	1,0	0,0
Ieco - Boulay based (MCFi - SET 1)	84,2	8,7	3,3	2,3	1,4	0,0

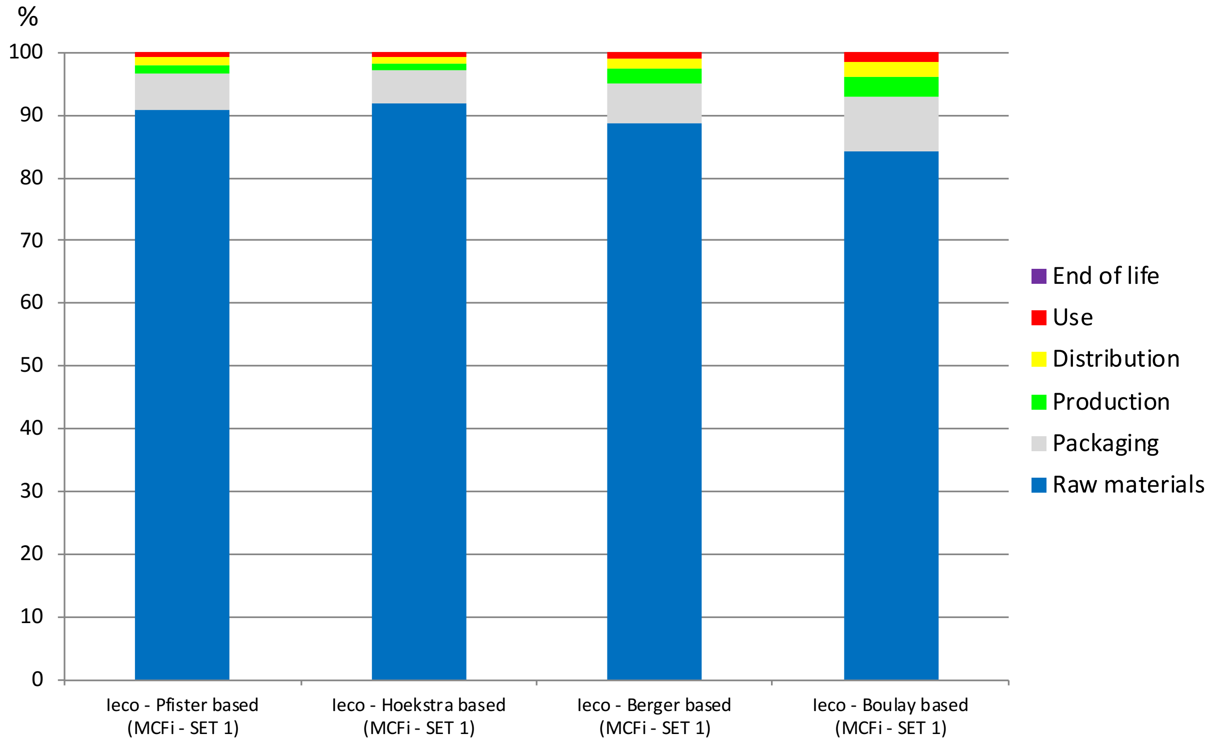

Figure 3.11 *Graphical representation of results from the sensitivity analysis 3. Results are represented in % and characterized according to the life cycle stages of the jar packaged ice cream.*

3.4.4 Case study #2: Fresh mozzarella cheese

The second case study investigated to test the applicability and effectiveness of the new proposed method for the assessment in monetary terms of water scarcity impacts concerns a fresh mozzarella cheese produced by a company in the northwest Italy.

The company belong to a multinational dairy products corporation involved since several years in the implementation of plans aimed to pursue the sustainability, as demonstrated by the results obtained in the last 6 years with a global reduction by 12% in electricity consumption, by 11% in thermal energy consumption, by 11% in water consumption and by 19% in the emissions of CO_2.

According to this trend, this study represents for the company a further step towards a better responsibility for its activities in the dairy sector, answering at the same time to the need of the research work since it is based on agriculture processes that are recognized to be water intensive.

For confidentiality reason any reference to the company and its suppliers has been omitted in the description, as well as any sensitive data has been described only in qualitative terms.

3.4.4.1 Goal and scope definition

The goal of this case study application is to test the new proposed method for the assessment of water scarcity impacts in monetary terms applying the new developed sets of monetary characterization factors, performing a hotspots analysis of the results throughout the life cycle stages of the fresh mozzarella cheese under study.

Moreover, according to the criteria described in the previous chapter 2 (§ 2.2.1), a sensitivity analysis is also performed applying the new proposed method to 4 existing water scarcity impact assessment methods selected according to the criteria defined in the previous chapter 2 (§ 2.2.1.3).

The analysis was aimed on the one hand to provide a description of water scarcity impacts in monetary terms identifying the processes of the whole product supply chain characterized by the most significant contribution to the total impact, on the other hand to understand if this may change according to different water scarcity impact assessment methods.

The product under study is a fresh cheese with spun dough, obtained from whole fat cow’s milk and lactic fermentation. It is characterized by a slightly elastic and soft consistency, with a fresh and delicate taste.

The product, with a net weight of 125 grams, includes a primary packaging made of a plastic tray and a closing plastic film (Figure 3.12). Moreover, the tray can be simple or sleeved according to the format of distribution. The product under study consists in a fresh mozzarella cheese immersed in the governing liquid, which is typically a mix of water and salt.

Figure 3.12 *Fresh mozzarella cheese product.*

<u>Function, functional unit and reference flow</u>

The function of the product under study is to satisfy a human food need that can be usually linked to the energy and nutrient requirements but more often to the need to feed.

The functional unit of this study corresponds to 1 kg of fresh mozzarella cheese packaged in plastic tray, produced by an Italian company located in the northwest Italy and distributed and consumed in the Italian market. The reference flow, instead, has been fixed equal to the net weight of the product, thus 125 g of fresh mozzarella cheese.

<u>System boundary</u>

The system boundary has been defined including all the processes attributable to the product in its whole life cycle according to the adopted reference year of 2017. All the elementary flows entering /leaving the system have been accounted for all the product life cycle stages, according to the schematic flow chart of Figure 3.13, adopting a cradle to grave approach. Each life cycle stage has been analyzed to identify all the process units responsible for water resource consumption, according to the following description:

- Raw materials: starting from their production, including also the mid-term processing and the transport to the company plant.

- Packaging: considering production and transport to the plant of all the elements adopted for the primary packaging, including also the secondary and tertiary packaging need for the final distribution in the market.
- Production: considering all the processing involved in the production of the fresh mozzarella cheese, focusing on inputs and outputs flows of the production plant (e.g. water consumption, energy consumptions, auxiliary materials, wastes, etc.).
- Distribution: considering the refrigerated transport of the final product from the plant to the different stores placed in the Italian market, including also the final disposal of wastes generated by the secondary and tertiary packaging.
- Use: considering processes linked to the consumption of the product by the final user.
- End of life: corresponding to the final dismission of the primary packaging of the product.

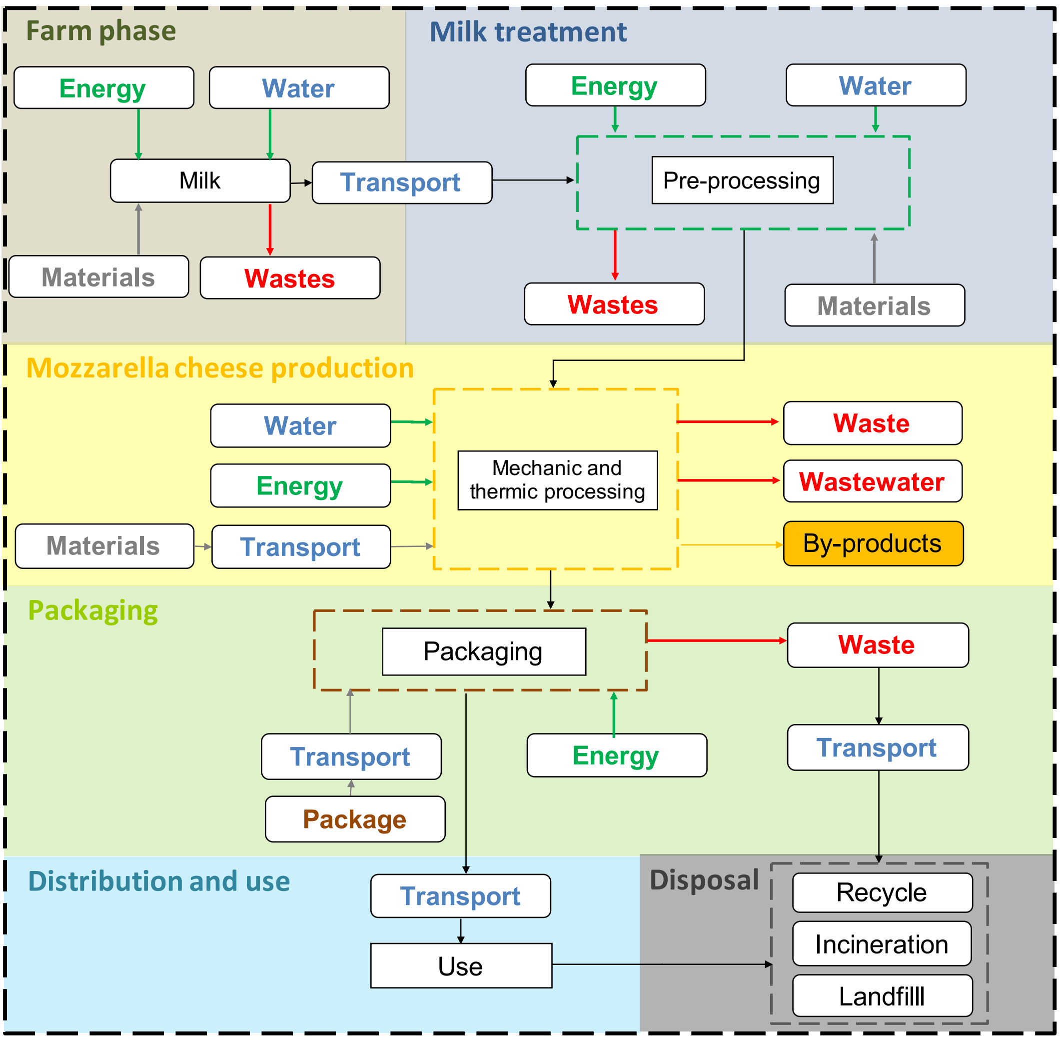

Figure 3.13 *Schematic representation of the system boundaries of the study according to the different life cycle stages of the fresh mozzarella cheese.*

Cut-off and allocation rules

In this study a cut-off rule of 1% by mass was used, avoiding thus the collection of data representing a percentage of the total flows less than 1%. Flows within this threshold are typically those characterized by a not significant mass with respect to the total or those for which it was impossible to collect specific data.

However, all processes for which data were available although their contribution was less than 1%, were included in the analysis. This choice is confirmed by several LCA studies in the literature (Humbert et al., 2009).

Furthermore, in modeling the recycling operations within the end of life stage it was applied the cut-off approach that gives null impacts to these kind of processes (Frischknecht, 2010), associating the 100% of impacts from recycling operations to the next product system in which the recycled material will be used.

According to the standard requirements (ISO 14044, 2006) in this study some allocations were performed considering the physical properties (mass, volume) of the fluxes to be allocated. Table 3.15 contains all the allocation criteria applied in this study.

Table 3.15 *Allocation rules applied according to the different kind of data collected for the modeling of the fresh mozzarella cheese.*

Elementary flow	Cause	Allocation rule
Raw material from the farm phase	Allocation has been done according to the Bulletin of International Dairy Federation 479/2015 (IDF, 2015) in order to have a proper distribution of the emissions between raw milk and meat to be sold.	Allocation has been done applying the equation provided by the report from IDF, accounting for the ratio between kg of meat sold and kg of raw milk produced. Moreover, the amount of raw milk produced has been adjusted by the FPCM (Fat and Protein Corrected Milk) factor.
Consumption/production of energy, chemicals, wastes within the production plant	Data were available according to the total amount consumed by the plant	Allocation has been done according to mass rule
Milky mixture processed in the plant	From the pre-processing of the milk arise two co-products, the curd to produce the mozzarella cheese, and the whey to produce the ricotta cheese	Allocation has been done according to the Product Category Rule (PCR) UN CPC 2223, 2224 & 2225 (IES, 2017)
Final product excluded by the distribution	A small amount of mozzarella cheese produced is used for other different purposes (e.g. zootechnical)	Allocation has been done according to mass rule

Data quality

In this study data collection has been performed giving priority to primary information collected on site, particularly those related to farm phase, production processes and packaging that are directly under control of the company. When this was not feasible, secondary data from reliable sources have been adopted.

Considering the farm phase, because of the strict collaboration between the company and the several small and mid-sized farms providing raw milk to the company itself, it was possible to collect primary data about the processes involved in raw milk production.

For the production life cycle stage, the main data collected have been energy and water consumptions, wastes, input and output of water resources, total amount of final products, chemicals consumption and specific product recipe.

Considering the packaging life cycle stage, the main data collected concern all the elements involved in the final product distribution, including also the packaging of the raw materials entering the plant. According to the distribution, all the logistic fluxes have been characterized considering distance and type of vehicle involved in the transport of the final product to the store.

Data collected about packaging production, use and end of life stages have been collected from a mix of secondary sources, adopting universally recognized database and technical report from national institutions.

The whole data quality level has been assessed by a critical review according to the following requirements fixed by the reference standard (ISO 14044, 2006):

- Time-related coverage: this requirement has been met adopting primary data from the most recent representative period, adopting the year 2017 as reference in this study. When only secondary data were available, the most recent and representative ones have been selected for the collection. Furthermore, the reference datasets adopted were those referred to the most recent version available at the time of the modeling.
- Geographical coverage: to meet this requirement all primary data collected are site specific and, when this was not possible, the reference datasets adopted have been selected considering the average production from the country of origin or the most representative market as proxy (e.g. European context).
- Technology coverage: data collected in this study concerns technologies representative as much as possible of the real production system under study.

- Completeness: according to this requirement the percentage of primary data collected is good, having the possibility to integrate to the information under the direct control of the company also data about the suppliers and the raw materials produced in other plants extracted from the available technical data sheets, which refer to materials composition and place of production. For all the secondary data collected, assumptions were made according to benchmark analysis and industry practices. Finally, the cut-off rule which is usually fixed at 5% by weight of the product materials, in this study has been fixed at 1% with and expected no effect on the outcome of the final results.
- Consistency: this requirement has been met by a consistent and uniform implementation of the new method proposed in this research work to all the components of the product under study, in terms of modeling and assumptions made.
- Reproducibility: to meet this requirement the modeling has been performed allowing its implementation also in another similar study.
- Uncertainty: primary data are characterized by an almost total absence of uncertainty, while the most part of the secondary data concern datasets containing uncertainty information.

To model the product system under study the LCA software SimaPro version 8.5.2.0 has been used (PRé Consultants, 2018), adopting the databases Ecoinvent v3.4 (Ecoinvent, 2018).

3.4.4.2 Life cycle inventory

The life cycle inventory includes a mix of foreground and background inventories. The first is based on primary data collected directly from the producer company concerning direct resources consumption ad emissions, including all the water withdrawals and releases as well as all the other kind of information not directly related to water (e.g. energy consumption and raw materials), the second is based mainly on inventory databases where the inventory data have been determined and processed according to ISO 14046 (2014) to account for all the water flows involved.
In this paragraph all the data collected are reported, according to the different life cycle stages investigated.

Raw materials
This stage concerns all the processes involved in the extraction and processing of raw materials needed for the production of the fresh mozzarella cheese under study.

The product has been modeled according to specific information provided by the company, which are omitted in this study for confidentiality reasons.

For almost all the elements involved in the fresh mozzarella cheese production it was possible to use existent datasets, accounting for the processes within the farm phase where milk is produced by cows and the next transport to the company plant. For some ingredients of less importance for the final assessment, such as enzymes and yeasts that are characterized by an incidence by mass of less than 1% over the total final product, it was applied the cut-off rule.

Considering the raw milk, which is the main ingredient adopted in the production of the fresh mozzarella cheese under study, the processes involved in the farm phase includes the use of animal feed, the consumption of water and electricity, the use of agricultural vehicles and the treatment of wastes. Furthermore, emissions arising from the enteric fermentation processes of livestock and from the manure storage have been considered, applying the methodology TIER 1 according to the guidelines provided by the IPCC (IPCC, 2006).

Emissions from the use of fertilizers are also accounted through the use of datasets provided by the LCA software.

It is important to highlight that because of the huge number of raw milk suppliers, more than 100, to perform the study it was considered only a sample of them.

The other two raw materials adopted to produce the fresh mozzarella cheese are salt, from two different European suppliers, and water, for which it was considered its withdrawal from surface sources and from groundwater wells by pumping, according to the information provided by the company.

Information about the raw materials included in the analysis are reported as follows:

- Animal feed: each raw milk supplier adopts a different feed mix, resulting in a large variety of raw materials. In Table 3.16 a full list of animal feeds and related datasets adopted in the modeling is provided, considering that some assumptions have been done because of the absence of a specific datasets within the LCA software adopted to modeling the system under study.

Table 3.16 *Data on animal feed and related datasets adopted in the modeling of the fresh mozzarella cheese.*

Type of animal feed	Dataset
Maize silage	Maize silage, Swiss integrated production {GLO}| market for | Cut-off, U
Mash	Maize silage, Swiss integrated production {GLO}| market for | Cut-off, U
Forage grass	Grass, Swiss integrated production {CH}| grass production, permanent grassland, Swiss integrated production, intensive | Cut-off, U
Alfalfa forage	Alfalfa-grass mixture, Swiss integrated production {GLO}| market for | Cut-off, U
Soybean	Soybean, Swiss integrated production {GLO}| market for | Cut-off, U
Cotton	Protein feed, 100% crude {GLO}| cotton seed meal to generic market for protein feed | Cut-off, U
Rye grass	Rye grass silage {GLO}| market for | Cut-off, U
Wheat silage	Wheat grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Forage grass silage	Grass silage, Swiss integrated production {GLO}| market for | Cut-off, U
Rye silage	Rye grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Forage grass dried	Hay, Swiss integrated production, intensive {GLO}| market for | Cut-off, U
Protein mix	Protein feed, 100% crude {GLO}| sweet sorghum grain to generic market for energy feed | Cut-off, U
Meal	Protein feed, 100% crude {GLO}| rape meal to generic market for protein feed | Cut-off, U
Hay	Hay, Swiss integrated production, intensive {GLO}| market for | Cut-off, U
Hay bale	Hay, Swiss integrated production, intensive {GLO}| market for | Cut-off, U
Potatoes	Potato, Swiss integrated production {GLO}| market for | Cut-off, U
Fodder	Fodder beet, Swiss integrated production {GLO}| market for | Cut-off, U
Linseed expeller	Rape seed {GLO}| market for | Cut-off, U
Cornmeal	Maize silage, Swiss integrated production {GLO}| market for | Cut-off, U
Brewers grains	Barley grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Integrators	Sodium chloride, powder {GLO}| market for | Cut-off, U Limestone, crushed, washed {GLO}| market for | Cut-off, U Magnesium oxide {GLO}| market for | Cut-off, U

Type of animal feed	Dataset
Barley meal	Barley grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Nucleus proteins	Protein feed, 100% crude {GLO}| soybean meal to generic market for protein feed | Cut-off, U Integrators
Molasses	Protein feed, 100% crude {GLO}| molasses, from sugar beet, to generic market for energy feed | Cut-off, U
Beet pulp	Protein feed, 100% crude {GLO}| sugar beet pulp to generic market for energy feed | Cut-off, U
Sunflower	Sunflower silage {GLO}| market for | Cut-off, U

- Salt: this raw material has been modeled adopting the dataset "Sodium chloride, powder {RER}| production | Cut-off, U".
- Water: this raw material is used in two different stages:
  - Farm phase: according to the primary data collected, it consists in a portion withdrawn from the national supply network, which has been modeled through the dataset "Tap water {Europe without Switzerland}| market for | Cut-off, U" modified to take into account for the specific country of origin, and a portion withdrawn from the groundwater well, which has been modeled through the dataset "Tap water {Europe without Switzerland}| tap water production, underground water without treatment | Cut-off, U" modified to take into account for the specific country of origin;
  - Production phase: the amount of water consumed at the production plant, which is withdrawal from the groundwater wells, has been modeled through the dataset "Tap water {Europe without Switzerland} | tap water production, underground water without treatment | Cut-off, U" modified to consider the specific country of origin.

For all the previously described raw materials it was considered also the transport from the suppliers to the company plant, adopting the dataset "Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U". This emission class is justified by the literature that highlight in Italy a vehicle flat characterized by this kind of emission class. The weighted average distance, resulting from the analysis of all the raw milk suppliers, to the plant is equal to 50 km, reflecting the territorial nature of this raw material.

The operations made by vehicles at farms, instead, have been modeled through the dataset "Transport, tractor and trailer, agricultural {CH}| processing | Cut-off, U".
Moreover, the electricity energy consumed by farmers in raw milk production has been modeled with the dataset "Electricity, low voltage {IT}| market for | Cut-off, U" and, when specified, with the dataset "Electricity, low voltage {IT}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, U".

Packaging

In this stage all the packaging involved in the product under study have been modeled, particularly considering:

- Primary packaging, such as the PS plastic tray (which can be simple or sleeved) and the plastic film.
- Secondary and tertiary packaging, used for the distribution of the final product, such as the wood standard EU pallet, the cardboard box, the cardboard top cover, the stretch film, plastic bag.

For all the packaging it was considered the production process and next transport to the company plant according to the cradle to industry gate approach. Moreover, they were also included in the modeling the different packaging elements necessary for their transport to the company plant, thus cardboard boxes, plastic bags, plastic stretch film and top covers, wood pallets. Information about the packaging included in the analysis are reported as follows:

- PS tray: characterized by a mass of 8 grams of polystyrene, it was modeled though the dataset "Polystyrene, high impact {RER}| production | Cut-off, U" and the reference production process "Thermoforming, with calendering {RER}| production | Cut-off, U" modified according to the country of origin of the supplier that is Italian.
- PET/PE stretch film: characterized by a mass of 1,5 grams and made of a multilayer of polyethylene terephthalate and polyethylene, it was modeled with the dataset "Polyethylene terephthalate, granulate, amorphous {RER}| production | Cut-off, U", and "Packaging film, low density polyethylene {RER}| production | Cut-off, U". The adhesive material used to keep together the two layers was modeled trough the dataset "Urea formaldehyde resin {RER}| production | Cut-off, U". Finally, the production process has been modeled considering the

dataset “Thermoforming, with calendering {RER}| production | Cut-off, U” modified according to the country of origin of the supplier that is Italian.

- Sleeve: characterized by a mass of 4 grams, it is used only for some format of distribution, it has been modeled through the dataset “Polyvinylchloride, bulk polymerized {RER}| polyvinylchloride production, bulk polymerization | Cut-off, U” including the production process “Extrusion, plastic film {RER}| production | Cut-off, U” modified according to the country of origin of the supplier that is Italian.
- PE plastic bag: used for the transport of the PP plastic trays, it was modeled with the dataset “Polyethylene, high density, granulate {RER}| production | Cut-off, U” and production process “Stretch blow molding {RER}| production | Cut-off, U”.
- Cardboard tray: used to transport the final product on the pallet, it was modeled using the dataset “Corrugated board box {RER}| production | Cut-off, U” and the production process “Carton board box production, with offset printing {RoW}| carton board box production service, with offset printing | Cut-off, U”.
- Cardboard box: used to transport the plastic trays to the plant, it was modeled using the dataset “Corrugated board box {RER}| production | Cut-off, U” and the production process “Carton board box production, with offset printing {RoW}| carton board box production service, with offset printing | Cut-off, U”.
- Cardboard top cover: used to protect the upper part of the finished palled ready to be delivered, it was modeled using the dataset “Corrugated board box {RER}| production | Cut-off, U” and the production process “Carton board box production, with offset printing {RoW}| carton board box production service, with offset printing | Cut-off, U”.
- Stretch film: adopted to wrap the final products placed on the pallet to be distributed, it was modeled with the dataset “Polyethylene, linear low density, granulate {RER}| production | Cut-off, U” including also the production process “Extrusion, plastic film {RER}| production | Cut-off, U”.
- Pallet: made according to the standard format EU, it was modeled considering a reuse factor equal to 20 with the dataset “EUR-flat pallet {RER}| production | Cut-off, U” including also the production process “Wood chipping, industrial residual wood, stationary electric chipper {RER}| processing | Cut-off, U”.

For all the above described packaging the transport process has been modeled through the dataset “Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U”.

Production

The production of the fresh mozzarella cheese starts with a thermal pre-processing and storage of raw milk entering the company plant. The resulting milk mixture is then subjected to heating and cooling processes followed by mixing with the enzymes. The next stirring and cutting steps allow to obtain the first two main co-products: the curd, which is used to produce the mozzarella cheese, and the whey, which is used to produce the ricotta cheese.

According to the mozzarella cheese production process, the curd continues to be processed by shredding, spinning and heat treatment. Finally, the resulting final product goes into primary packaging together with the governing liquid and when sealed it is ready to proceed toward the next secondary and tertiary packaging for the final distribution in pallets.

During the production process under study, chemicals and wastes have been considered according to primary information provided by the company. Moreover, considering the operations performed to refill the refrigeration systems, for the reference year of this study it was observed a leak of 7,2 kg of R-410A.

The main sources of energy involved in the process are electricity and methane gas for the production of heat. The first has been modeled according to the different source as follows:

- National supply network: modeled through the dataset ““Electricity, medium voltage {IT}| market for | Cut-off, U”.
- Cogeneration, natural gas: modeled through the dataset “Electricity, high voltage {Europe without Switzerland} | heat and power co-generation, natural gas, 1MW electrical, lean burn | Cut-off, U” modified according to primary information.
- Cogeneration, biogas: modeled through the dataset “Electricity, high voltage {Europe without Switzerland} | heat and power co-generation, natural gas, 1MW electrical, lean burn | Cut-off, U” modified according to primary information.

The second has been modeled according to the different sources as follows:

- Boiler: modeled through the dataset "Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating >100kW | Cut-off, U".
- Cogeneration, natural gas: modeled through the dataset "Electricity, high voltage {Europe without Switzerland}| heat and power co-generation, natural gas, 1MW electrical, lean burn | Cut-off, U" modified according to primary information.

Considering the heat generated by the biogas cogeneration, to date the company has not fully implemented procedures for its collection and reuse within the productive system, with the only exception for a small quantity that is used by the wastewater treatment plant.

Considering chemicals involved in the fresh mozzarella cheese production, they were modeled according to primary information from company and adopting datasets as reported in Table 3.17. For each chemical it was considered the production process and the transport to the company plant.

Table 3.17 *Data on chemicals and related datasets adopted in the modeling of the fresh mozzarella cheese.*

Function	Type of chemical	Dataset
Water pre-treatment	Sodium hypochlorite	Sodium hypochlorite, without water, in 15% solution state {RER}| sodium hypochlorite production, product in 15% solution state | Cut-off, U
Production process	Nitric acid	Nitric acid, without water, in 50% solution state {GLO}| market for | Cut-off, U
	Acid detergent	Hydrogen peroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U Acetic acid, without water, in 98% solution state {GLO}| market for | Cut-off, U Water, unspecified natural origin, IT
	Alkaline detergent	Nitric acid, without water, in 50% solution state {GLO}| market for | Cut-off, U Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U Water, unspecified natural origin, IT
	Oxonia	Acetic acid, without water, in 98% solution state {GLO}| market for | Cut-off, U Hydrogen peroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U Water, unspecified natural origin, IT
	Sodium hydroxide	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U

Function	Type of chemical	Dataset
Wastewater treatment	DonauKlarFloc 40	Iron (III) chloride, without water, in 40% solution state {CH}| iron (III) chloride production, product in 40% solution state | Cut-off, U
	P3 Polix EM 494	Chemical, inorganic {GLO}| production | Cut-off, U
	Tillflock cl 1391	Chemical, inorganic {GLO}| production | Cut-off, U

For all the chemicals it has been considered also the transport from the suppliers to the company plant, adopting the dataset "Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U".
Focusing on refrigerants used in the cooling equipment at the plant, R410a is the only one for which it was considered the amount consumed during the operations of refill.

The different fluxes of waste generated during the production of the fresh mozzarella cheese have been modeled according to primary data from the company and, when this was not possible, adopting secondary data from the literature (ISPRA 2017a), considering different treatments as follows:

- Treatment of sludge (CER 020502): the 100% of this waste is recycled and has been modeled through a generic dataset for the recycling.
- Treatment of paper and carton (CER 150101): the different treatments of this waste have been modeled according to the datasets "Waste paperboard {CH}| treatment of, municipal incineration | Cut-off, U", "Waste paperboard {CH}| treatment of, sanitary landfill | Cut-off, U" and "Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U".
- Treatment of plastic (CER 150102): the different treatments of this waste have been modeled according to the datasets "Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, U", "Waste plastic, mixture {CH}| treatment of, sanitary landfill | Cut-off, U" and "Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U".
- Treatment of wood (CER 150103): the different treatments of this waste have been modeled according to the datasets "Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U", "Waste wood, untreated {CH}| treatment of, sanitary landfill | Cut-off, U" and a generic dataset for the recycling.
- Treatment of mix materials (CER 150106): the different treatments of this waste have been modeled according to the datasets "Municipal solid waste {IT}| treatment of, incineration |

Cut-off, U", "Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U" and a generic dataset for the recycling.

- Treatment of hazardous waste (CER 150110): the different treatments of this waste have been modeled according to the datasets "Hazardous waste, for incineration {CH}| treatment of hazardous waste, hazardous waste incineration | Cut-off, U, "Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U"" e di and a generic dataset for the recycling.
- Treatment of metals CER 170405: the different treatments of this waste have been modeled according to the datasets "Waste aluminum {CH}| treatment of, sanitary landfill | Cut-off, U" and "Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Cut-off, U".
- Treatment of exhausted activated carbon CER 190904: the 100% of this waste is recycled and has been modeled through a generic dataset for the recycling.

For all the above described waste treatment it was also included the transport process from the company plant to the final destination, modeled through the dataset "Municipal waste collection service by 21 metric ton lorry {CH}| processing | Cut-off, U", considering the specific distances according to primary information given by the company and contained into the waste register.

Distribution

This life cycle stage has been modeled accounting for the different positions of the market stores, which are all within the national context, where the final product has to be delivered.

The transport, which occurs mainly by refrigerated trucks with a weighted average distance of 112 km, has been modeled through the dataset "Transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, R134a refrigerant, cooling {GLO}| market for | Cut-off, U". Furthermore, even if in a smaller part, the transport occurs also by ship with a weighted average distance of 19 km. This has been modeled through the dataset "Transport, freight, inland waterways, barge {RER}| processing | Cut-off, U"".

The life cycle stage of distribution also accounts for the treatment of wastes arising from the secondary and tertiary packaging, which were modeled according to the following information:

- Treatment of paper and carton: this flux of waste is made of a fraction to be incinerated which was modeled with the dataset "Waste paperboard {Europe without Switzerland}| treatment of waste paperboard, municipal incineration | Cut-off, U", a fraction to be landfilled modeled with the dataset "Waste paperboard {Europe without Switzerland}| treatment of waste paperboard, sanitary landfill | Cut-off, U", and a fraction to be recycled modeled through the dataset "Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U".

- Treatment of plastic: this flux of waste considering a mix of datasets, according to the different treatment processes, equal to "Waste polyethylene {Europe without Switzerland}| treatment of waste polyethylene, municipal incineration | Cut-off, U", "Waste polyethylene {Europe without Switzerland}| treatment of waste polyethylene, sanitary landfill | Cut-off, U", "PE (waste treatment) {GLO}| recycling of PE | Cut-off, U".
- Treatment of wood: this waste has been modeled through the datasets "Waste wood, untreated {Europe without Switzerland}| treatment of waste wood, municipal incineration | Cut-off, U", "Waste wood, untreated {Europe without Switzerland}| treatment of waste wood, sanitary landfill | Cut-off, U", "Waste wood, untreated {CH}| treatment of, recycling | Cut-off, U" according to the different treatment processes.

Table 3.18 contains information from the literature (ISPRAa, 2017) about the values applied to account for the different treatment processes of the wastes generated in the distribution life cycle stage.

Table 3.18 *Waste treatment scenario adopted in the modeling of the distribution stage of the mozzarella cheese.*

Type of waste	Recycling	Incineration	Landfill
Paper and carton	79,6%	8,6%	11,8%
Plastic	38,0%	44,5%	17,5%
Wood	59,7%	3,4%	36,9%

Assuming a shelf life of a week, in this life cycle stage it was also possible to account for the energy consumption at the retailer, adopting literature data (Cecchinato et al., 2010), as well as for the energetic consumption due to the storage in a fridge modeled trough secondary data.

Use

In this stage, both the transport of the product from the retailer to the house of the final user and the energy consumption for the store of the product in a domestic fridge have been considered in the analysis.

The first has been modeled through the dataset "Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Cut-off, U", which is comparable to a mid-size family car, assuming an average distance equal to 5 km according to literature data (Point et al., 2012).
The amount of energy consumed by the domestic fridge, modeled through the dataset "Electricity, low voltage {IT}| market for | Cut-off, U", has been calculated on the basis of an annual consumption of electricity equal to 300 kWh according to the requirements of the PCR (IES, 2017), with a half shelf life of 10 days according to the primary information from the company.

End of life
In the last life cycle stage all the elements of the primary packaging of the product, thus plastic tray and stretch film, are subjected to the final disposal. According to the different type of material, a different treatment has been applied according to secondary data (ISPRAb, 2017).
Since all the packaging components are made of plastic material, thus the same percentage of treatment have been applied to all of them, particularly 41,7% for recycling, 43,7% for incineration and 15,6% for disposal in landfill. In this life cycle stage, it was also included the transport of the waste to the final destination, assuming a distance of 30 km.
Finally, it is important to highlight that the contribution given by the mozzarella cheese itself in terms of human digestion was not assessed because of the difficulties in performing accurate estimations and, in any case, it is very likely that it could be not significant for the purpose of the study.

Starting from the whole inventory data described above and adopting the LCA software SimaPro to process all the information, the water inventory results for the system product under study in terms of input (raw materials) and outputs (water, air, soil) are listed in the Table 3.19.

Table 3.19 *Water inventory data of the whole life cycle of the fresh mozzarella cheese.*

Substance	Compartment	Unit	Value
Water, AR	Water	m3	1,74E-05
Water, AT	Water	m3	9,44E-01
Water, AU	Water	m3	5,07E-02
Water, BA	Water	m3	5,50E-02
Water, BE	Water	m3	3,14E-03
Water, BG	Water	m3	2,70E-02
Water, BR	Water	m3	1,20E-01
Water, CA	Water	m3	1,42E-01
Water, CH	Water	m3	2,81E+00
Water, CL	Water	m3	2,74E-02
Water, CN	Water	m3	1,56E+00
Water, CO	Water	m3	2,06E-07
Water, cooling, unspecified natural origin, AT	Raw material	m3	2,39E-04

Substance	Compartment	Unit	Value
Water, cooling, unspecified natural origin, AU	Raw material	m3	6,01E-04
Water, cooling, unspecified natural origin, BA	Raw material	m3	1,08E-04
Water, cooling, unspecified natural origin, BE	Raw material	m3	4,02E-04
Water, cooling, unspecified natural origin, BG	Raw material	m3	3,81E-04
Water, cooling, unspecified natural origin, BR	Raw material	m3	2,30E-04
Water, cooling, unspecified natural origin, CA	Raw material	m3	7,65E-04
Water, cooling, unspecified natural origin, CH	Raw material	m3	6,65E-03
Water, cooling, unspecified natural origin, CL	Raw material	m3	5,46E-05
Water, cooling, unspecified natural origin, CN	Raw material	m3	8,53E-03
Water, cooling, unspecified natural origin, CY	Raw material	m3	7,19E-06
Water, cooling, unspecified natural origin, CZ	Raw material	m3	4,60E-03
Water, cooling, unspecified natural origin, DE	Raw material	m3	6,15E-03
Water, cooling, unspecified natural origin, DK	Raw material	m3	8,53E-05
Water, cooling, unspecified natural origin, EE	Raw material	m3	1,26E-04
Water, cooling, unspecified natural origin, ES	Raw material	m3	1,03E-03
Water, cooling, unspecified natural origin, Europe without Switzerland	Raw material	m3	3,52E-04
Water, cooling, unspecified natural origin, FI	Raw material	m3	2,79E-04
Water, cooling, unspecified natural origin, FR	Raw material	m3	1,52E-02
Water, cooling, unspecified natural origin, GB	Raw material	m3	9,94E-04
Water, cooling, unspecified natural origin, GLO	Raw material	m3	1,66E-04
Water, cooling, unspecified natural origin, GR	Raw material	m3	1,00E-03
Water, cooling, unspecified natural origin, HR	Raw material	m3	1,11E-04
Water, cooling, unspecified natural origin, HU	Raw material	m3	3,09E-04
Water, cooling, unspecified natural origin, ID	Raw material	m3	3,03E-04
Water, cooling, unspecified natural origin, IE	Raw material	m3	9,51E-05
Water, cooling, unspecified natural origin, IN	Raw material	m3	2,62E-03
Water, cooling, unspecified natural origin, IR	Raw material	m3	5,22E-04
Water, cooling, unspecified natural origin, IS	Raw material	m3	4,52E-08
Water, cooling, unspecified natural origin, IT	Raw material	m3	6,00E-02
Water, cooling, unspecified natural origin, JP	Raw material	m3	9,55E-04
Water, cooling, unspecified natural origin, KR	Raw material	m3	7,92E-04
Water, cooling, unspecified natural origin, LT	Raw material	m3	1,88E-05
Water, cooling, unspecified natural origin, LU	Raw material	m3	1,14E-05
Water, cooling, unspecified natural origin, LV	Raw material	m3	2,85E-05
Water, cooling, unspecified natural origin, MA	Raw material	m3	3,19E-05
Water, cooling, unspecified natural origin, MK	Raw material	m3	3,83E-05
Water, cooling, unspecified natural origin, MT	Raw material	m3	1,94E-05
Water, cooling, unspecified natural origin, MX	Raw material	m3	2,69E-04
Water, cooling, unspecified natural origin, MY	Raw material	m3	1,84E-04
Water, cooling, unspecified natural origin, NL	Raw material	m3	5,03E-04
Water, cooling, unspecified natural origin, NO	Raw material	m3	1,94E-05
Water, cooling, unspecified natural origin, NP	Raw material	m3	1,76E-09
Water, cooling, unspecified natural origin, PE	Raw material	m3	3,63E-05
Water, cooling, unspecified natural origin, PH	Raw material	m3	4,85E-07
Water, cooling, unspecified natural origin, PL	Raw material	m3	4,08E-03
Water, cooling, unspecified natural origin, PT	Raw material	m3	9,81E-05
Water, cooling, unspecified natural origin, RER	Raw material	m3	3,36E-02
Water, cooling, unspecified natural origin, RNA	Raw material	m3	1,03E-07
Water, cooling, unspecified natural origin, RO	Raw material	m3	7,42E-04
Water, cooling, unspecified natural origin, RoW	Raw material	m3	2,46E-02
Water, cooling, unspecified natural origin, RS	Raw material	m3	9,14E-04
Water, cooling, unspecified natural origin, RU	Raw material	m3	4,66E-03
Water, cooling, unspecified natural origin, SA	Raw material	m3	4,74E-04
Water, cooling, unspecified natural origin, SE	Raw material	m3	6,23E-04
Water, cooling, unspecified natural origin, SI	Raw material	m3	8,27E-03
Water, cooling, unspecified natural origin, SK	Raw material	m3	5,77E-04
Water, cooling, unspecified natural origin, TH	Raw material	m3	1,72E-04
Water, cooling, unspecified natural origin, TR	Raw material	m3	3,11E-04
Water, cooling, unspecified natural origin, TW	Raw material	m3	2,80E-04
Water, cooling, unspecified natural origin, TZ	Raw material	m3	7,00E-06
Water, cooling, unspecified natural origin, UA	Raw material	m3	1,34E-03
Water, cooling, unspecified natural origin, US	Raw material	m3	5,14E-03

Substance	Compartment	Unit	Value
Water, cooling, unspecified natural origin, WEU	Raw material	m3	1,82E-07
Water, cooling, unspecified natural origin, ZA	Raw material	m3	5,60E-04
Water, CY	Water	m3	7,15E-06
Water, CZ	Water	m3	1,85E-02
Water, DE	Water	m3	1,96E-01
Water, DK	Water	m3	1,26E-04
Water, EE	Water	m3	1,23E-04
Water, ES	Water	m3	1,52E-01
Water, Europe without Switzerland	Water	m3	1,70E-04
Water, FI	Water	m3	4,98E-02
Water, FR	Water	m3	1,95E+00
Water, GB	Water	m3	1,17E-03
Water, GLO	Water	m3	1,03E-03
Water, GR	Water	m3	2,79E-02
Water, HR	Water	m3	1,02E-02
Water, HU	Water	m3	2,62E-03
Water, IAI Area, Africa	Water	m3	2,20E-06
Water, IAI Area, Asia, without China and GCC	Water	m3	4,07E-06
Water, IAI Area, EU27 & EFTA	Water	m3	5,17E-05
Water, IAI Area, Gulf Cooperation Council	Water	m3	4,91E-06
Water, IAI Area, North America, without Quebec	Water	m3	3,02E-06
Water, IAI Area, Russia & RER w/o EU27 & EFTA	Water	m3	7,64E-06
Water, IAI Area, South America	Water	m3	2,76E-06
Water, ID	Water	m3	2,96E-03
Water, IE	Water	m3	3,72E-03
Water, IL	Water	m3	3,82E-10
Water, IN	Water	m3	1,12E-01
Water, IR	Water	m3	2,08E-02
Water, IS	Water	m3	2,08E-02
Water, IT	Water	m3	8,05E+00
Water, JP	Water	m3	7,83E-02
Water, KR	Water	m3	3,82E-03
Water, lake, CA	Raw material	m3	1,23E-04
Water, lake, CH	Raw material	m3	2,54E-05
Water, lake, CN	Raw material	m3	3,74E-08
Water, lake, DE	Raw material	m3	2,36E-08
Water, lake, Europe without Switzerland	Raw material	m3	1,05E-05
Water, lake, GLO	Raw material	m3	1,72E-12
Water, lake, IT	Raw material	m3	7,98E-04
Water, lake, RER	Raw material	m3	2,00E-06
Water, lake, RNA	Raw material	m3	1,09E-08
Water, lake, RoW	Raw material	m3	5,23E-05
Water, lake, US	Raw material	m3	5,19E-11
Water, LT	Water	m3	8,70E-05
Water, LU	Water	m3	1,86E-03
Water, LV	Water	m3	2,90E-05
Water, MA	Water	m3	2,29E-05
Water, MK	Water	m3	1,56E-03
Water, MT	Water	m3	1,93E-05
Water, MX	Water	m3	4,58E-02
Water, MY	Water	m3	3,31E-03
Water, NL	Water	m3	1,14E-03
Water, NO	Water	m3	1,72E-02
Water, NORDEL	Water	m3	9,42E-08
Water, NP	Water	m3	4,59E-03
Water, PE	Water	m3	4,85E-04
Water, PG	Water	m3	3,37E-07
Water, PH	Water	m3	2,77E-05
Water, PL	Water	m3	1,63E-02
Water, PT	Water	m3	6,15E-02
Water, RAF	Water	m3	2,96E-05
Water, RAS	Water	m3	3,23E-05

Substance	Compartment	Unit	Value
Water, RER	Water	m3	2,34E-02
Water, river, AU	Raw material	m3	3,74E-06
Water, river, BR	Raw material	m3	8,63E-04
Water, river, CH	Raw material	m3	5,29E-02
Water, river, CN	Raw material	m3	8,14E-03
Water, river, DE	Raw material	m3	4,15E-04
Water, river, ES	Raw material	m3	4,59E-04
Water, river, Europe without Switzerland	Raw material	m3	2,22E-04
Water, river, FR	Raw material	m3	1,09E-03
Water, river, GLO	Raw material	m3	7,79E-05
Water, river, IN	Raw material	m3	8,16E-03
Water, river, IT	Raw material	m3	1,22E-02
Water, river, KR	Raw material	m3	9,99E-06
Water, river, MY	Raw material	m3	1,90E-04
Water, river, NL	Raw material	m3	7,23E-08
Water, river, PE	Raw material	m3	3,26E-09
Water, river, PH	Raw material	m3	1,42E-03
Water, river, RAS	Raw material	m3	6,60E-05
Water, river, RER	Raw material	m3	2,97E-03
Water, river, RLA	Raw material	m3	1,56E-05
Water, river, RNA	Raw material	m3	2,71E-05
Water, river, RO	Raw material	m3	2,80E-05
Water, river, RoW	Raw material	m3	3,24E-02
Water, river, RU	Raw material	m3	8,05E-06
Water, river, SE	Raw material	m3	8,39E-08
Water, river, TN	Raw material	m3	3,39E-05
Water, river, TZ	Raw material	m3	4,88E-08
Water, river, US	Raw material	m3	4,38E-03
Water, river, WEU	Raw material	m3	7,42E-12
Water, river, ZA	Raw material	m3	1,00E-05
Water, RLA	Water	m3	9,31E-06
Water, RME	Water	m3	2,91E-04
Water, RNA	Water	m3	4,31E-05
Water, RO	Water	m3	1,13E-01
Water, RoW	Water	m3	1,79E+00
Water, RS	Water	m3	5,71E-02
Water, RU	Water	m3	5,70E-01
Water, SA	Water	m3	4,76E-04
Water, salt, ocean	Raw material	m3	6,40E-04
Water, salt, sole	Raw material	m3	2,77E-04
Water, SE	Water	m3	3,24E-01
Water, SI	Water	m3	1,19E-02
Water, SK	Water	m3	2,72E-02
Water, TH	Water	m3	1,40E-03
Water, TR	Water	m3	3,23E-02
Water, turbine use, unspecified natural origin, AT	Raw material	m3	9,44E-01
Water, turbine use, unspecified natural origin, AU	Raw material	m3	5,01E-02
Water, turbine use, unspecified natural origin, BA	Raw material	m3	5,49E-02
Water, turbine use, unspecified natural origin, BE	Raw material	m3	2,73E-03
Water, turbine use, unspecified natural origin, BG	Raw material	m3	2,67E-02
Water, turbine use, unspecified natural origin, BR	Raw material	m3	1,20E-01
Water, turbine use, unspecified natural origin, CA	Raw material	m3	1,42E-01
Water, turbine use, unspecified natural origin, CH	Raw material	m3	2,76E+00
Water, turbine use, unspecified natural origin, CL	Raw material	m3	2,74E-02
Water, turbine use, unspecified natural origin, CN	Raw material	m3	1,55E+00
Water, turbine use, unspecified natural origin, CZ	Raw material	m3	1,41E-02
Water, turbine use, unspecified natural origin, DE	Raw material	m3	1,89E-01
Water, turbine use, unspecified natural origin, DK	Raw material	m3	9,74E-05
Water, turbine use, unspecified natural origin, ES	Raw material	m3	1,51E-01
Water, turbine use, unspecified natural origin, FI	Raw material	m3	4,95E-02
Water, turbine use, unspecified natural origin, FR	Raw material	m3	1,94E+00
Water, turbine use, unspecified natural origin, GB	Raw material	m3	1,64E-04

Substance	Compartment	Unit	Value
Water, turbine use, unspecified natural origin, GLO	Raw material	m3	1,78E-07
Water, turbine use, unspecified natural origin, GR	Raw material	m3	2,69E-02
Water, turbine use, unspecified natural origin, HR	Raw material	m3	1,02E-02
Water, turbine use, unspecified natural origin, HU	Raw material	m3	2,31E-03
Water, turbine use, unspecified natural origin, ID	Raw material	m3	2,64E-03
Water, turbine use, unspecified natural origin, IE	Raw material	m3	3,62E-03
Water, turbine use, unspecified natural origin, IN	Raw material	m3	1,09E-01
Water, turbine use, unspecified natural origin, IR	Raw material	m3	2,03E-02
Water, turbine use, unspecified natural origin, IS	Raw material	m3	2,09E-02
Water, turbine use, unspecified natural origin, IT	Raw material	m3	7,95E+00
Water, turbine use, unspecified natural origin, JP	Raw material	m3	7,73E-02
Water, turbine use, unspecified natural origin, KR	Raw material	m3	3,03E-03
Water, turbine use, unspecified natural origin, LT	Raw material	m3	6,92E-05
Water, turbine use, unspecified natural origin, LU	Raw material	m3	1,85E-03
Water, turbine use, unspecified natural origin, MK	Raw material	m3	1,53E-03
Water, turbine use, unspecified natural origin, MX	Raw material	m3	4,56E-02
Water, turbine use, unspecified natural origin, MY	Raw material	m3	3,12E-03
Water, turbine use, unspecified natural origin, NL	Raw material	m3	6,77E-04
Water, turbine use, unspecified natural origin, NO	Raw material	m3	1,78E-02
Water, turbine use, unspecified natural origin, NP	Raw material	m3	4,59E-03
Water, turbine use, unspecified natural origin, PE	Raw material	m3	4,65E-04
Water, turbine use, unspecified natural origin, PL	Raw material	m3	1,27E-02
Water, turbine use, unspecified natural origin, PT	Raw material	m3	6,14E-02
Water, turbine use, unspecified natural origin, RER	Raw material	m3	1,33E-04
Water, turbine use, unspecified natural origin, RNA	Raw material	m3	8,57E-06
Water, turbine use, unspecified natural origin, RO	Raw material	m3	1,12E-01
Water, turbine use, unspecified natural origin, RoW	Raw material	m3	1,73E+00
Water, turbine use, unspecified natural origin, RS	Raw material	m3	5,62E-02
Water, turbine use, unspecified natural origin, RU	Raw material	m3	5,66E-01
Water, turbine use, unspecified natural origin, SE	Raw material	m3	3,24E-01
Water, turbine use, unspecified natural origin, SI	Raw material	m3	3,81E-03
Water, turbine use, unspecified natural origin, SK	Raw material	m3	2,67E-02
Water, turbine use, unspecified natural origin, TH	Raw material	m3	1,23E-03
Water, turbine use, unspecified natural origin, TR	Raw material	m3	3,20E-02
Water, turbine use, unspecified natural origin, TZ	Raw material	m3	6,17E-04
Water, turbine use, unspecified natural origin, UA	Raw material	m3	4,30E-02
Water, turbine use, unspecified natural origin, US	Raw material	m3	3,27E-01
Water, turbine use, unspecified natural origin, ZA	Raw material	m3	6,86E-04
Water, TW	Water	m3	2,79E-04
Water, TZ	Water	m3	6,22E-04
Water, UA	Water	m3	4,43E-02
Water, UCTE	Water	m3	1,12E-09
Water, UCTE without Germany	Water	m3	4,81E-10
Water, UN-OCEANIA	Water	m3	2,93E-06
Water, unspecified natural origin, AU	Raw material	m3	1,75E-16
Water, unspecified natural origin, CA	Raw material	m3	3,85E-06
Water, unspecified natural origin, CH	Raw material	m3	2,64E-04
Water, unspecified natural origin, CL	Raw material	m3	8,31E-10
Water, unspecified natural origin, CN	Raw material	m3	2,24E-05
Water, unspecified natural origin, DE	Raw material	m3	3,78E-09
Water, unspecified natural origin, Europe without Switzerland	Raw material	m3	4,59E-06
Water, unspecified natural origin, GLO	Raw material	m3	3,30E-04
Water, unspecified natural origin, IAI Area, Africa	Raw material	m3	1,66E-06
Water, unspecified natural origin, IAI Area, Asia, without China and GCC	Raw material	m3	3,08E-06
Water, unspecified natural origin, IAI Area, EU27 & EFTA	Raw material	m3	1,80E-05
Water, unspecified natural origin, IAI Area, Gulf Cooperation Council	Raw material	m3	3,70E-06
Water, unspecified natural origin, IAI Area, North America, without Quebec	Raw material	m3	2,34E-06
Water, unspecified natural origin, IAI Area, Russia & RER w/o EU27 & EFTA	Raw material	m3	5,46E-06
Water, unspecified natural origin, IAI Area, South America	Raw material	m3	2,20E-06
Water, unspecified natural origin, PG	Raw material	m3	4,11E-08

Substance	Compartment	Unit	Value
Water, unspecified natural origin, PH	Raw material	m3	1,21E-07
Water, unspecified natural origin, RAF	Raw material	m3	3,49E-05
Water, unspecified natural origin, RER	Raw material	m3	9,87E-04
Water, unspecified natural origin, RME	Raw material	m3	3,43E-04
Water, unspecified natural origin, RNA	Raw material	m3	5,29E-06
Water, unspecified natural origin, RoW	Raw material	m3	2,23E-03
Water, unspecified natural origin, RU	Raw material	m3	4,88E-05
Water, unspecified natural origin, TH	Raw material	m3	9,04E-08
Water, unspecified natural origin, UN-OCEANIA	Raw material	m3	2,21E-06
Water, unspecified natural origin, US	Raw material	m3	2,87E-06
Water, unspecified natural origin, WEU	Raw material	m3	1,39E-08
Water, US	Water	m3	3,36E-01
Water, well, in ground, AT	Raw material	m3	1,04E-13
Water, well, in ground, AU	Raw material	m3	5,48E-05
Water, well, in ground, BR	Raw material	m3	2,00E-04
Water, well, in ground, CA	Raw material	m3	6,48E-06
Water, well, in ground, CH	Raw material	m3	1,50E-02
Water, well, in ground, CN	Raw material	m3	3,74E-03
Water, well, in ground, DE	Raw material	m3	1,47E-03
Water, well, in ground, ES	Raw material	m3	2,71E-04
Water, well, in ground, Europe without Switzerland	Raw material	m3	3,77E-05
Water, well, in ground, FR	Raw material	m3	8,75E-04
Water, well, in ground, GLO	Raw material	m3	5,91E-05
Water, well, in ground, ID	Raw material	m3	1,46E-05
Water, well, in ground, IN	Raw material	m3	1,41E-02
Water, well, in ground, IS	Raw material	m3	5,43E-10
Water, well, in ground, IT	Raw material	m3	5,50E-02
Water, well, in ground, JP	Raw material	m3	2,72E-10
Water, well, in ground, MA	Raw material	m3	5,18E-06
Water, well, in ground, MX	Raw material	m3	6,06E-10
Water, well, in ground, MY	Raw material	m3	1,66E-05
Water, well, in ground, NORDEL	Raw material	m3	1,11E-07
Water, well, in ground, PE	Raw material	m3	5,29E-09
Water, well, in ground, PG	Raw material	m3	3,55E-07
Water, well, in ground, PH	Raw material	m3	2,22E-04
Water, well, in ground, PL	Raw material	m3	1,69E-05
Water, well, in ground, PT	Raw material	m3	1,52E-11
Water, well, in ground, RER	Raw material	m3	5,46E-04
Water, well, in ground, RLA	Raw material	m3	1,96E-06
Water, well, in ground, RNA	Raw material	m3	1,22E-05
Water, well, in ground, RoW	Raw material	m3	1,91E-02
Water, well, in ground, RU	Raw material	m3	7,08E-06
Water, well, in ground, SE	Raw material	m3	1,46E-08
Water, well, in ground, TH	Raw material	m3	1,04E-13
Water, well, in ground, TN	Raw material	m3	5,22E-05
Water, well, in ground, TR	Raw material	m3	3,69E-10
Water, well, in ground, US	Raw material	m3	7,42E-03
Water, well, in ground, WEU	Raw material	m3	2,38E-05
Water, well, in ground, ZA	Raw material	m3	6,49E-06
Water, WEU	Water	m3	2,65E-05
Water, ZA	Water	m3	1,27E-03
Water/m3	Air	m3	1,19E-01

3.4.5 Life cycle impact assessment

Starting from the life cycle inventory above described, in this paragraph results of the life cycle impact assessment are reported, particularly referring to the monetary assessment of water scarcity impacts related to the product under study.

According to the reasons already reported in the life cycle impact assessment phase of the previous case study #1 (§ 3.4.2), also in this case study the monetary assessment has been performed through the application of the new monetary characterization factors developed in this research work to the method proposed by Pfister et al. (2009), which has been assumed as reference.

Moreover, the same sensitivity analysis described in the previous case study #1 (§ 3.4.3) have been also performed, evaluating the effects on final results from the application of the new proposed method to 4 existing water scarcity impact assessment methods, and the effects on final results from the adoption of the modified monetary base constant MK (§ 3.3) in the calculation of the new monetary characterization factors.

The next Table 3.20 reports the results from the application of the new proposed method in absolute terms according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.20 *Monetary impact assessment resulting from the application of the new proposed method to the fresh mozzarella cheese. Results are expressed in US$/FU and characterized according to the life cycle stages.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
I_{eco} - Pfister based (MCFi - SET EQ)	5,959	0,044	0,032	0,008	0,024	0,000	**6,066**
I_{eco} - Pfister based (MCFi - SET 1)	9,336	0,059	0,045	0,010	0,031	0,000	**9,480**
I_{eco} - Pfister based (MCFi - SET 2)	8,545	0,079	0,058	0,014	0,044	-0,001	**8,740**
I_{eco} - Pfister based (MCFi - SET 3)	10,844	0,089	0,067	0,012	0,041	0,000	**11,053**
I_{eco} - Pfister based (MCFi - SET 4)	9,127	0,073	0,055	0,012	0,038	0,000	**9,305**
I_{eco} - Pfister based (MCFi - SET 5)	6,650	0,045	0,033	0,008	0,025	0,000	**6,761**
I_{eco} - Pfister based (MCFi - SET 6)	8,940	0,069	0,052	0,012	0,038	0,000	**9,110**

Results show a variability in the absolute values obtained from the application of the 7 different proposed set of characterization factors developed according to the weighting approaches described in the previous chapter 2 (§ 2.2.1.1).

The total value of the monetary assessment of water scarcity impacts of the fresh mozzarella cheese resulted to be in the range between 6,066 US$/FU of the monetary impact $I_{eco\ -\ Pfister\ based}$ applying $MCF_{i\ -\ SET\ EQ}$, and 11,053 US$/FU of the monetary impact $I_{eco\ -\ Pfister\ based}$ applying $MCF_{i\ -\ SET\ 3}$, confirming what observed in the previous case study #1 where the same sets were responsible respectively of the minimum and the maximum absolute value of the monetary impact among all the 7 sets applied.

As already observed in the life cycle impact assessment phase of the previous case study #1 (§ 3.4.2), it is important to analyze the results in terms of incidence among the different life cycle stages in order to highlight which is the most incident one over the whole supply chain allowing the proper identification of the hotspots.

Thus, the values listed in the Table 3.20 in absolute terms are reported also in percentage terms in the next Table 3.21 and Figure 3.14 in order to allow a better understanding of the incidence of the results.

Table 3.21 *Monetary assessment of water scarcity impacts resulting from the application of the new proposed method to the fresh mozzarella cheese. Results are expressed in % and characterized according to the life cycle stages.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
I_{eco} - Pfister based (MCFi - SET EQ)	98,2	0,7	0,5	0,1	0,4	0,0
I_{eco} - Pfister based (MCFi - SET 1)	98,5	0,6	0,5	0,1	0,3	0,0
I_{eco} - Pfister based (MCFi - SET 2)	97,8	0,9	0,7	0,2	0,5	0,0
I_{eco} - Pfister based (MCFi - SET 3)	98,1	0,8	0,6	0,1	0,4	0,0
I_{eco} - Pfister based (MCFi - SET 4)	98,1	0,8	0,6	0,1	0,4	0,0
I_{eco} - Pfister based (MCFi - SET 5)	98,4	0,7	0,5	0,1	0,4	0,0
I_{eco} - Pfister based (MCFi - SET 6)	98,1	0,8	0,6	0,1	0,4	0,0

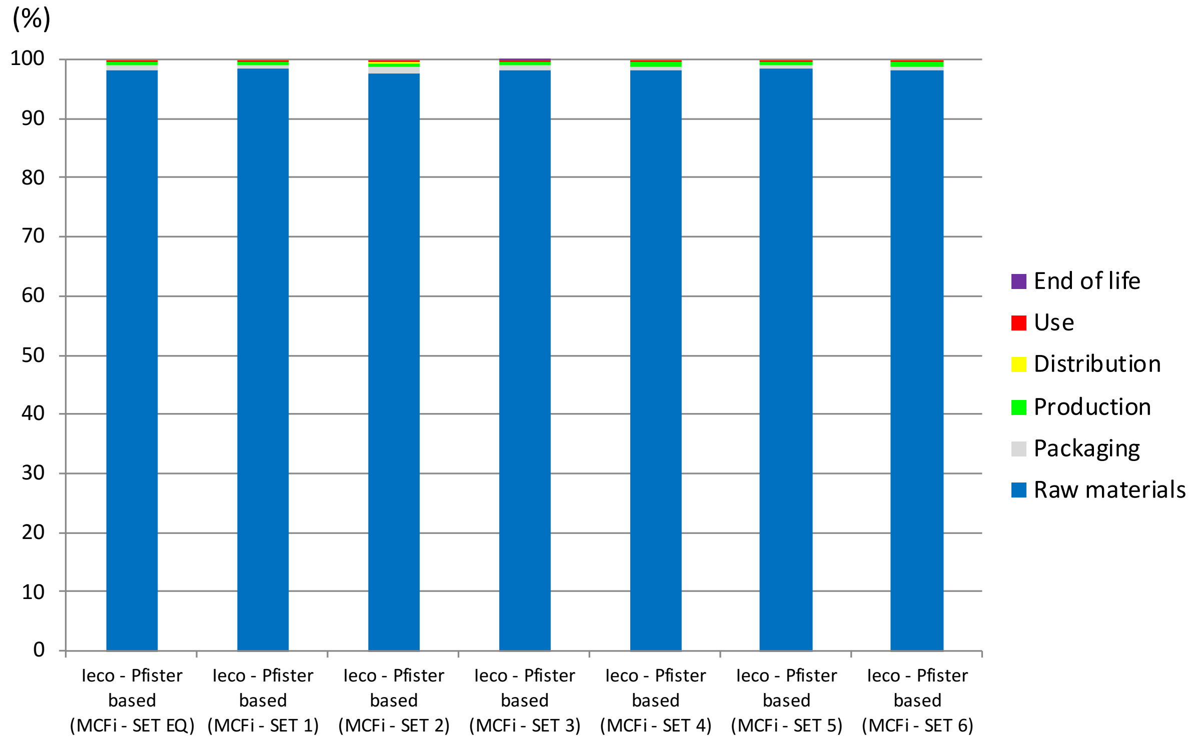

Figure 3.14 *Graphical representation of results from the application of the new proposed method to the fresh mozzarella cheese. Results are represented in % and characterized according to the life cycle stages.*

Analyzing the results in percentage terms along the whole supply chain it was possible to observe that the application of the 7 different proposed sets of characterization factors, as already highlighted in the previous case study #1, resulted to have the same incidence on the different life cycle stages, with a very low variation (less than 1%) among the 7 proposed sets of characterization factors.
Moreover, all the applications of the different sets confirmed that raw materials is the most impactful life cycle stage, characterized by an average incidence of about 98% on the overall impact, with a marginal contribution, instead, of the other life cycle stages.

3.4.6 Life cycle interpretation and hotspots analysis

In this stage results are analyzed in order to highlight the hotspots related to the impact assessment performed in this case study.
Moreover, according to the research objectives and adopting the same approach of the previous case study #1 (§ 3.4.3), some sensitivity analysis have been also performed in order to investigate: (i) the effects on the final results from the application of the new proposed method to different existing water scarcity impact assessment methods, including the one from Pfister et al. (2009) adopted as reference

in the previous stage; (ii) the effects on the final results from the adoption of the modified monetary base constant MK (§ 3.3) in the calculation of the new monetary characterization factors.

Results from the monetary assessment of water scarcity impacts of the fresh mozzarella cheese under study, performed applying different sets of proposed monetary characterization factors, confirmed that raw materials is the most impactful life cycle stage with an average incidence of about 98% on the overall impact. A deep analysis shown that, similarly to what observed in the previous cases study #1, also for the fresh mozzarella cheese the most part of the impact is due to a dairy ingredient, in this case milk, in particular because of the high amount of water required for the irrigation of crops used in animal feeds.

For this reason, according to the high incidence of the animal feeds on the total impact, thus it has been also performed an additional sensitivity analysis in order to investigate the potential effects on the results from the change of the datasets adopted to model the farm stage.

Sensitivity analysis 1: adoption of alternative water scarcity impact assessment methods

According to the research objectives in this analysis the effects on results from the application of new proposed method for the monetary assessment to different existing water scarcity impact assessment methods have been investigated.

The methods selected to perform the analysis have been chosen according to the criteria described in the chapter 2 (§ 2.2.1.3), resulting in the application of the new proposed method to 4 different existing water scarcity impact assessment methods.

According to the results from the life cycle impact assessment phase of this case study (§ 3.4.5), highlighting a very low variation in the percentage incidence of the final results from the application of the 7 different proposed set of characterization factors, as already done in the previous case study #1 also in this sensitivity analysis it was assumed one single set of monetary characterization factors as reference, in particular $MCF_{i\text{ - SET 1}}$.

The next Table 3.22 contains results in absolute terms from the sensitivity analysis according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.22 *Results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are expressed in US$/FU and characterized according to the life cycle stages of the fresh mozzarella cheese.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
I_{eco} - Pfister based (MCFi - SET 1)	9,336	0,059	0,045	0,010	0,031	0,000	**9,480**
I_{eco} - Hoekstra based (MCFi - SET 1)	23,294	0,120	0,096	0,014	0,049	0,002	**23,575**
I_{eco} - Berger based (MCFi - SET 1)	7,371	0,064	0,049	0,015	0,047	-0,001	**7,544**
I_{eco} - Boulay based (MCFi - SET 1)	309,479	4,744	3,667	1,079	3,223	-0,101	**322,092**

Results in Table 3.22 show a high variability in the absolute values obtained from the application of the $MCF_{i\text{ - SET 1}}$ to different existing water scarcity impact assessment methods.

As already explained in the previous case study #1, this is due to the different approach adopted by the authors in developing the water scarcity index (WSI) of each method (§ 2.2.1.3), with the consequent effect of different range of minimum and maximum characterization factors.

For this reason, in order to have a better comprehension about the variability of the incidence on final results when adopting different existing water scarcity impact assessment methods, it was important to analyze impact values in percentage terms, as reported in the next Table 3.23 and Figure 3.15.

Table 3.23 *Results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are expressed in % and characterized according to the life cycle stages of the fresh mozzarella cheese.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
I_{eco} - Pfister based (MCFi - SET 1)	98,5	0,6	0,5	0,1	0,3	0,0
I_{eco} - Hoekstra based (MCFi - SET 1)	98,8	0,5	0,4	0,1	0,2	0,0
I_{eco} - Berger based (MCFi - SET 1)	97,7	0,8	0,6	0,2	0,6	0,0
I_{eco} - Boulay based (MCFi - SET 1)	96,1	1,5	1,1	0,3	1,0	0,0

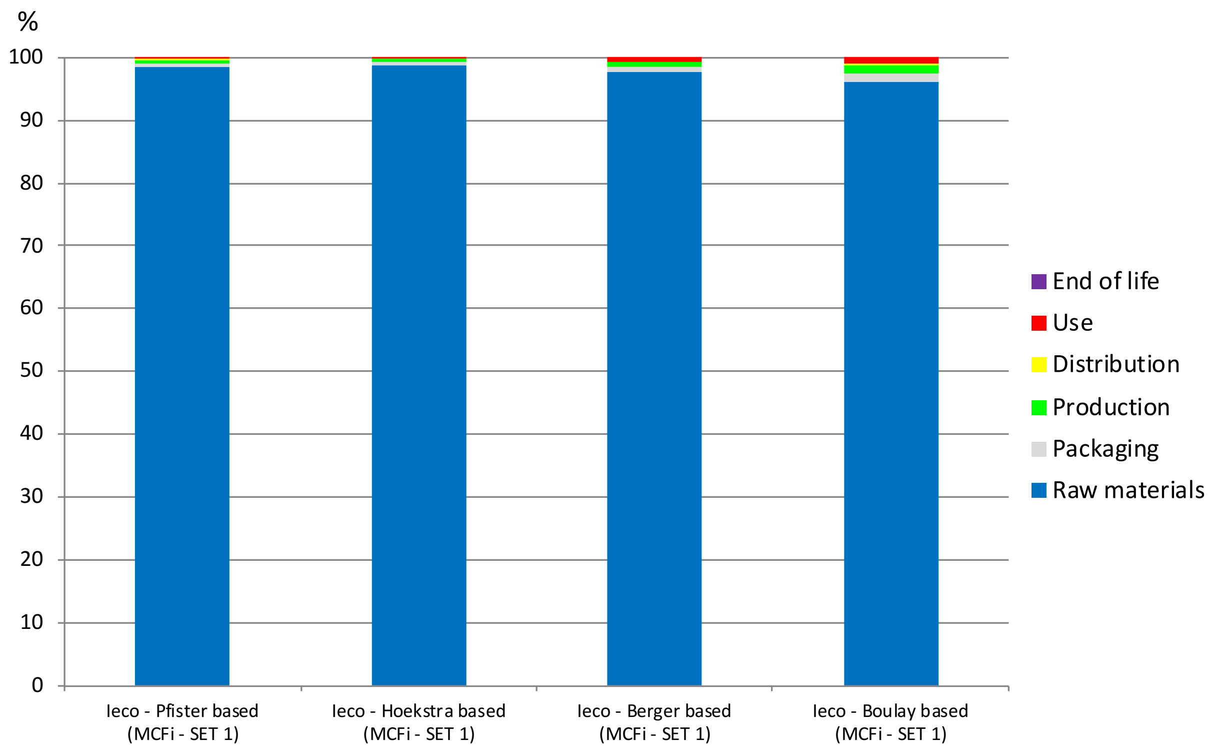

Figure 3.15 *Graphical representation of results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are represented in % and characterized according to the life cycle stages of the fresh mozzarella cheese.*

The analysis of results expressed in percentage terms allowed to confirm that raw materials is the life cycle stage characterized by the most incidence on the overall impact. Moreover, in contrast to what observed in the previous case study #1, in this case when comparing results within the same life cycle stage from the application of the new proposed method to the different existing water scarcity impact assessment methods, it was observed that each method gives more or less the same incidence to the life cycle stage analyzed.

Considering raw materials, which is the most impactful life cycle stage, it was possible to highlight an incidence variation between the minimum and the maximum value of less than 2,5%, while in the previous case study the difference was higher than 7%.

Even if this allowed to have a higher accuracy in the hotspots analysis, nevertheless it is highly recommended to be careful in performing interpretation of results, especially when adopting different methods to perform the assessment.

Sensitivity analysis 2: adoption of the modified monetary base constant MK

According to the review of the monetary base constant MK (§ 2.2.1.2) performed in this research work, this sensitivity analysis is aimed to confirm the observations reported in the chapter 2 (§ 2.2.1.2) about the expected very low variation in final results when applying the new proposed monetary characterization factors calculated adopting the modified monetary base constant MK.

Since it was observed from the life cycle impact assessment phase of this case study (§ 3.4.5) a very low variation of the percentage incidence of the final results from the application of the 7 different proposed set of characterization factors, thus, according also to what already done in the previous case study #1, it was chosen one single set of monetary characterization factors ($MCF_{i\ -\ SET\ 1}$) to perform the assessment.

In Figure 3.16 results are reported graphically to highlight the differences between the application of $MCF_{i\ -\ SET\ 1}$ to Pfister et al. (2009) method and the application of $MCF_{i\ -\ SET\ 1*}$, which has been calculated adopting the monetary base constant MK modified, to the same water scarcity impact assessment method adopted as reference. As expected, the final water scarcity impact expressed in monetary terms showed a low variation, with resulting values equal to 9,480 US$/FU when applying $MCF_{i\ -\ SET\ 1}$ and 9,907 US$/FU when applying $MCF_{i\ -\ SET\ 1*}$.

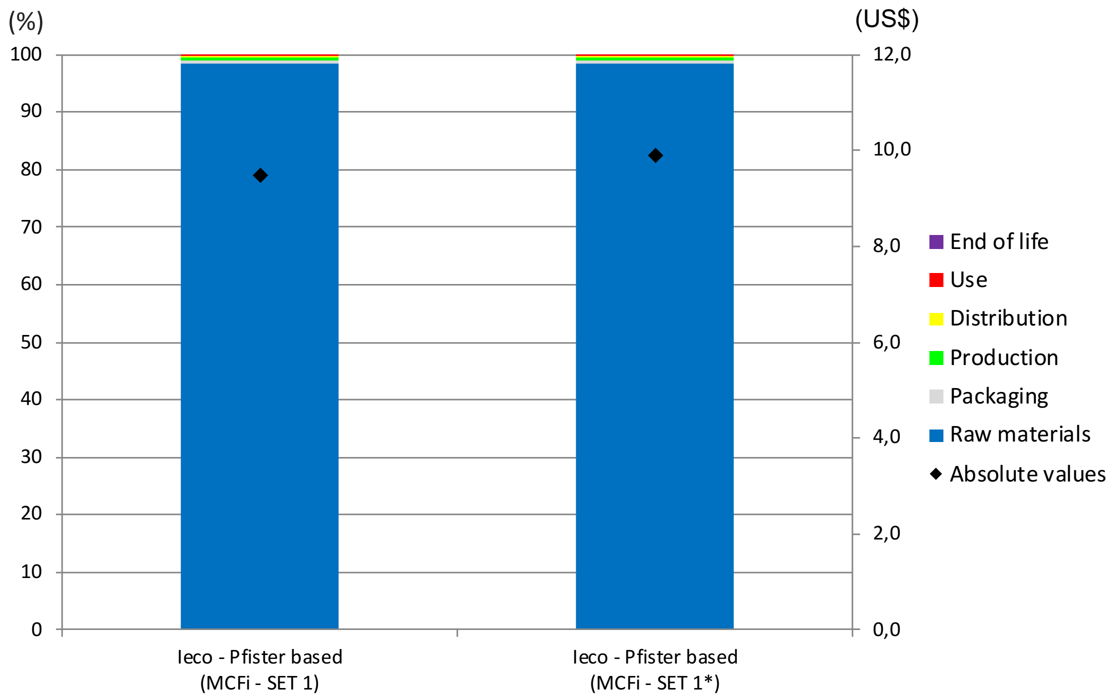

Figure 3.16 *Graphical representation of results from the sensitivity analysis performed to evaluate effects on final results from the application of the monetary base constant MK modified. Results are represented in % and characterized according to the life cycle stages of the fresh mozzarella cheese, with black squares in the middle of the columns representing total values in absolute terms.*

Sensitivity analysis 3: change of water related datasets adopted in the farm stage

According to the results of the hotspots analysis, which showed a high incidence of the animal feeds on the total impact, it has been performed an additional sensitivity analysis aimed to investigate the effects on final results from the change of the datasets adopted to model the farm stage.

In particular, the analysis has been done modifying all the datasets adopted in the modeling of animal feeds (§ Table 3.16), assuming where practicable Italy as country of reference for the processes of irrigation, water withdrawals and releases in water bodies and air.

It is important to clarify that, since it was not possible to collect primary data about where all the animal feeds used in the breeding stage by the raw milk suppliers are produced all around the world, so the one adopted in this sensitivity analysis is only an assumption made to investigate the effects from the change of the regional context adopted by each dataset.

Furthermore, the analysis has been performed applying the $MCF_{i - SET\ 1}$ to 4 different existing water scarcity impact assessment methods as already done in the sensitivity 2 of this case study.

The next Table 3.24 contains results in absolute terms from the sensitivity analysis according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.24 *Results from the sensitivity analysis performed modifying the water related datasets adopted in the modeling of the farm stage and applying the new prosed method to 4 different existing water scarcity impact assessment methods. Results are expressed in US$/FU and characterized according to the life cycle stages of the fresh mozzarella cheese.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
I_{eco} - Pfister based (MCFi - SET 1)	2,085	0,059	0,045	0,010	0,031	0,000	2,230
I_{eco} - Hoekstra based (MCFi - SET 1)	5,012	0,120	0,096	0,014	0,049	0,002	5,293
I_{eco} - Berger based (MCFi - SET 1)	1,801	0,064	0,049	0,015	0,047	-0,001	1,974
I_{eco} - Boulay based (MCFi - SET 1)	85,514	4,744	3,667	1,079	3,223	-0,101	98,127

As observed in the sensitivity analysis 2, the results show a high variability in the absolute values obtained from the application of the $MCF_{i - SET\ 1}$ to different existing water scarcity impact assessment methods.

Again, the reason is the same that was already explained previously, thus the different approach adopted by the authors in developing the water scarcity index (WSI) of each method (§ 2.2.1.3).
Moreover, the most important result from this sensitivity analysis is that final impacts are highly reduced if compared to the results from the sensitivity analysis 2, with a variation equal to more than -70% for each method.
This is due to the changes applied to the water irrigation processes that, for several type of crops, were associated by the database adopted during the modeling to countries placed outside Europe and, more important, to countries characterized by a high values of characterization factors such as India.
In order to better understand how this variation may affect the hotspots analysis, results have been also analyzed in percentage terms, as reported in the next Table 3.25 and Figure 3.17.
The analysis of results expressed in percentage terms on the one hand confirmed that raw materials is the life cycle stage characterized by the most incidence on the total final impact, on the other hand highlighted a reduction in the incidence of the life cycle stage itself for all the different methods applied, with a variation in the range between the minimum of -4%, when applying $MCF_{i\text{ - SET 1}}$ to Hoekstra et al. (2012) method, and the maximum of -9%, when applying $MCF_{i\text{ - SET 1}}$ to Boulay et al. (2016) method.

Table 3.25 *Results from the sensitivity analysis performed modifying the water related datasets adopted in the modeling of the farm stage and applying the new prosed method to 4 different existing water scarcity impact assessment methods. Results are expressed in % and characterized according to the life cycle stages of the fresh mozzarella cheese.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 1)	93,5	2,6	2,0	0,4	1,4	0,0
$I_{eco\text{ - Hoekstra based}}$ (MCFi - SET 1)	94,7	2,3	1,8	0,3	0,9	0,0
$I_{eco\text{ - Berger based}}$ (MCFi - SET 1)	91,2	3,2	2,5	0,8	2,4	-0,1
$I_{eco\text{ - Boulay based}}$ (MCFi - SET 1)	87,1	4,8	3,7	1,1	3,3	-0,1

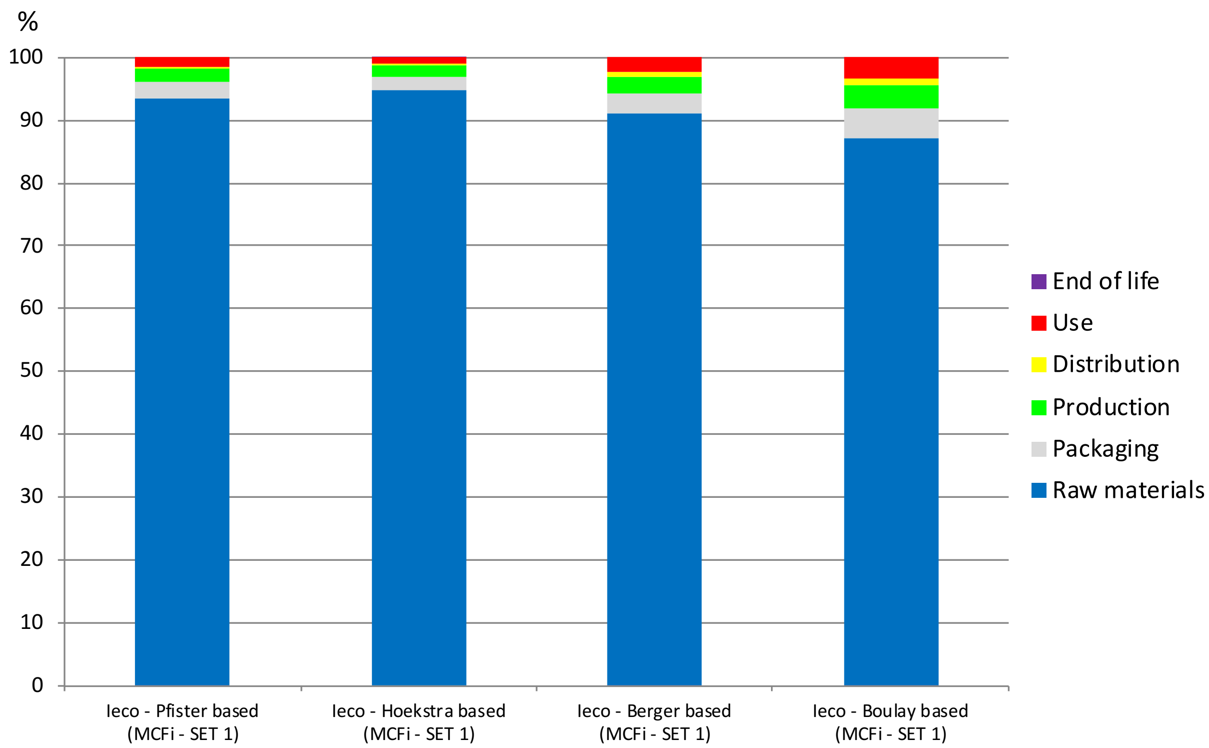

Figure 3.17 *Graphical representation of results from the sensitivity analysis 3. Results are represented in % and characterized according to the life cycle stages of the fresh mozzarella cheese.*

3.4.7 Case study #3: Parma ham

The third case study investigated to test the applicability and effectiveness of the new proposed method for the assessment in monetary terms of water scarcity impacts concerns a Parma ham with bone seasoned for 12 months, produced by a company in the northeast Italy according to the protected designation of origin specification (P.D.O.).

The company has evolved rapidly in the last years, with a high increase in production of the Parma ham which is a brand exported all around the world.

To ensure a constant high level of their performance, as well as the possibility to monitor their operations in the best way, the company has obtained several certifications, such as UNI EN ISO 22000:2005, UNI EN ISO 22005:2008, BS OHSAS 18001:2007, UNI EN ISO 14001:2004, EMAS Reg. (CE) n. 1221/2009.

According to this policy, the company has decided to further invest in sustainability in order to increase their environmental performance, performing an assessment of its flagship product according to the Environmental Product Footprint (PEF) recently introduced by European Union (EU, 2013).

The analysis of the activities of the company involved in the production of the Parma ham P.D.O. allowed to perform a deep assessment of the water related issues, resulting in the possibility to apply the new proposed method evaluating how results may be strategic for the company purposes.
For confidentiality reason any reference to the company and its suppliers has been omitted in the description, as well as any sensitive data that was described only in qualitative terms.

3.4.7.1 Goal and scope definition

The goal of this case study application is to test the new proposed method for the assessment of water scarcity impacts in monetary terms applying the new developed sets of monetary characterization factors, performing a hotspots analysis of the results throughout the life cycle stages of the Parma ham P.D.O. under study.
Moreover, according to the criteria described in the previous chapter 2 (§ 2.2.1), a sensitivity analysis is also performed applying the new proposed method to 4 existing water scarcity impact assessment methods selected according to the criteria defined in the previous chapter 2 (§ 2.2.1.3).
The analysis was aimed on the one hand to provide a description of water scarcity impacts in monetary terms identifying the processes of the whole product supply chain characterized by the most significant contribution to the total impact, on the other hand to understand if this may change according to different water scarcity impact assessment methods.

The product under study (Figure 3.18) is obtained from a long maturation of the hind legs of specially bred and fed Italian pigs, in compliance with the requirements of the protected designation of origin specification (P.D.O.) "Prosciutto di Parma", which is based on the Regulation (EEC) No. 2081/92 (EEC, 1992).
This specification certifying that the product has been made according to traditional methods in a defined geographic region, which is a very small area that includes the territory of the province of Parma, located on the south of the Via Emilia at a max allowed distance of 5 km (up to a max altitude of 900 m) and limited on the east by the river Enza and on the west by the river Stirone.
The climatic conditions of this limited area are ideals for giving to the Parma ham its sweetness and flavor.
According to the requirements of the specification, weight and age of the pig must be respectively not less than 145 kg and 9 months, while the race must be Large White, Landrance or Duroc. After the slaughter, the thighs resulting suitable for the next treatment are identified with the P.P mark

application. The specific features of the product under study, after a minimum cured phase of 12 months, are defined by the specification as follows (EEC, 1992):

- Curved exterior: without distal part (trotter), devoid of external blemishes likely to impair the product's image, with exposure of the muscular part above the head of the femur (best end) limited to 6 centimeters (short trimming);
- weight: as a rule, between 8 and 10 kilograms but not less than 7;
- color when sliced: uniformly ranging between pink to red, interspersed with pure white in the fatty parts;
- Aroma and flavor: mild and delicate flavor, slightly salty with a fragrant and distinctive flavor;
- Satisfies predetermined analytical parameters.

Figure 3.18 *Parma ham P.D.O. product.*

Function, functional unit and reference flow

The function of the product under study is to satisfy a human food need that can be usually linked to the energy and nutrient requirements but more often to the need to feed.

The functional unit and the reference flow in this study match each other, corresponding to 1 kg of Parma ham with bone seasoned for at least 12 months, produced by an Italian company located in the northeast Italy according to the P.D.O. specification, including slicing and packaging at retailer within the Italian market.

System boundary

The system boundary has been defined including all the processes attributable to the product in its whole life cycle according to the adopted reference year of 2015.

All the elementary flows entering /leaving the system have been accounted for all the product life cycle stages, according to the schematic flow chart of Figure 3.19, adopting a cradle to grave approach.

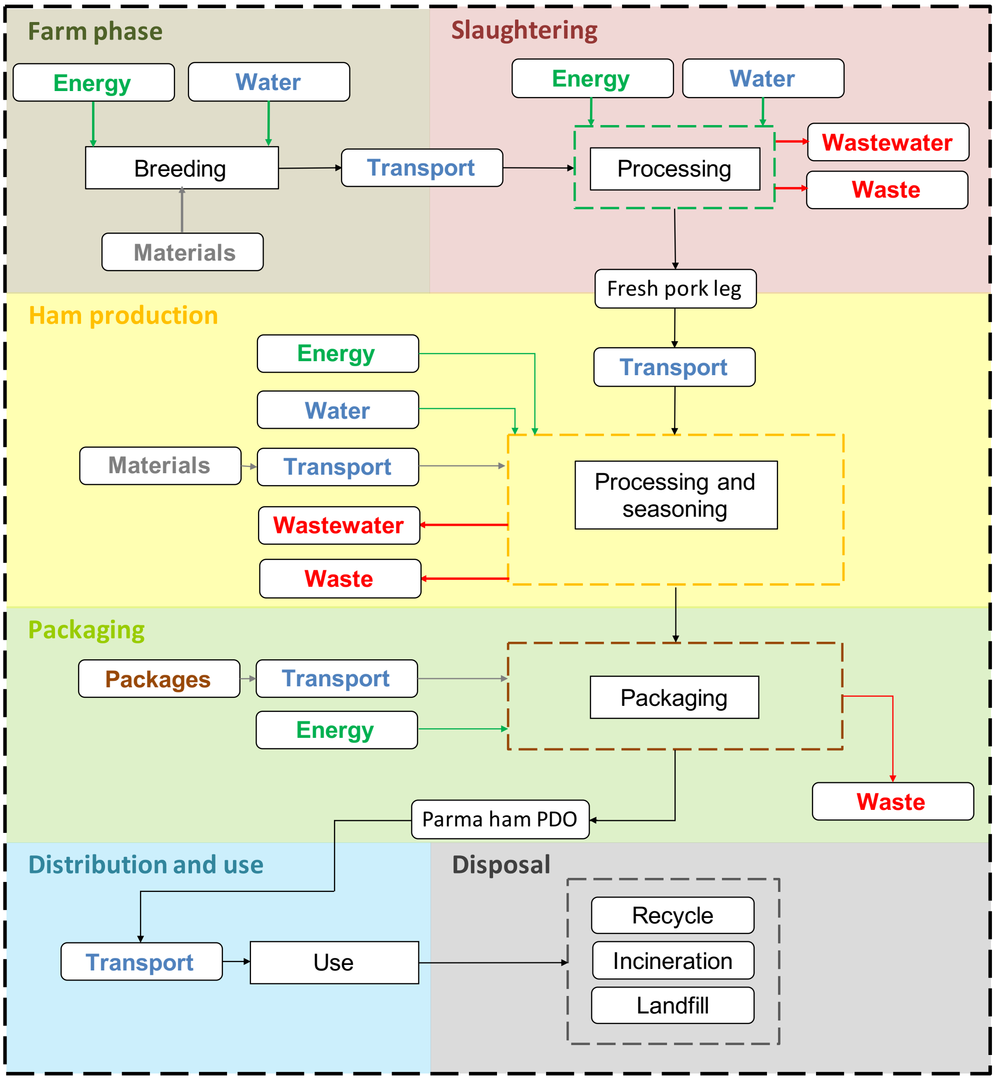

Figure 3.19 *Schematic representation of the system boundaries of the Parma ham P.D.O. according to the different life cycle stages.*

Each life cycle stage has been analyzed to identify all the process units responsible for water resource consumption, according to the following description:

- Raw materials: considering all the processes involved in the hid leg, thus breeding and slaughtering, including also the transport to the company plant.
- Packaging: considering production and transport to the plant of the elements adopted for the packaging of the final product, including also the secondary and tertiary packaging need for the final distribution in the market.
- Production: considering all the activities involved in the processing and seasoning of the Parma ham, focusing on inputs and outputs flows of the production plant (e.g. water consumption, energy consumptions, auxiliary materials, wastes, etc.).
- Distribution: considering the transport of the final product from the plant to the different stores placed in the Italian market, including also the final disposal of wastes generated by the secondary and tertiary packaging.
- Use: considering processes linked to the consumption of the product by the final user.
- End of life: corresponding to the final dismission of the packaging of the product.

Cut-off and allocation rules

In this study a cut-off rule of 1% by mass was used, avoiding thus the collection of data representing a percentage of the total flows less than 1%. Flows within this threshold are typically those characterized by a not significant mass with respect to the total or those for which it was impossible to collect specific data.

However, all processes for which data were available although their contribution was less than 1%, were included in the analysis. This choice is confirmed by several LCA studies in the literature (Humbert et al., 2009).

Furthermore, in modeling the recycling operations within the end of life stage it was applied the cut-off approach that gives null impacts to these kind of processes (Frischknecht, 2010), associating the 100% of impacts from recycling operations to the next product system in which the recycled material will be used.

According to the standard requirements (ISO 14044, 2006) in this study some allocations were performed considering the physical properties (mass, volume) of the fluxes to be allocated. Table 3.26 contains all the allocation criteria applied in this study.

Table 3.26 *Allocation rules applied in this study according to different kind of data collected for the modeling of the Parma ham P.D.O.*

Elementary flow	Cause	Allocation rule
Raw material “piglets for fattening stage” coming from the sow-piglet system	Allocation has been done in order to have a proper distribution of impacts among the by-products leaving the breeding system	Allocation has been done according to economic rule applied by the dataset Agri-footprint chosen as reference
Raw material “fresh pork leg” coming from the slaughterhouse	Allocation has been done in order to have a proper distribution of impacts among the by-products leaving the slaughtering process	Allocation has been done according to economic rule applied by the dataset Agri-footprint chosen as reference
Whey coming from the dairy production system	Allocation has been done in order to have a proper distribution of impacts between curd and whey from milk processing	Allocation has been done according to the Product Category Rule (PCR) UN CPC 2223, 2224 & 2225 (IES, 2013)
Consumption/production of energy, chemicals, wastes within the production plant	Data were available according to the total amount consumed by the plant	Allocation has been done according to mass rule and estimations from the company

Data quality

In this study data collection has been performed giving priority to primary information collected on site, particularly those related to production processes and packaging that are directly under control of the company, and when this was not feasible secondary data from reliable sources.

Considering the production life cycle stage, the main data collected have been energy and water consumptions, wastes, input and output of water resources, total amount of final products, chemicals consumption and specific product recipe.

Considering the packaging life cycle stage, the main data collected concern all the elements involved in the final product distribution, including also the packaging of the raw materials entering the plant.

According to the distribution life cycle stage, all the logistic fluxes have been characterized considering distance and type of vehicle involved in the distribution of the final product to the store.

Data collected about agricultural process involved in raw materials production, as well as packaging production, use and end of life stages have been collected from a mix of secondary sources, adopting widely accepted database and technical report from national institutions.

The whole data quality level has been assessed by a critical review according to the following requirements fixed by the reference standard (ISO 14044, 2006):

- Time-related coverage: this requirement has been met adopting primary data from the most recent available period, with the 2015 adopted as reference year in this study. When only secondary data were available, the most recent and representative ones have been selected for the collection. Furthermore, the reference datasets adopted were those referred to the most recent version available at the time of the modeling.
- Geographical coverage: to meet this requirement all primary data collected are site specific and, when this was not possible, the reference datasets adopted have been selected considering the average production from the country of origin or the most representative market as proxy (e.g. national context).
- Technology coverage: data collected in this study concerns technologies representative as much as possible of the real production system under study.
- Completeness: according to this requirement the percentage of primary data collected is good, having the possibility to integrate to the information under the direct control of the company also data about the suppliers and the raw materials produced in other plants extracted from the available technical data sheets and company management systems. For all the secondary data collected, assumptions were made according to benchmark analysis and industry practices. Finally, the cut-off rule which is usually fixed at 5% by weight of the product materials, in this study has been fixed at 1% with and expected no effect on the outcome of the final results.
- Consistency: this requirement has been met by a consistent and uniform implementation of the new method proposed in this research work to all the components of the product under study, in terms of modeling and assumptions made.
- Reproducibility: to meet this requirement the modeling has been performed allowing its implementation also in another similar study.
- Uncertainty: Raw primary data are characterized by an almost total absence of uncertainty, while the most part of the secondary data concern datasets containing uncertainty information.

To model the product system under study the LCA software SimaPro version 8.5.2.0 has been used (PRé Consultants, 2018), adopting the databases Ecoinvent v3.4 (Ecoinvent, 2018) and Agri-footprint v4.0 (Agri-footprint, 2017).

3.4.7.2 Life cycle inventory

The life cycle inventory includes a mix of foreground and background inventories. The first is based on primary data collected directly from the producer company concerning direct resources consumption ad emissions, including all the water withdrawals and releases as well as all the other kind of information not directly related to water (e.g. energy consumption and raw materials), the second is based mainly on inventory databases where the inventory data have been determined and processed according to ISO 14046 (2014) to account for all the water flows involved.

In this paragraph all the data collected are reported, according to the different life cycle stages investigated.

Raw materials

This stage concerns all the processes involved in the production of the raw materials needed for the production of the Parma ham P.D.O. under study.

The product has been modeled according to specific information provided by the company, which are omitted in this study for confidentiality reasons.

For almost all the elements involved in the Parma ham P.D.O. production it was possible to use existent datasets, accounting for the processes within the farm phase where pigs are bred, the next slaughtering and the final transport to the company plant of the fresh pork leg.

Considering the latter, which is the main ingredient adopted in the production of the Parma ham P.D.O. under study, the processes involved in the farm phase includes the use of animal feed, the consumption of water and electricity, the use of agricultural vehicles and the treatment of wastes. Furthermore, emissions arising from the enteric fermentation processes of livestock and from the manure storage have been considered, applying the methodology TIER 1 according to the guidelines provided by the IPCC (IPCC, 2006).

Emissions from the use of fertilizers are also accounted through the use of datasets provided by the LCA software.

It is important to highlight that because of there is no direct contact between company and farmers, since the first receives the fresh pork legs directly from the slaughterhouses, thus it was not possible to collect primary data on pig production system. To tackle this limitation, the modeling has been done adopting a database developed to perform this kind of analysis, i.e. Agri-footprint (2017), and integrating information and requirements from the P.D.O. specification. This allowed to model the feed mix used in the breeding of pigs and all the other processes involved in the sow-piglet system.

The other two raw materials adopted to produce the Parma ham P.D.O. are salt, used in the processing of the fresh pork leg at the company plant, and suet, which is placed on the head of the thigh once it is ready for the curing. This last, even if according to the P.D.O. specification is not considered an ingredient, it has been still included in the modeling.
Considering the slaughtering, they were included in the modeling all the consumption of electricity, thermal energy and water, accounting also for the presence of other by-products leaving this process additionally to fresh pork leg, particularly adopted for food uses, for feed uses and others commercial uses of less value.
Information about the raw materials included in the analysis are reported as follows:

- Animal feed: it was considered a specific mix according to the different breeding stage, thus feed for sows (Table 3.27), feed for piglets (Table 3.28) and feed for pigs (Table 3.29), through the adoption of the Agri-footprint database as starting point for the modeling introducing also information according to the P.D.O. specification.

Table 3.27 *Data on animal feed and related datasets adopted to feed sows.*

Type of animal feed	%	Dataset
Durum wheat	23%	Wheat grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Barley	37%	Barley grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Maize silage	7%	Maize grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Sorghum	1%	Protein feed, 100% crude {GLO}| sweet sorghum grain to generic market for energy feed | Cut-off, U
Molasses	2%	Protein feed, 100% crude {GLO}| molasses, from sugar beet, to generic market for energy feed | Cut-off, U
Sugar beet pulp	9%	Protein feed, 100% crude {GLO}| sugar beet pulp to generic market for energy feed | Cut-off, U
Soybean meal	8%	Protein feed, 100% crude {GLO}| soybean meal to generic market for protein feed | Cut-off, U
Rye	7%	Rye grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Rapeseed meal	7%	Protein feed, 100% crude {GLO}| rape meal to generic market for protein feed | Cut-off, U

Table 3.28 *Data on animal feed and related datasets adopted to feed piglets.*

Type of animal feed	%	Dataset
Durum wheat	27%	Wheat grain, consumption mix, at feed compound plant/NL Mass
Barley	38%	Barley grain, consumption mix, at feed compound plant/NL Mass
Maize silage	6%	Maize, consumption mix, at feed compound plant/NL Mass
Sorghum	1%	Protein feed, 100% crude {GLO}| sweet sorghum grain to generic market for energy feed | Cut-off, U
Molasses	1%	Sugar beet molasses, consumption mix, at feed compound plant/NL Mass
Sugar beet pulp	1%	Sugar beet pulp, dried, consumption mix, at feed compound plant/NL Mass
Soybean meal	16%	Soybean meal, consumption mix, at feed compound plant/NL Mass
Rye	0%	Sunflower seed meal, consumption mix, at feed compound plant/NL Mass
Whey	10%	Whey {GLO}| market for, Cut-off, U

Table 3.29 *Data on animal feed and related datasets adopted to feed pigs.*

Type of animal feed	%	Dataset
Durum wheat	35%	Wheat grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Barley	40%	Barley grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Maize silage	3%	Maize grain, feed, Swiss integrated production {GLO}| market for | Cut-off, U
Sorghum	3%	Protein feed, 100% crude {GLO}| sweet sorghum grain to generic market for energy feed | Cut-off, U
Molasses	1%	Protein feed, 100% crude {GLO}| molasses, from sugar beet, to generic market for energy feed | Cut-off, U
Sugar beet pulp	1%	Protein feed, 100% crude {GLO}| sugar beet pulp to generic market for energy feed | Cut-off, U
Soybean meal	17%	Protein feed, 100% crude {GLO}| soybean meal to generic market for protein feed | Cut-off, U

In the next Table 3.30 the consumption of energy per kg of animal feed are reported according to the information within the database adopted as reference.

Table 3.30 *Data on energy consumption during breeding and related datasets adopted in the modeling.*

Elementary flow	Unit	Value	Dataset
Electricity energy mix for sows feed	MJ/kg	0,315	Electricity, low voltage {IT}| market for | Cut-off, U
Electricity energy mix for piglets feed	MJ/kg	0,315	Electricity, low voltage {IT}| market for | Cut-off, U
Electricity energy mix for pigs feed	MJ/kg	0,315	Electricity, low voltage {IT}| market for | Cut-off, U
Thermal energy mix for sows feed	MJ/kg	0,135	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating <100kW | Cut-off, U
Thermal energy mix for piglets feed	MJ/kg	0,135	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating <100kW | Cut-off, U
Thermal energy mix for pigs feed	MJ/kg	0,135	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating <100kW | Cut-off, U

- Fresh pork leg: this raw material has been modeled adopting the dataset "Pig meat, fresh, at slaughterhouse/NL Economic", where pigs form the fattening stage are processed to obtain the fresh pork legs. Each upstream farm stage where pigs grow up has been modeled according to the different datasets from Agri-footprint (2017): in the first stage, modeled with the dataset "Piglets, sow-piglet system, at farm/NL Economic", sows give birth to piglets, which are raised to about 25 kg. After that they are transferred to the second stage of the production system, the pig fattening stage, which has been modeled with the dataset "Piglets, sow-piglet system, at farm/NL Economic". In this stage pigs are fattened to a live weight of about 120 kg and once they have achieved the target weight, so they are sent to slaughter.
  In the next Tables 3.31, 3.32 and 3.33 the main fluxes involved in these processes are listed, including information about consumption of energy, water, animal feed and their transport, as well as information about slaughtering of pigs from the fattening.

Table 3.31 *Main data of the sow-piglet system. Values are based on 1 sow / year, with a.p.s. = average present sow (Adaptation from Agri-footprint, 2017).*

Elementary flow	Unit	Value	Dataset
Feed for sows	kg/ a.p.s.	1.169	(§ Table 3.27)
Feed for piglets	kg/ a.p.s.	783	(§ Table 3.28)
Water	kg/ a.p.s./ year	7.594	Tap water {Europe without Switzerland}| market for | Cut-off, U
Transport	tkm/ a.p.s.	195,2	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U
Electricity energy	kWh/ a.p.s./ year	150	Electricity, low voltage {IT}| market for | Cut-off, U
Thermal energy	MJ/ a.p.s./ year	1.840	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating <100kW | Cut-off, U

Table 3.32 *Main data of the pigs fattening system. Values are based on 1 pig / year, with a.p.p. = average present pig (Adaptation from Agri-footprint, 2017).*

Elementary flow	Unit	Value	Dataset
Feed for pigs	kg/ a.p.p.	763	(§ Table 3.29)
Water	kg/ a.p.p./ year	3.179	Tap water {Europe without Switzerland}| market for | Cut-off, U
Transport	tkm/ a.p.p.	76,3	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U
Electricity energy	kWh/ a.p.p./ year	5	Electricity, low voltage {IT}| market for | Cut-off, U
Thermal energy	MJ/ a.p.p./ year	36,8	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating <100kW | Cut-off, U

Table 3.33 *Main data of the pigs slaughtering. Values are based on 1 kg of total pig meat processed (Adaptation from Agri-footprint, 2017).*

Elementary flow	Unit	Value	Dataset
Water	kg/ kg	3,16	Tap water {Europe without Switzerland}| market for | Cut-off, U
Transport	kgkm/ kg	100	Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U
Electricity energy	MJ/ kg	0,4	Electricity, medium voltage {IT}| market for | Cut-off, U
Thermal energy	MJ/ kg	0,34	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating <100kW | Cut-off, U
Wastes	kg/kg	0,065	Biowaste {GLO}| treatment of biowaste, municipal incineration | Cut-off, U

Considering the slaughtering, as already stated, it is important to observe that pig processing leads to the production of some different co-products for other uses different from the one of the fresh pork legs under study. Thus, since the main purpose of the system is to produce fresh pork meat. Moreover, electricity and thermal energy consumptions have been modified adopting primary data provided by the company, as well as the value of the scraps generated during the slaughtering. Finally, in was included in the analysis also the refrigerated transport from the 4 local slaughters to the plant, which has been modeled through the dataset Transport, freight, lorry with refrigeration machine, 7.5-16 ton, EURO4, R134a refrigerant, cooling {GLO}| market for | Cut-off, U".

- Salt: used during the processing of the fresh pork leg in a quantity equal to 177.260 kg/year, it has been modeled adopting the dataset "Sodium chloride, powder {RER}| production | Cut-off, U", including also the transport from the Italian supplier through the dataset "Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U".
- Suet: this raw material, which is used in a quantity equal to 16.590 kg/year, has been modeled through the dataset "Food grade fat, from fat melting, at plant/NL Economic", modified to account for the input of by-product for food purpose coming from the pig slaughtering, and

considering also energy consumptions equal to 0,306 MJ/kg for electricity energy, which was modeled with the dataset "Electricity, medium voltage {IT}| market for | Cut-off, U", and equal to 1,717 MJ/kg for thermal energy, which was modeled through the dataset "Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating <100kW | Cut-off, U". It was also included the transport modeled with the dataset "Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U".

Packaging

In this stage all the packaging involved in the product under study have been modeled, particularly considering:

- Primary packaging, just made of a small metal seal, a cord to be used to hang the final product and a label placed to the ham.
- Secondary and tertiary packaging, used for the distribution of the final product and consisting in the wood standard EU pallet, the cardboard box, the plastic bag and the plastic stretch film.

For all the packaging it was considered the production process and next transport to the company plant according to the cradle to industry gate approach. Information about the packaging included in the analysis are reported as follows:

- Metal seal: applied to the final product, it has been modeled with the dataset "Steel, chromium steel 18/8, hot rolled {RER}| production | Cut-off, U" including the production process "Metal working, average for chromium steel product manufacturing {RER}| processing | Cut-off, U".
- Cord: used in a quantity equal to 1.962 kg/anno, it has been modeled with the dataset "Yarn, jute {GLO}| market for | Cut-off, U".
- Label: applied to the final product before to be delivered to the market, it has been modeled with the dataset "Polyethylene, high density, granulate {RER}| production | Cut-off, U" and the related production process "Stretch blow molding {RER}| production | Cut-off, U".
- Plastic bag: used to contain the seasoned products ready for the packaging, it has been modeled through the dataset "Polyethylene, linear low density, granulate {RER}| production | Cut-off, U" and the specific production process "Stretch blow molding {RER}| production | Cut-off, U".

- Cardboard box: used to put the final products within the plastic bag on the pallet, it has been modeled through the dataset “Corrugated board box {RER}| production | Cut-off, U” including also the production process “Carton board box production, with offset printing {RoW}| carton board box production service, with offset printing | Cut-off, U”.
- Stretch film: adopted to wrap the final products placed on the pallet to be distributed, it was modeled with the dataset “Polyethylene, linear low density, granulate {RER}| production | Cut-off, U” including also the production process “Extrusion, plastic film {RER}| production | Cut-off, U”.
- Pallet: made according to the standard format EU, it was modeled considering a reuse factor equal to 20 with the dataset “EUR-flat pallet {RER}| production | Cut-off, U” including also the production process “Wood chipping, industrial residual wood, stationary electric chipper {RER}| processing | Cut-off, U”.

For all the above described packaging it has been assumed also the transport process modeled through the dataset “Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U”.

Production

The production of the Parma ham P.D.O. starts from the reception of the fresh pork legs that are subjected to a first pre-processing of boiling, sealing and first salting. In the next step the thighs are placed in a cell at a temperature of about 2°C with a monitored humidity of about 80%.

After one week, the thighs are washed and brushed to remove the residual of salt and then they are subjected to a second salting. After few days, the thighs are brushed again and placed in cell at a temperature of about 5°C with a monitored humidity of about 75%. After this phase, the thighs are trimmed and washed with warm water before to be placed in a dryer room where they are left for an average time of one week at a temperature of 15°C.

After that, the next process is a pre-curing in room characterized by natural air ventilation, followed by the curing and the greasing with the application of pork derived suet on the most exposed part of the thigh, which is the head of the femur.

Finally, the thigh is moved to a cell where maturing ends according to the time period fixed by the specification, thus never less than 12 months since the beginning of the fresh thighs processing.

The two main fluxes of energy involved in the production of the Parma ham P.D.O. correspond to electricity energy from national supply network, modeled through the dataset “Electricity, medium voltage {IT}| market for | Cut-off, U”, and thermal energy from the industrial boiler, modeled through the dataset “Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating >100kW | Cut-off, U” modified when possible according to the country of origin of the company that is Italian.

Considering the consumption of water at the plant, which is equal to 13.470 m^3 per year, its withdrawal from the groundwater well has been modeled with the dataset “Tap water {Europe without Switzerland}| tap water production, underground water without treatment | Cut-off, U” modified to account for the specific country of origin which is Italy. Additionally, it has been included also the withdrawal from the national supply network for a smaller amount of 179 m^3 per year, which was modeled through the dataset “Tap water {Europe without Switzerland}| market for | Cut-off, U”.

Considering chemicals involved in the production of the Parma ham P.D.O., they were modeled according to primary information from company and adopting datasets as reported in Table 3.34. For each chemical it was considered the production process and the transport to the company plant, according to the dataset “Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U”.

Table 3.34 *Data on chemicals and related datasets adopted in the modeling of the Parma ham P.D.O.*

Function	Type of chemical	Dataset
Water pre-treatment	Sodium hypochlorite	Sodium hypochlorite, without water, in 15% solution state {RER}| sodium hypochlorite production, product in 15% solution state | Cut-off, U
	ACQ 188/A50	Chemical, inorganic {GLO}| production | Cut-off, U
Production process	Aciplusfoam VF59	Phosphoric acid, industrial grade, without water, in 85% solution state {GLO}| market for | Cut-off, U Nitric acid, without water, in 50% solution state {GLO}| market for | Cut-off, U Ethoxylated alcohol (AE7) {GLO}| market for | Cut-off, U Chemical, organic {GLO}| production | Cut-off, U Water, unspecified natural origin, IT
	Diverfoam Active VT70	Hydrogen peroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U Acetic acid, without water, in 98% solution state {GLO}| market for | Cut-off, U

Function	Type of chemical	Dataset
		Chemical, organic {GLO}| production | Cut-off, U Water, unspecified natural origin, IT
	Hypofoam	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U Sodium hypochlorite, without water, in 15% solution state {RER}| sodium hypochlorite production, product in 15% solution state | Cut-off, U Chemical, organic {GLO}| production | Cut-off, U Water, unspecified natural origin, IT
	Tego	Chemical, inorganic {GLO}| production | Cut-off, U
	Sodium hydroxide	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U
Wastewater treatment	Aluminium Polychloride	Chemical, inorganic {GLO}| production | Cut-off, U

Focusing on refrigerants used in the cooling equipment at the plant, for the reference year of the study it was observed a consumption of 34 kg of R410a, and a consumption of 15 kg of R427a in the operations of refill due to the leaks from the cooling equipment.

The different fluxes of waste generated during the production of the Parma ham P.D.O. have been modeled according to primary data from the company and, when this was not possible, adopting secondary data from the literature (ISPRA 2017a), according to the information listed in the next Table 3.35.

Table 3.35 *Waste treatment scenario adopted in the modeling of the Parma ham P.D.O.*

Type of waste	Recycling	Incineration	Landfill	Other
Sludge	67,8%	16,5%	1,8%	13,9%
Plastic	98,2%	0,8%	1,0%	0%
Wood	98,2%	0,8%	1,0%	0%
Exhausted salt	100%	0%	0%	0%
Mix materials	0%	0%	0%	100%
Metals	0%	0%	0%	100%

Information about how the different fluxes of waste were modeled are reported as follows:

- Treatment of sludge (CER 020204): the different treatments of this waste have been modeled according to the datasets “Sewage sludge {CH}| treatment of by anaerobic digestion | Cut-off, U”, “Raw sewage sludge {CH}| treatment of, municipal incineration | Cut-off, U”, “Refinery sludge {CH}| treatment of, sanitary landfill | Cut-off, U” and a generic dataset for the recycling.
- Treatment of plastic (CER 150102): the different treatments of this waste have been modeled according to the datasets “Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, U”, “Waste plastic, mixture {CH}| treatment of, sanitary landfill | Cut-off, U” and “Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U”.
- Treatment of wood (CER 150103): the different treatments of this waste have been modeled according to the datasets “Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U”, “Waste wood, untreated {CH}| treatment of, sanitary landfill | Cut-off, U” and a generic dataset for the recycling.
- Treatment of exhausted salt (CER 020299): the 100% of this waste is recycled and has been modeled through a generic dataset for the recycling.
- Treatment of scraps from trimming: the 100% of this waste is recycled and has been modeled through the dataset “Wastewater from potato starch production {CH}| treatment of, capacity 1.1E10l/year | Cut-off, U”.
- Treatment of S.O.A cat.3: the 100% of this waste is recycled and has been modeled through the dataset “Slaughterhouse waste {CH}| treatment of, rendering | Cut-off, U”.

<u>*Distribution*</u>

This life cycle stage has been modeled accounting for the different positions of the market stores (Table 3.36), which are all within the national context, where the final product has to be delivered. The transport, which occurs by trucks, has been modeled through the dataset “Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U”.

Table 3.36 *Final destinations of the Parma ham P.D.O. in the national market.*

Final destination	Average distance (km)
Milano	141
Torino	260
Parma	13,6
Brescia	133
Napoli	672
Como	192
Modena	13,6

In the life cycle stage of distribution, it was also included the treatment of wastes arising from the secondary and tertiary packaging, which were modeled according to the following information:

- Treatment of paper and carton: this flux of waste is made of a fraction to be incinerated which was modeled with the dataset "Waste paperboard {Europe without Switzerland}| treatment of waste paperboard, municipal incineration | Cut-off, U", a fraction to be landfilled modeled with the dataset "Waste paperboard {Europe without Switzerland}| treatment of waste paperboard, sanitary landfill | Cut-off, U", and a fraction to be recycled modeled through the dataset "Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U".
- Treatment of plastic: this flux of waste considering a mix of datasets, according to the different treatment processes, equal to "Waste polyethylene {Europe without Switzerland}| treatment of waste polyethylene, municipal incineration | Cut-off, U", "Waste polyethylene {Europe without Switzerland}| treatment of waste polyethylene, sanitary landfill | Cut-off, U", "PE (waste treatment) {GLO}| recycling of PE | Cut-off, U".
- Treatment of wood: this waste has been modeled through the datasets "Waste wood, untreated {Europe without Switzerland}| treatment of waste wood, municipal incineration | Cut-off, U", "Waste wood, untreated {Europe without Switzerland}| treatment of waste wood, sanitary landfill | Cut-off, U", "Waste wood, untreated {CH}| treatment of, recycling | Cut-off, U" according to the different treatment processes.

Assuming a shelf life of a week, in this life cycle stage it was also possible to account for the energy consumption at the retailer, adopting literature data (Cecchinato et al., 2010), as well as for the energetic consumption due to the storage in a fridge modeled trough secondary data.

Use

In this stage, both the transport of the product from the retailer to the house of the final user and the energy consumption for the store of the product in a domestic fridge have been considered in the analysis. Moreover, it has been also accounted for the energy consumption for slicing and for the packaging for the transport of the sliced ham from the retailer to the consumer house.

The first has been modeled through the dataset "Transport, freight, light commercial vehicle {Europe without Switzerland}| processing | Cut-off, U", which is comparable to a mid-size family car, assuming an average distance equal to 5 km according to literature data (Point et al., 2012).

The amount of energy consumed by the domestic fridge, modeled through the dataset "Electricity, low voltage {IT}| market for | Cut-off, U", has been assumed on the basis of a shelf life of 4 days, considering an annual consumption of electricity equal to 450 kWh for a fridge of 240 liters of volume (BigEE, 2016).

The energy consumption due to the slicing, which has been modeled through the dataset "Electricity, low voltage {IT}| market for | Cut-off, U", was calculated on the basis of literature data on average consumption of commercial meat slicer with a nominal power of about 400 W.

Finally, the packaging needed for the transport of the sliced ham has been modeled according to practical assumption based on direct observation and measurements easier to do, assuming a plastic coated paper modeled through the datasets "Polyethylene, linear low density, granulate {RER}| production | Cut-off, U" for the 25%, and the dataset "Kraft paper, bleached {RER}| production | Cut-off, U" for the remaining 75%, including also the production process "Extrusion, plastic film {RER}| production | Cut-off, U".

End of life

In the last life cycle stage, the only element of the product to be disposed is the packaging used for its transport from the retailer to the consumer house, which has been modeled according to secondary data.

Finally, it is important to highlight that the contribution given by the Parma ham P.D.O. itself in terms of human digestion was not assessed because of the difficulties in performing accurate estimations and, in any case, it is very likely that it could be not significant for the purpose of the study.

Starting from the whole inventory data described above and adopting the LCA software SimaPro to process all the information, the water inventory results for the system product under study in terms of input (raw materials) and outputs (water, air, soil) are listed in the Table 3.37.

Table 3.37 *Water inventory data of the whole life cycle of the Parma ham P.D.O.*

Substance	Compartment	Unit	Value
Water, AR	Water	m3	3,06E-06
Water, AT	Water	m3	1,32E+00
Water, AU	Water	m3	3,56E-02
Water, BA	Water	m3	2,96E-02
Water, BE	Water	m3	1,89E-03
Water, BG	Water	m3	1,55E-02
Water, BR	Water	m3	1,34E-01
Water, CA	Water	m3	1,31E-01
Water, CH	Water	m3	6,72E+00
Water, CL	Water	m3	3,07E-02
Water, CN	Water	m3	1,54E+00
Water, CO	Water	m3	8,72E-08
Water, cooling, unspecified natural origin, AT	Raw material	m3	3,40E-04
Water, cooling, unspecified natural origin, AU	Raw material	m3	4,46E-04
Water, cooling, unspecified natural origin, BA	Raw material	m3	7,02E-05
Water, cooling, unspecified natural origin, BE	Raw material	m3	2,54E-04
Water, cooling, unspecified natural origin, BG	Raw material	m3	2,21E-04
Water, cooling, unspecified natural origin, BR	Raw material	m3	3,40E-04
Water, cooling, unspecified natural origin, CA	Raw material	m3	1,02E-03
Water, cooling, unspecified natural origin, CH	Raw material	m3	1,44E-02
Water, cooling, unspecified natural origin, CL	Raw material	m3	6,11E-05
Water, cooling, unspecified natural origin, CN	Raw material	m3	7,46E-03
Water, cooling, unspecified natural origin, CY	Raw material	m3	7,99E-06
Water, cooling, unspecified natural origin, CZ	Raw material	m3	4,49E-03
Water, cooling, unspecified natural origin, DE	Raw material	m3	7,54E-03
Water, cooling, unspecified natural origin, DK	Raw material	m3	6,91E-05
Water, cooling, unspecified natural origin, EE	Raw material	m3	7,28E-05
Water, cooling, unspecified natural origin, ES	Raw material	m3	6,25E-04
Water, cooling, unspecified natural origin, Europe without Switzerland	Raw material	m3	6,24E-04
Water, cooling, unspecified natural origin, FI	Raw material	m3	1,69E-04
Water, cooling, unspecified natural origin, FR	Raw material	m3	1,68E-02
Water, cooling, unspecified natural origin, GB	Raw material	m3	5,73E-04
Water, cooling, unspecified natural origin, GLO	Raw material	m3	1,61E-04
Water, cooling, unspecified natural origin, GR	Raw material	m3	6,04E-04
Water, cooling, unspecified natural origin, HR	Raw material	m3	9,51E-05
Water, cooling, unspecified natural origin, HU	Raw material	m3	2,18E-04
Water, cooling, unspecified natural origin, ID	Raw material	m3	3,07E-04
Water, cooling, unspecified natural origin, IE	Raw material	m3	5,67E-05
Water, cooling, unspecified natural origin, IN	Raw material	m3	2,60E-03
Water, cooling, unspecified natural origin, IR	Raw material	m3	5,87E-04
Water, cooling, unspecified natural origin, IS	Raw material	m3	2,14E-08
Water, cooling, unspecified natural origin, IT	Raw material	m3	5,27E-02
Water, cooling, unspecified natural origin, JP	Raw material	m3	1,07E-03
Water, cooling, unspecified natural origin, KR	Raw material	m3	8,97E-04
Water, cooling, unspecified natural origin, LT	Raw material	m3	1,95E-05
Water, cooling, unspecified natural origin, LU	Raw material	m3	9,10E-06
Water, cooling, unspecified natural origin, LV	Raw material	m3	2,51E-05
Water, cooling, unspecified natural origin, MA	Raw material	m3	6,20E-05
Water, cooling, unspecified natural origin, MK	Raw material	m3	2,25E-05
Water, cooling, unspecified natural origin, MT	Raw material	m3	1,08E-05
Water, cooling, unspecified natural origin, MX	Raw material	m3	3,01E-04
Water, cooling, unspecified natural origin, MY	Raw material	m3	2,04E-04
Water, cooling, unspecified natural origin, NL	Raw material	m3	3,39E-04

Substance	Compartment	Unit	Value
Water, cooling, unspecified natural origin, NO	Raw material	m3	1,02E-05
Water, cooling, unspecified natural origin, NP	Raw material	m3	1,94E-09
Water, cooling, unspecified natural origin, PE	Raw material	m3	4,12E-05
Water, cooling, unspecified natural origin, PH	Raw material	m3	5,56E-08
Water, cooling, unspecified natural origin, PL	Raw material	m3	2,48E-03
Water, cooling, unspecified natural origin, PT	Raw material	m3	6,71E-05
Water, cooling, unspecified natural origin, RER	Raw material	m3	1,19E-02
Water, cooling, unspecified natural origin, RNA	Raw material	m3	9,68E-11
Water, cooling, unspecified natural origin, RO	Raw material	m3	4,37E-04
Water, cooling, unspecified natural origin, RoW	Raw material	m3	3,01E-02
Water, cooling, unspecified natural origin, RS	Raw material	m3	5,37E-04
Water, cooling, unspecified natural origin, RU	Raw material	m3	5,58E-03
Water, cooling, unspecified natural origin, SA	Raw material	m3	5,59E-04
Water, cooling, unspecified natural origin, SE	Raw material	m3	3,62E-04
Water, cooling, unspecified natural origin, SI	Raw material	m3	7,16E-03
Water, cooling, unspecified natural origin, SK	Raw material	m3	3,42E-04
Water, cooling, unspecified natural origin, TH	Raw material	m3	1,92E-04
Water, cooling, unspecified natural origin, TR	Raw material	m3	3,52E-04
Water, cooling, unspecified natural origin, TW	Raw material	m3	3,11E-04
Water, cooling, unspecified natural origin, TZ	Raw material	m3	7,91E-06
Water, cooling, unspecified natural origin, UA	Raw material	m3	8,06E-04
Water, cooling, unspecified natural origin, US	Raw material	m3	6,78E-03
Water, cooling, unspecified natural origin, WEU	Raw material	m3	7,28E-07
Water, cooling, unspecified natural origin, ZA	Raw material	m3	6,32E-04
Water, CY	Water	m3	7,94E-06
Water, CZ	Water	m3	1,80E-02
Water, DE	Water	m3	2,37E-01
Water, DK	Water	m3	9,56E-05
Water, EE	Water	m3	7,14E-05
Water, ES	Water	m3	8,68E-02
Water, Europe without Switzerland	Water	m3	4,28E-04
Water, FI	Water	m3	2,77E-02
Water, FR	Water	m3	3,16E+00
Water, GB	Water	m3	6,35E-04
Water, GLO	Water	m3	1,20E-03
Water, GR	Water	m3	1,63E-02
Water, HR	Water	m3	8,25E-03
Water, HU	Water	m3	1,78E-03
Water, IAI Area, Africa	Water	m3	7,24E-07
Water, IAI Area, Asia, without China and GCC	Water	m3	1,34E-06
Water, IAI Area, EU27 & EFTA	Water	m3	1,70E-05
Water, IAI Area, Gulf Cooperation Council	Water	m3	1,62E-06
Water, IAI Area, North America, without Quebec	Water	m3	9,94E-07
Water, IAI Area, Russia & RER w/o EU27 & EFTA	Water	m3	2,51E-06
Water, IAI Area, South America	Water	m3	9,06E-07
Water, ID	Water	m3	3,12E-03
Water, IE	Water	m3	2,07E-03
Water, IL	Water	m3	9,74E-10
Water, IN	Water	m3	1,23E-01
Water, IR	Water	m3	2,15E-02
Water, IS	Water	m3	7,08E-03
Water, IT	Water	m3	7,03E+00
Water, JP	Water	m3	8,04E-02
Water, KR	Water	m3	4,26E-03
Water, lake, CA	Raw material	m3	2,88E-04
Water, lake, CH	Raw material	m3	1,08E-04
Water, lake, CN	Raw material	m3	5,93E-11
Water, lake, DE	Raw material	m3	1,57E-08
Water, lake, Europe without Switzerland	Raw material	m3	5,26E-05
Water, lake, GLO	Raw material	m3	1,86E-12
Water, lake, IT	Raw material	m3	2,04E-03
Water, lake, RER	Raw material	m3	1,13E-07

Substance	Compartment	Unit	Value
Water, lake, RNA	Raw material	m3	1,02E-11
Water, lake, RoW	Raw material	m3	1,70E-04
Water, lake, US	Raw material	m3	7,09E-11
Water, LT	Water	m3	5,71E-05
Water, LU	Water	m3	1,27E-03
Water, LV	Water	m3	2,55E-05
Water, MA	Water	m3	4,84E-05
Water, MK	Water	m3	8,91E-04
Water, MT	Water	m3	1,07E-05
Water, MX	Water	m3	5,13E-02
Water, MY	Water	m3	3,51E-03
Water, NL	Water	m3	7,08E-04
Water, NO	Water	m3	8,86E-03
Water, NORDEL	Water	m3	2,75E-08
Water, NP	Water	m3	5,06E-03
Water, PE	Water	m3	5,46E-04
Water, PG	Water	m3	4,98E-07
Water, PH	Water	m3	3,18E-06
Water, PL	Water	m3	9,88E-03
Water, PT	Water	m3	3,42E-02
Water, RAF	Water	m3	5,14E-05
Water, RAS	Water	m3	3,94E-05
Water, RER	Water	m3	8,58E-03
Water, river, AU	Raw material	m3	4,62E-06
Water, river, BR	Raw material	m3	6,84E-04
Water, river, CH	Raw material	m3	3,32E-01
Water, river, CN	Raw material	m3	3,01E-03
Water, river, DE	Raw material	m3	2,67E-04
Water, river, ES	Raw material	m3	6,04E-04
Water, river, Europe without Switzerland	Raw material	m3	9,16E-04
Water, river, FR	Raw material	m3	5,04E-04
Water, river, GLO	Raw material	m3	7,93E-05
Water, river, IN	Raw material	m3	6,55E-03
Water, river, IT	Raw material	m3	3,13E-02
Water, river, KR	Raw material	m3	1,11E-05
Water, river, MY	Raw material	m3	1,43E-04
Water, river, NL	Raw material	m3	7,06E-08
Water, river, PE	Raw material	m3	5,01E-09
Water, river, PH	Raw material	m3	1,10E-03
Water, river, RAS	Raw material	m3	8,04E-05
Water, river, RER	Raw material	m3	1,52E-03
Water, river, RLA	Raw material	m3	1,93E-05
Water, river, RNA	Raw material	m3	3,32E-05
Water, river, RO	Raw material	m3	1,52E-05
Water, river, RoW	Raw material	m3	3,46E-02
Water, river, RU	Raw material	m3	1,49E-05
Water, river, SE	Raw material	m3	9,79E-08
Water, river, TN	Raw material	m3	2,69E-05
Water, river, TZ	Raw material	m3	7,68E-08
Water, river, US	Raw material	m3	1,48E-02
Water, river, WEU	Raw material	m3	2,79E-11
Water, river, ZA	Raw material	m3	2,20E-05
Water, RLA	Water	m3	1,13E-05
Water, RME	Water	m3	5,05E-04
Water, RNA	Water	m3	4,22E-05
Water, RO	Water	m3	6,17E-02
Water, RoW	Water	m3	1,92E+00
Water, RS	Water	m3	3,34E-02
Water, RU	Water	m3	3,41E-01
Water, SA	Water	m3	5,62E-04
Water, salt, ocean	Raw material	m3	6,06E-04
Water, salt, sole	Raw material	m3	6,09E-04

Substance	Compartment	Unit	Value
Water, SE	Water	m3	1,84E-01
Water, SI	Water	m3	8,65E-03
Water, SK	Water	m3	1,55E-02
Water, TH	Water	m3	1,55E-03
Water, TR	Water	m3	3,47E-02
Water, turbine use, unspecified natural origin, AT	Raw material	m3	1,32E+00
Water, turbine use, unspecified natural origin, AU	Raw material	m3	3,52E-02
Water, turbine use, unspecified natural origin, BA	Raw material	m3	2,95E-02
Water, turbine use, unspecified natural origin, BE	Raw material	m3	1,64E-03
Water, turbine use, unspecified natural origin, BG	Raw material	m3	1,53E-02
Water, turbine use, unspecified natural origin, BR	Raw material	m3	1,34E-01
Water, turbine use, unspecified natural origin, CA	Raw material	m3	1,31E-01
Water, turbine use, unspecified natural origin, CH	Raw material	m3	6,43E+00
Water, turbine use, unspecified natural origin, CL	Raw material	m3	3,07E-02
Water, turbine use, unspecified natural origin, CN	Raw material	m3	1,53E+00
Water, turbine use, unspecified natural origin, CZ	Raw material	m3	1,36E-02
Water, turbine use, unspecified natural origin, DE	Raw material	m3	2,29E-01
Water, turbine use, unspecified natural origin, DK	Raw material	m3	6,62E-05
Water, turbine use, unspecified natural origin, ES	Raw material	m3	8,61E-02
Water, turbine use, unspecified natural origin, FI	Raw material	m3	2,76E-02
Water, turbine use, unspecified natural origin, FR	Raw material	m3	3,14E+00
Water, turbine use, unspecified natural origin, GB	Raw material	m3	5,58E-05
Water, turbine use, unspecified natural origin, GLO	Raw material	m3	1,92E-07
Water, turbine use, unspecified natural origin, GR	Raw material	m3	1,57E-02
Water, turbine use, unspecified natural origin, HR	Raw material	m3	8,29E-03
Water, turbine use, unspecified natural origin, HU	Raw material	m3	1,56E-03
Water, turbine use, unspecified natural origin, ID	Raw material	m3	2,80E-03
Water, turbine use, unspecified natural origin, IE	Raw material	m3	2,01E-03
Water, turbine use, unspecified natural origin, IN	Raw material	m3	1,21E-01
Water, turbine use, unspecified natural origin, IR	Raw material	m3	2,09E-02
Water, turbine use, unspecified natural origin, IS	Raw material	m3	7,10E-03
Water, turbine use, unspecified natural origin, IT	Raw material	m3	6,98E+00
Water, turbine use, unspecified natural origin, JP	Raw material	m3	7,93E-02
Water, turbine use, unspecified natural origin, KR	Raw material	m3	3,37E-03
Water, turbine use, unspecified natural origin, LT	Raw material	m3	3,85E-05
Water, turbine use, unspecified natural origin, LU	Raw material	m3	1,26E-03
Water, turbine use, unspecified natural origin, MK	Raw material	m3	8,71E-04
Water, turbine use, unspecified natural origin, MX	Raw material	m3	5,10E-02
Water, turbine use, unspecified natural origin, MY	Raw material	m3	3,31E-03
Water, turbine use, unspecified natural origin, NL	Raw material	m3	3,95E-04
Water, turbine use, unspecified natural origin, NO	Raw material	m3	9,15E-03
Water, turbine use, unspecified natural origin, NP	Raw material	m3	5,06E-03
Water, turbine use, unspecified natural origin, PE	Raw material	m3	5,22E-04
Water, turbine use, unspecified natural origin, PL	Raw material	m3	7,70E-03
Water, turbine use, unspecified natural origin, PT	Raw material	m3	3,42E-02
Water, turbine use, unspecified natural origin, RER	Raw material	m3	6,02E-05
Water, turbine use, unspecified natural origin, RNA	Raw material	m3	8,02E-09
Water, turbine use, unspecified natural origin, RO	Raw material	m3	6,13E-02
Water, turbine use, unspecified natural origin, RoW	Raw material	m3	1,86E+00
Water, turbine use, unspecified natural origin, RS	Raw material	m3	3,29E-02
Water, turbine use, unspecified natural origin, RU	Raw material	m3	3,30E-01
Water, turbine use, unspecified natural origin, SE	Raw material	m3	1,84E-01
Water, turbine use, unspecified natural origin, SI	Raw material	m3	1,64E-03
Water, turbine use, unspecified natural origin, SK	Raw material	m3	1,51E-02
Water, turbine use, unspecified natural origin, TH	Raw material	m3	1,36E-03
Water, turbine use, unspecified natural origin, TR	Raw material	m3	3,44E-02
Water, turbine use, unspecified natural origin, TZ	Raw material	m3	6,98E-04
Water, turbine use, unspecified natural origin, UA	Raw material	m3	2,41E-02
Water, turbine use, unspecified natural origin, US	Raw material	m3	3,68E-01
Water, turbine use, unspecified natural origin, ZA	Raw material	m3	5,95E-04
Water, TW	Water	m3	3,10E-04
Water, TZ	Water	m3	7,04E-04

Substance	Compartment	Unit	Value
Water, UA	Water	m3	2,49E-02
Water, UCTE	Water	m3	1,33E-09
Water, UCTE without Germany	Water	m3	6,07E-10
Water, UN-OCEANIA	Water	m3	9,64E-07
Water, unspecified natural origin, AU	Raw material	m3	1,91E-16
Water, unspecified natural origin, CA	Raw material	m3	8,40E-06
Water, unspecified natural origin, CH	Raw material	m3	2,18E-04
Water, unspecified natural origin, CL	Raw material	m3	5,43E-10
Water, unspecified natural origin, CN	Raw material	m3	7,35E-06
Water, unspecified natural origin, DE	Raw material	m3	3,12E-09
Water, unspecified natural origin, Europe without Switzerland	Raw material	m3	4,85E-06
Water, unspecified natural origin, GLO	Raw material	m3	3,22E-04
Water, unspecified natural origin, IAI Area, Africa	Raw material	m3	5,45E-07
Water, unspecified natural origin, IAI Area, Asia, without China and GCC	Raw material	m3	1,01E-06
Water, unspecified natural origin, IAI Area, EU27 & EFTA	Raw material	m3	5,91E-06
Water, unspecified natural origin, IAI Area, Gulf Cooperation Council	Raw material	m3	1,22E-06
Water, unspecified natural origin, IAI Area, North America, without Quebec	Raw material	m3	7,69E-07
Water, unspecified natural origin, IAI Area, Russia & RER w/o EU27 & EFTA	Raw material	m3	1,80E-06
Water, unspecified natural origin, IAI Area, South America	Raw material	m3	7,23E-07
Water, unspecified natural origin, IN	Raw material	m3	1,16E-04
Water, unspecified natural origin, IT	Raw material	m3	1,00E-07
Water, unspecified natural origin, PG	Raw material	m3	6,08E-08
Water, unspecified natural origin, PH	Raw material	m3	1,39E-08
Water, unspecified natural origin, RAF	Raw material	m3	6,05E-05
Water, unspecified natural origin, RER	Raw material	m3	1,27E-03
Water, unspecified natural origin, RME	Raw material	m3	5,95E-04
Water, unspecified natural origin, RNA	Raw material	m3	6,89E-06
Water, unspecified natural origin, RoW	Raw material	m3	3,92E-03
Water, unspecified natural origin, RU	Raw material	m3	8,46E-05
Water, unspecified natural origin, TH	Raw material	m3	4,81E-07
Water, unspecified natural origin, UN-OCEANIA	Raw material	m3	7,26E-07
Water, unspecified natural origin, US	Raw material	m3	2,85E-06
Water, unspecified natural origin, WEU	Raw material	m3	5,43E-08
Water, US	Water	m3	3,97E-01
Water, well, in ground, AT	Raw material	m3	9,21E-14
Water, well, in ground, AU	Raw material	m3	1,45E-05
Water, well, in ground, BR	Raw material	m3	1,58E-04
Water, well, in ground, CA	Raw material	m3	2,29E-05
Water, well, in ground, CH	Raw material	m3	9,37E-02
Water, well, in ground, CN	Raw material	m3	1,55E-03
Water, well, in ground, DE	Raw material	m3	8,94E-04
Water, well, in ground, ES	Raw material	m3	3,56E-04
Water, well, in ground, Europe without Switzerland	Raw material	m3	1,89E-04
Water, well, in ground, FR	Raw material	m3	4,06E-04
Water, well, in ground, GLO	Raw material	m3	1,02E-04
Water, well, in ground, ID	Raw material	m3	1,57E-05
Water, well, in ground, IN	Raw material	m3	1,13E-02
Water, well, in ground, IS	Raw material	m3	4,80E-10
Water, well, in ground, IT	Raw material	m3	1,17E-02
Water, well, in ground, JP	Raw material	m3	2,40E-10
Water, well, in ground, MA	Raw material	m3	1,59E-05
Water, well, in ground, MX	Raw material	m3	5,36E-10
Water, well, in ground, MY	Raw material	m3	1,24E-05
Water, well, in ground, NORDEL	Raw material	m3	3,23E-08
Water, well, in ground, PE	Raw material	m3	8,13E-09
Water, well, in ground, PG	Raw material	m3	5,25E-07
Water, well, in ground, PH	Raw material	m3	1,72E-04
Water, well, in ground, PL	Raw material	m3	1,48E-05
Water, well, in ground, PT	Raw material	m3	1,34E-11
Water, well, in ground, RER	Raw material	m3	3,53E-04

Substance	Compartment	Unit	Value
Water, well, in ground, RLA	Raw material	m3	2,16E-06
Water, well, in ground, RNA	Raw material	m3	1,43E-05
Water, well, in ground, RoW	Raw material	m3	2,03E-02
Water, well, in ground, RU	Raw material	m3	7,48E-06
Water, well, in ground, SE	Raw material	m3	1,70E-08
Water, well, in ground, TH	Raw material	m3	9,21E-14
Water, well, in ground, TN	Raw material	m3	4,14E-05
Water, well, in ground, TR	Raw material	m3	8,02E-10
Water, well, in ground, US	Raw material	m3	2,64E-02
Water, well, in ground, WEU	Raw material	m3	2,71E-05
Water, well, in ground, ZA	Raw material	m3	1,03E-05
Water, WEU	Water	m3	3,06E-05
Water, ZA	Water	m3	1,26E-03
Water/m3	Air	m3	2,33E-01

3.4.8 Life cycle impact assessment

Starting from the life cycle inventory above described, in this paragraph results of the life cycle impact assessment are reported, particularly referring to the monetary assessment of water scarcity impacts related to the product under study.

According to the comments reported in the same life cycle impact assessment phase of the previous case studies, the monetary assessment has been performed through the application of the new monetary characterization factors developed in this research work to the method proposed by Pfister et al. (2009), which has been assumed as reference.

Adopting the same approach of the previous case studies, also the sensitivity analysis performed in this case study were aimed to evaluate the effects on final results from the application of the new proposed method to 4 existing water scarcity impact assessment methods, and to evaluate the effects on final results from the adoption of the modified monetary base constant MK (§ 3.3) in the calculation of the new monetary characterization factors.

Furthermore, since the nature of the system product under study is similar to that of the previous case study #2, which is characterized by a significant farm stage within the whole life cycle of the investigated product, thus a third sensitivity analysis has been performed adopting the same approach explained in the sensitivity analysis 3 of the previous case study #2.

The next Table 3.38 reports the results from the application of the new proposed method in absolute terms according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.38 *Monetary impact assessment resulting from the application of the new proposed method to the Parma ham P.D.O. Results are expressed in US$/FU and characterized according to the life cycle stages.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
$I_{eco\text{ - Pfister based}}$ ($MCF_{i\text{ - SET EQ}}$)	5,166	0,033	0,015	0,001	0,007	0,000	**5,221**
$I_{eco\text{ - Pfister based}}$ ($MCF_{i\text{ - SET 1}}$)	7,877	0,052	0,018	0,001	0,009	0,000	**7,957**
$I_{eco\text{ - Pfister based}}$ ($MCF_{i\text{ - SET 2}}$)	7,519	0,047	0,027	0,002	0,012	0,000	**7,608**
$I_{eco\text{ - Pfister based}}$ ($MCF_{i\text{ - SET 3}}$)	9,280	0,060	0,023	0,002	0,014	0,000	**9,378**
$I_{eco\text{ - Pfister based}}$ ($MCF_{i\text{ - SET 4}}$)	7,866	0,051	0,022	0,002	0,011	0,000	**7,952**
$I_{eco\text{ - Pfister based}}$ ($MCF_{i\text{ - SET 5}}$)	5,721	0,037	0,015	0,001	0,007	0,000	**5,780**
$I_{eco\text{ - Pfister based}}$ ($MCF_{i\text{ - SET 6}}$)	7,698	0,050	0,022	0,002	0,011	0,000	**7,783**

Results in Table 3.38 highlighted a variability in the absolute values obtained from the application of the 7 different proposed set of characterization factors developed according to the weighting approaches described in the previous chapter 2 (§ 2.2.1.1).

The total value of the monetary assessment of water scarcity impacts of the Parma ham P.D.O. resulted to be in the range between 5,221 US$/FU of the monetary impact $I_{eco\text{ - Pfister based}}$ applying $MCF_{i\text{ - SET EQ}}$, and 9,378 US$/FU of the monetary impact $I_{eco\text{ - Pfister based}}$ applying $MCF_{i\text{ - SET 3}}$, confirming what observed in the previous case studies where the same sets were responsible respectively of the minimum and the maximum absolute value of the monetary impact among all the 7 sets applied.

As already observed in the life cycle impact assessment phase of the previous case studies, analyzing the incidence of the results in percentage terms throughout the different life cycle stages is fundamental for a properly identification of the hotspots along the whole supply chain of the product under study.

Thus, the values listed in absolute terms in the previous Table 3.38 have been also reported in percentage terms in the next Table 3.39 and Figure 3.20 in order to allow a better understanding of the incidence of the results.

Table 3.39 *Monetary assessment of water scarcity impacts resulting from the application of the new proposed method to the Parma ham P.D.O. Results are expressed in % and characterized according to the life cycle stages.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
I_{eco} - Pfister based (MCFi - SET EQ)	98,9	0,6	0,3	0,0	0,1	0,0
I_{eco} - Pfister based (MCFi - SET 1)	99,0	0,6	0,2	0,0	0,1	0,0
I_{eco} - Pfister based (MCFi - SET 2)	98,8	0,6	0,4	0,0	0,2	0,0
I_{eco} - Pfister based (MCFi - SET 3)	98,9	0,6	0,2	0,0	0,1	0,0
I_{eco} - Pfister based (MCFi - SET 4)	98,9	0,6	0,3	0,0	0,1	0,0
I_{eco} - Pfister based (MCFi - SET 5)	99,0	0,6	0,3	0,0	0,1	0,0
I_{eco} - Pfister based (MCFi - SET 6)	98,9	0,6	0,3	0,0	0,1	0,0

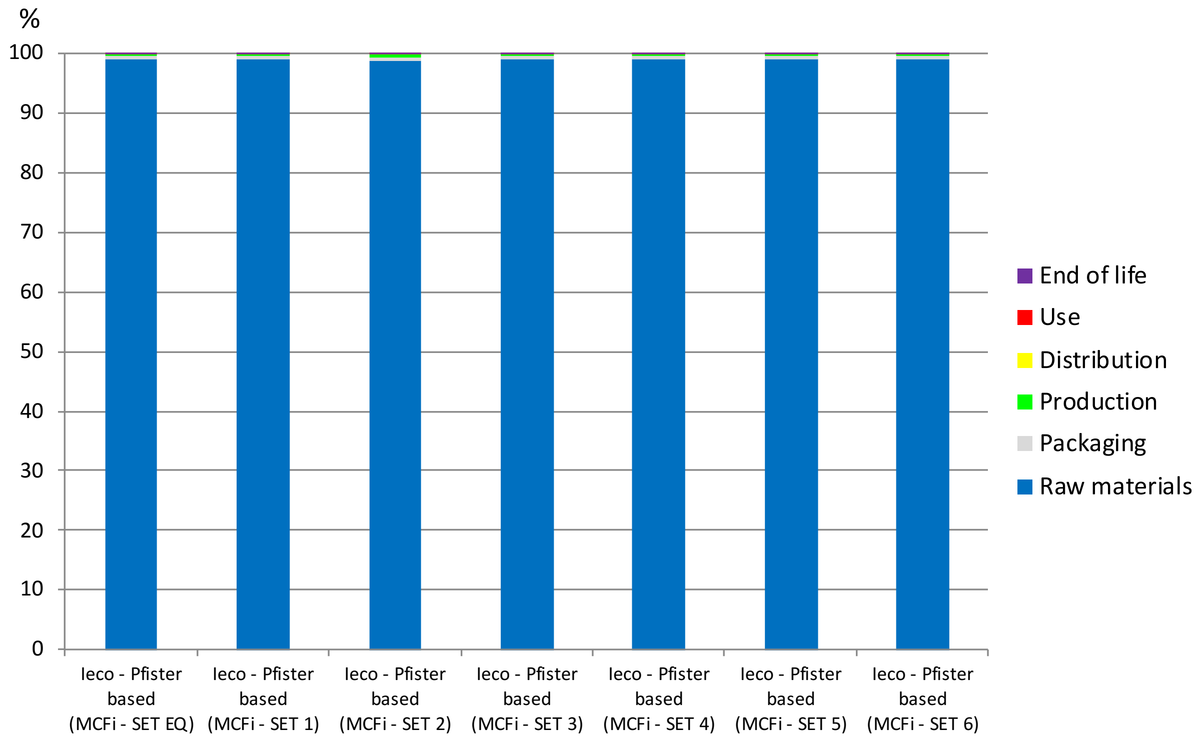

Figure 3.20 *Graphical representation of results from the application of the new proposed method to the Parma ham P.D.O. Results are represented in % and characterized according to the life cycle stages.*

Observing the results expressed in percentage terms along the whole supply chain it was possible to highlight that the application of the 7 different proposed sets of characterization factors, like in the previous case studies, resulted to have the same incidence on the different life cycle stages, with a very low variation (less than 1%) among the 7 proposed sets of characterization factors.

Furthermore, all the applications of the different sets confirmed that raw materials is the most impactful life cycle stage characterized, as already occurred in case study #2, by a very high average incidence (about 98%) on the overall impact. The other life cycle stages, instead, resulted to have an insignificant incidence on the total impact.

3.4.9 Life cycle interpretation and hotspots analysis

In this stage results are analyzed in order to highlight the hotspots related to the impact assessment performed in this case study.

According to the research objectives and to the same approach adopted in the life cycle interpretation phase of the previous case studies, some sensitivity analysis have been performed in order to investigate: (i) the effects on the final results from the application of the new proposed method to different existing water scarcity impact assessment methods, including the one from Pfister et al. (2009) adopted as reference in the previous stage; (ii) the effects on the final results from the adoption of the modified monetary base constant MK (§ 3.3) in the calculation of the new monetary characterization factors.

Moreover, according to the sensitivity analysis performed in the previous case study #2 aimed to assess the potential effects on the results from the change of the datasets adopted to model the breeding stage, the same analysis has been performed also in this case study.

Results from the monetary assessment of water scarcity impacts of the Parma ham P.D.O. under study, performed applying different sets of proposed monetary characterization factors, substantially confirmed that raw materials is the most impactful life cycle stage with an average incidence very close to the total overall impact (about 98%).

A deep analysis showed that, similarly to what observed in the previous case studies, also for the Parma ham P.D.O. the most part of the total impact is due to the farm stage where the main raw material is produced, in this case fresh pork meat, in particular because of the high amount of water required for the irrigation of crops used in animal feeds.

Sensitivity analysis 1: adoption of alternative water scarcity impact assessment methods

According to the research objectives in this analysis the effects on results from the application of new proposed method for the monetary assessment to different existing water scarcity impact assessment methods have been investigated.

The same methods selected to perform the analysis in the previous case studies have been adopted also in this sensitivity analysis, considering thus the criteria described in the chapter 2 (§ 2.2.1.3).

According to the results from the life cycle impact assessment phase of this case study (§ 3.4.8), which was characterized by a very low variation in the percentage incidence of the final results from the application of the 7 different proposed set of characterization factors, adopting the same approach of the previous case studies also in this sensitivity analysis it was assumed one single set of monetary characterization factors as reference, in particular $MCF_{i\text{ - SET 1}}$.

The next Table 3.40 contains results in absolute terms from the sensitivity analysis according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.40 *Results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are expressed in US$/FU and characterized according to the life cycle stages of the Parma ham P.D.O.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
I_{eco} - Pfister based (MCFi - SET 1)	7,877	0,052	0,018	0,001	0,009	0,000	**7,957**
I_{eco} - Hoekstra based (MCFi - SET 1)	19,284	0,129	0,022	0,002	0,019	0,000	**19,457**
I_{eco} - Berger based (MCFi - SET 1)	6,519	0,040	0,031	0,002	0,010	0,000	**6,603**
I_{eco} - Boulay based (MCFi - SET 1)	277,937	1,693	2,154	0,123	0,774	0,005	**282,685**

From the above results it was possible to observe a high variability in the absolute values obtained from the application of $MCF_{i\text{ - SET 1}}$ to different existing water scarcity impact assessment methods.
The minimum total value of the monetary assessment of water scarcity impacts of the Parma ham D.O.P. resulted to be 6,603 US$/FU when applying the new proposed method to the water scarcity impact assessment method from Berger et al. (2014), while the maximum resulted to be 282,685 US$/FU when applying the method from Boulay et al. (2016).
As already explained in the previous case studies, this is due to the different approach adopted by the authors in developing the water scarcity index (WSI) of each method (§ 2.2.1.3), with different resulting range of minimum and maximum values of the characterization factors.
For this reason, in order to have a better comprehension about the variability of the incidence on final results when adopting different existing water scarcity impact assessment methods, it was important to analyze impact values in percentage terms, as reported in the next Table 3.41 and Figure 3.21.

Table 3.41 *Results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are expressed in % and characterized according to the life cycle stages of the Parma ham P.D.O.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
I_{eco} - Pfister based (MCFi - SET 1)	99,0	0,6	0,2	0,0	0,1	0,0
I_{eco} - Hoekstra based (MCFi - SET 1)	99,1	0,7	0,1	0,0	0,1	0,0
I_{eco} - Berger based (MCFi - SET 1)	98,7	0,6	0,5	0,0	0,2	0,0
I_{eco} - Boulay based (MCFi - SET 1)	98,3	0,6	0,8	0,0	0,3	0,0

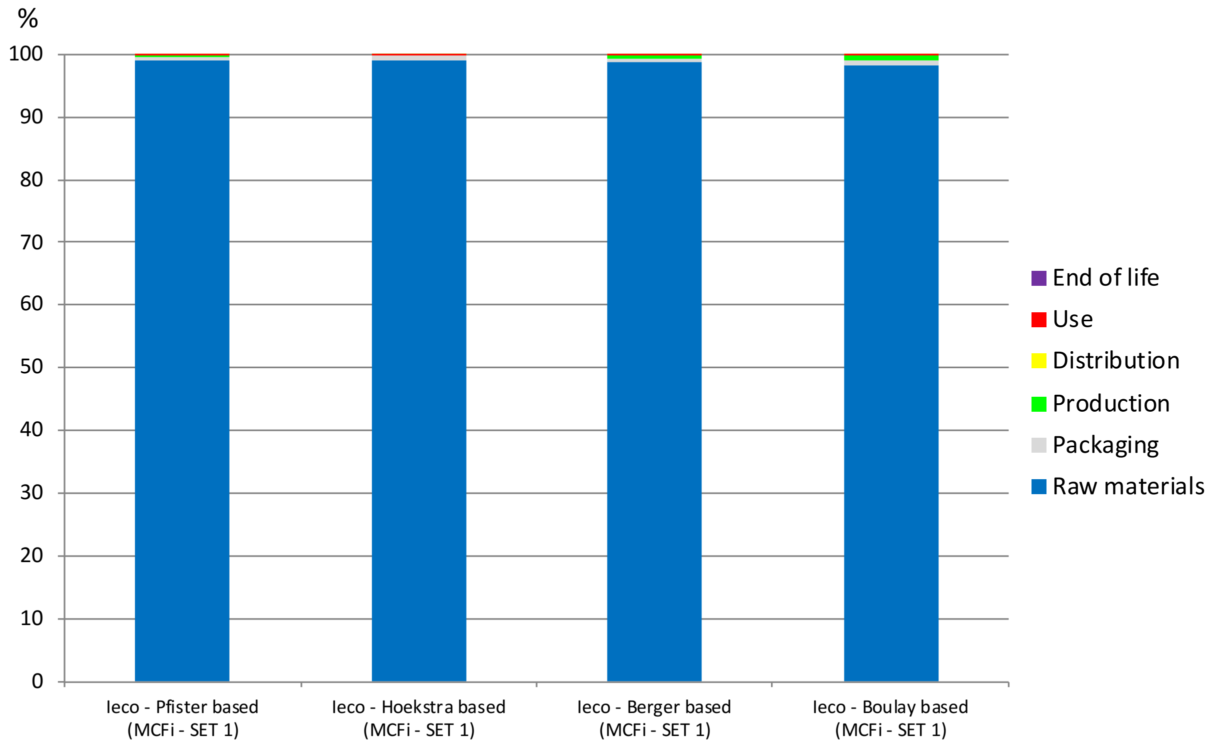

Figure 3.21 *Graphical representation of results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are represented in % and characterized according to the life cycle stages of the Parma ham P.D.O.*

The analysis of results expressed in percentage terms confirmed that raw materials is the life cycle stage characterized by the higher incidence on the overall impact. Moreover, as occurred in the previous case study #2, also in this case when comparing results within the same life cycle stage from the application of the new proposed method to the different existing water scarcity impact assessment methods it was observed that each method is characterized by more or less the same incidence on the life cycle stage analyzed.
Considering raw materials, which is the most impactful life cycle stage, it was possible to highlight an incidence variation between the minimum and the maximum value of less than 1%.
Even if this allowed to have a higher accuracy in the hotspots analysis, nevertheless it is highly recommended to be careful in performing interpretation of results, especially when adopting different methods to perform the assessment.

Sensitivity analysis 2: adoption of the modified monetary base constant MK

According to the review of the monetary base constant MK (§ 2.2.1.2) performed in this research work, this sensitivity analysis is aimed to confirm the observations reported in the chapter 2 (§ 2.2.1.2) about the expected very low variation in final results when applying the new proposed monetary characterization factors calculated adopting the modified monetary base constant MK.
Since it was observed from the life cycle impact assessment phase of this case study (§ 3.4.8) a very low variation in the percentage incidence of the final results from the application of the 7 different proposed set of characterization factors, thus, it was chosen one single set of monetary characterization factors ($MCF_{i\text{ - SET 1}}$) to perform the assessment, according to the approach adopted in the previous case studies.
The next Figure 3.22 reported the results graphically in order to highlight the differences between the application of $MCF_{i\text{ - SET 1}}$ to Pfister et al. (2009) method and the application of $MCF_{i\text{ - SET 1*}}$, which has been calculated considering the monetary base constant MK modified, to the same water scarcity impact assessment method adopted as reference.
As expected, the final water scarcity impact expressed in monetary terms showed a low variation, with values equal to 7,957 US$/FU and 8,316 US$/FU when applying respectively $MCF_{i\text{ - SET 1}}$ and $MCF_{i\text{ - SET 1*}}$.

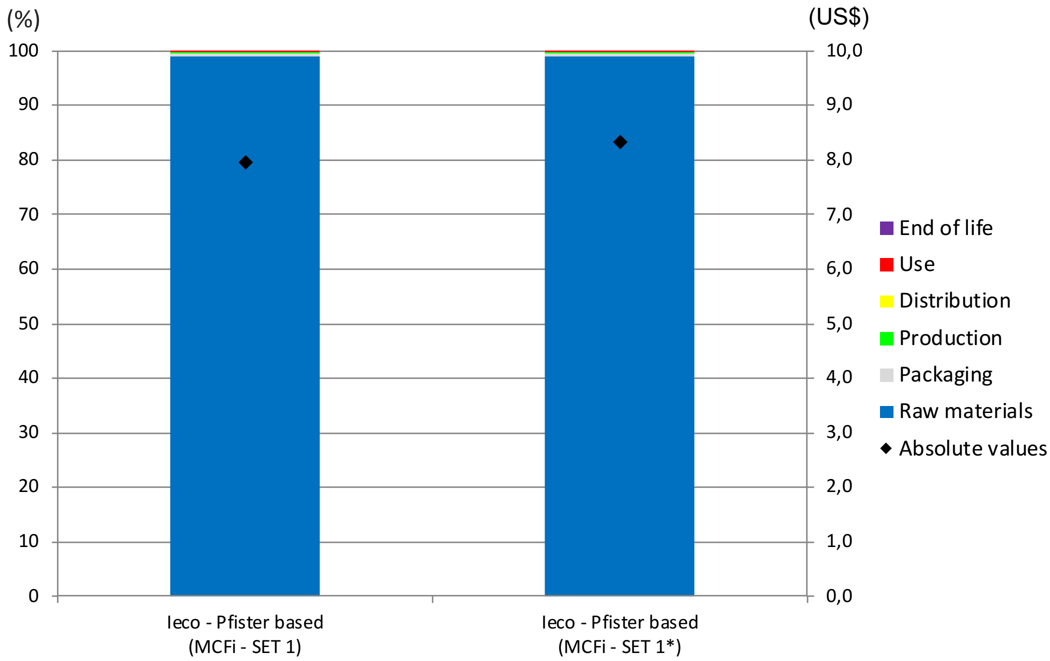

Figure 3.22 *Graphical representation of results from the sensitivity analysis performed to evaluate effects on final results from the application of the monetary base constant MK modified. Results are represented in % and characterized according to the life cycle stages of the Parma ham P.D.O., with black squares in the middle of the columns representing total values in absolute terms.*

Sensitivity analysis 3: change of water related datasets adopted in the farm stage

According to the approach described in the previous case study #2, also this analysis was aimed to assess the effects on final results from the change of the datasets adopted to model the farm stage.

In particular, the analysis has been done modifying all the datasets adopted in the modeling of animal feeds, particularly feed for sows (Table 3.27), feed for piglets (Table 3.28) and feed for pigs (Table 3.29), assuming where practicable Italy as country of reference for the processes of irrigation, water withdrawals and releases in water bodies and air.

The observation made in the sensitivity analysis 3 of the case study 2# is also valid for this analysis, thus since it was not possible to collect primary data about where all the animal feeds used by the farmers are produced all around the world, so the choice to modify the water related datasets to perform the sensitivity analysis is only an assumption made to investigate the effects from the change of the regional context adopted by each dataset.

Furthermore, the analysis has been performed applying $MCF_{i\text{ - SET 1}}$ to 4 different existing water scarcity impact assessment methods as already done in the case study #2.

The next Table 3.42 contains results in absolute terms from the sensitivity analysis according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.42 *Results from the sensitivity analysis performed modifying the water related datasets adopted in the modeling of the farm stage and applying the new prosed method to 4 different existing water scarcity impact assessment methods. Results are expressed in US$/FU and characterized according to the life cycle stages of the Parma ham P.D.O.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life	Total
I_{eco} - Pfister based (MCFi - SET 1)	1,091	0,052	0,018	0,001	0,009	0,000	1,171
I_{eco} - Hoekstra based (MCFi - SET 1)	1,980	0,129	0,022	0,002	0,019	0,000	2,153
I_{eco} - Berger based (MCFi - SET 1)	1,364	0,040	0,031	0,002	0,010	0,000	1,447
I_{eco} - Boulay based (MCFi - SET 1)	87,297	1,693	2,154	0,123	0,774	0,005	92,046

As observed in the sensitivity analysis 2, the results show a high variability in the absolute values obtained from the application of $MCF_{i\text{ - SET 1}}$ to different existing water scarcity impact assessment methods.

Again, the reason is the same that was already explained, so the different approach adopted by the authors in developing the water scarcity index (WSI) of each method (§ 2.2.1.3).

Moreover, as observed in the sensitivity analysis 3 of the case study 2#, the most significant result from this sensitivity analysis is that final impacts are highly reduced if compared to the results from the sensitivity analysis 2, with a reduction higher than 80% for each method.

This was because the changes applied to the water irrigation processes of many crops that were associated by the database of reference adopted in the modeling to countries placed outside Europe and, more important, to countries characterized by a high values of characterization factors such as India.

Because of the importance to better understand how this variation may affect the hotspots analysis, results have been also reported in percentage terms, according to the next Table 3.43 and Figure 3.23. Results confirmed that raw materials is the life cycle stage characterized by the most incidence on the total final impact, as well as that a reduction in the incidence of the life cycle stage itself occurred for all the different methods applied, with a variation in the range between the minimum of -3,5%, when applying $MCF_{i\text{ - SET 1}}$ to Boulay et al. (2016) method, and the maximum of about -7%, when applying $MCF_{i\text{ - SET 1}}$ to Hoekstra et al. (2012) method.

Table 3.43 *Results from the sensitivity analysis performed modifying the water related datasets adopted in the modeling of the farm stage and applying the new prosed method to 4 different existing water scarcity impact assessment methods. Results are expressed in % and characterized according to the life cycle stages of the Parma ham P.D.O.*

Method	Raw materials	Packaging	Production	Distribution	Use	End of life
Ieco - Pfister based (MCFi - SET 1)	93,2	4,4	1,5	0,1	0,8	0,0
Ieco - Hoekstra based (MCFi - SET 1)	92,0	6,0	1,0	0,1	0,9	0,0
Ieco - Berger based (MCFi - SET 1)	94,2	2,8	2,1	0,1	0,7	0,0
Ieco - Boulay based (MCFi - SET 1)	94,8	1,8	2,3	0,1	0,8	0,0

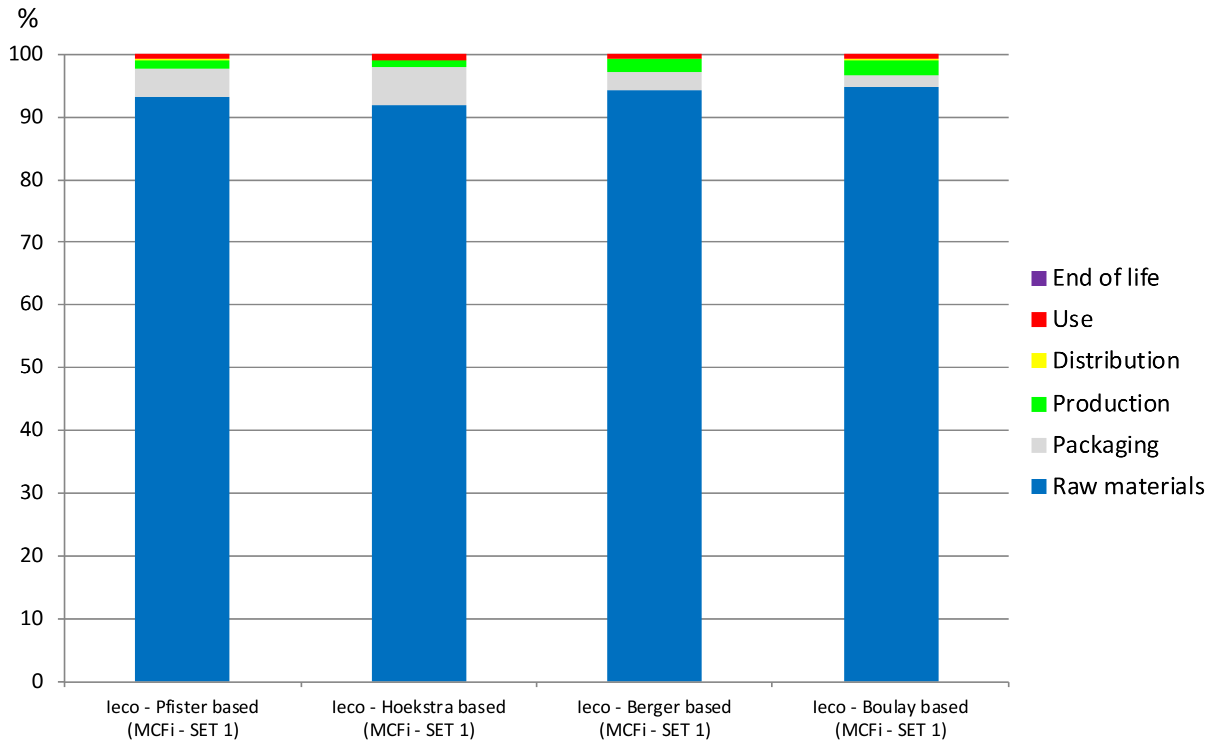

Figure 3.23 *Graphical representation of results from the sensitivity analysis 3. Results are represented in % and characterized according to the life cycle stages of the fresh mozzarella cheese.*

3.4.10 Case study #4: Hospital laundry service

The last case study investigated to test the applicability and effectiveness of the new proposed method for the assessment in monetary terms of water scarcity impacts concerns a hospital laundry service by a company in the southern Italy.

The awareness of the company on the importance of the environmental protection is demonstrated by the adoption of the environmental management system, certified according to the ISO 14001 standard, in the plant where it conduces all its activities.

The interest of the company towards the environmental sustainability and the diffusion of sustainable models in the laundry and sterilization sector, has led the company to perform an assessment of the water scarcity footprint associated to its hospital laundry service, adopting a life cycle approach according to the requirements of the standard ISO 14046:2014.

This case study fully answers the need of the research since it is characterized by water intensive processes, and furthermore it allows to analyze the performance of the new proposed method when applied to a service rather than a product.

For confidentiality reason any reference to the company and its suppliers has been omitted in the description, as well as any sensitive data has been described only in qualitative terms.

3.4.10.1 Goal and scope definition

The goal of this case study application is to test the new proposed method for the assessment of water scarcity impacts in monetary terms applying the new developed sets of monetary characterization factors, performing a hotspots analysis of the results throughout the life cycle stages of the hospital laundry service under study.

Moreover, according to the criteria described in the previous chapter 2 (§ 2.2.1), a sensitivity analysis has been also performed applying the new proposed method to 4 existing water scarcity impact assessment methods selected according to the criteria defined in the previous chapter 2 (§ 2.2.1.3).

The analysis was aimed on the one hand to provide a description of water scarcity impacts in monetary terms identifying the processes of the whole product supply chain characterized by the most significant contribution to the total impact, on the other hand to understand if this may change according to different water scarcity impact assessment methods.

The hospital laundry service provided by the company is aimed to ensure a proper supply of linen to the hospital users. The main tasks of the service concern sorting, washing, drying, ironing, folding and delivery. The term hospital linen includes all the textiles used in the hospital, such as mattress, blankets, towels, screens, and others similar materials (Figure 3.24).

Figure 3.24 *Hospital linen subjected to laundry service.*

The core of the service under study is represented by the overall activities carried out by the company at the plant, which is organized according to different operational areas:

- Sorting area.
- Laundry area, which is divided into a dirty area, for the washing machines, and a clean area, for dryers and press machines.
- Storage area for the cleaning agents.
- Sterilization area.
- Sewing, mending and ironing area.
- Storage area for clean linen.

Function, functional unit and reference flow

Since there are many ways in which the final users could use the hospital linen, thus in this study a specific function has not been defined.

The functional unit and the reference flow in this study match each other, corresponding to 1 kg of clean hospital linen, including distribution and final disposal of packaging.

System boundary

The system boundary has been defined including all the processes attributable to the service according to the adopted reference year of 2016. All the elementary flows entering /leaving the system have been accounted for the laundry service, according to the schematic flow chart of Figure 3.25, adopting a cradle to grave approach. Each life cycle stage has been analyzed to identify all the process units responsible for water resource consumption, according to the following description:

- Packaging: considering production and transport to the plant of all the elements adopted for the collection of the dirty hospital linen and, after the treatment, the next delivery to the hospitals.
- Production: considering all the processes involved in the hospital laundry service, focusing on inputs and outputs flows of the plant (e.g. water consumption, energy consumptions, auxiliary materials, wastes, etc.).
- Distribution: considering the transport of the clean hospital linen to the hospitals.
- End of life: corresponding to the final dismission of the packaging adopted to transport the clean hospital linen.

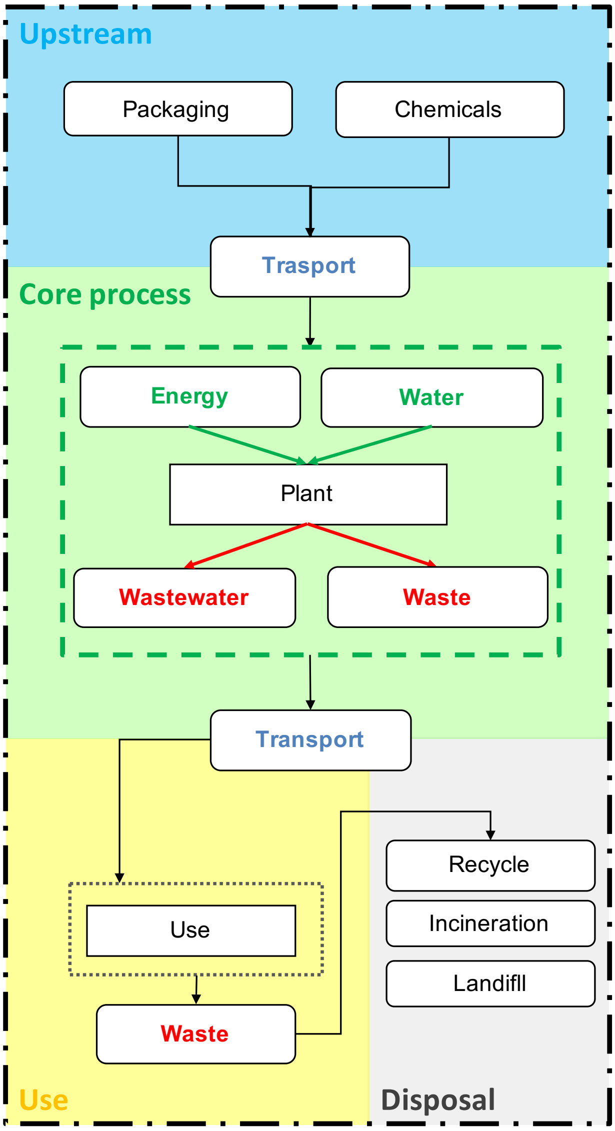

Figure 3.25 *Schematic representation of the system boundaries of the study according to the different life cycle stages of the hospital laundry service.*

According to the above flow chart, it is possible to observe that raw materials has been excluded by the system boundaries. This was because of the characteristic of the laundry service itself.

Moreover, the black dotted line around the use stage implies its exclusion from the assessment. This is choice is justified since the hospital linen which is subjected to the laundry service is reused several times, resulting in a very low incidence over the total of the analysis performed in this study.

Cut-off and allocation rules

In this study a cut-off rule of 1% by mass was used, avoiding thus the collection of data representing a percentage of the total flows less than 1%. Flows within this threshold are typically those characterized by a not significant mass with respect to the total or those for which it was impossible to collect specific data.

However, all processes for which data were available although their contribution was less than 1%, were included in the analysis. This choice is confirmed by several LCA studies in the literature (Humbert et al., 2009).

Furthermore, in modeling the recycling operations within the end of life stage it was applied the cut-off approach that gives null impacts to these kind of processes (Frischknecht, 2010), associating the 100% of impacts from recycling operations to the next product system in which the recycled material will be used.

According to the standard requirements (ISO 14044, 2006) in this study some allocations were performed considering the physical properties (mass, volume) of the fluxes to be allocated. Table 3.44 contains all the allocation criteria applied in this study.

Table 3.44 *Allocation rules applied in this study according to different kind of data collected for the modeling of the hospital laundry service.*

Elementary flow	Cause	Allocation rule
Packaging	Data were available according to the total amount consumed by the plant	Allocation has been done according to mass rule
Fuels for transport	Data were available according to the total amount consumed by the plant	Allocation has been done according to mass rule
Consumption/production of energy, chemicals, wastes within the production plant	Data were available according to the total amount consumed by the plant	Allocation has been done according to mass rule

Data quality

In this study data collection has been performed giving priority to primary information collected on site, particularly those related to the plant where almost all of the laundry operations take place. When this was not feasible, secondary data from reliable sources have been adopted.

Most of the collected data comes from the environmental declaration that company had commissioned for the same reference year of 2016.

Considering the production life cycle stage, the main data collected have been energy and water consumptions, wastes, input and output of water resources, total amount of linen processed, and chemicals consumption.

Considering the packaging life cycle stage, it refers to the total amount of materials involved in the transport phase.

The life cycle stage of distribution has been modeled considering primary data provided by the company about the collection of the dirty hospital linen and the distribution of the clean linen, as well as considering the fleet vehicles composition.

Data collected about packaging and chemicals production and end of life treatments have been collected from a mix of primary and secondary sources, adopting universally recognized database and technical report from national institutions for the modeling.

The whole data quality level has been assessed by a critical review according to the following requirements fixed by the reference standard (ISO 14044, 2006):

- Time-related coverage: this requirement has been met adopting primary data from the most recent available period, adopting the year 2016 as reference in this study. When only secondary data were available, the most recent and representative ones have been selected for the collection. Furthermore, the reference datasets adopted were those referred to the most recent version available at the time of the modeling.
- Geographical coverage: to meet this requirement all primary data collected are site specific and, when this was not possible, the reference datasets adopted have been selected considering the average production from the country of origin or the most representative market as proxy (e.g. national context).
- Technology coverage: data collected in this study concerns technologies representative as much as possible of the real production system under study.
- Completeness: according to this requirement the percentage of primary data collected is good, having the possibility to integrate to the information under the direct control of the company also other information arising from available reports and technical data sheets. For all the secondary data collected, assumptions were made according to benchmark analysis and industry practices. Finally, the cut-off rule which is usually fixed at 5% by weight of the product materials, in this study has been fixed at 1% with and expected no effect on the outcome of the final results.
- Consistency: this requirement has been met by a consistent and uniform implementation of the new method proposed in this research work to all the components of the product under study, in terms of modeling and assumptions made.

- Reproducibility: to meet this requirement the modeling has been performed allowing its implementation also in another similar study.
- Uncertainty: primary data are characterized by an almost total absence of uncertainty, while the most part of the secondary data concern datasets containing uncertainty information.

To model the product system under study the LCA software SimaPro version 8.5.2.0 has been used (PRé Consultants, 2018), adopting the databases Ecoinvent v3.4 (Ecoinvent, 2018).

3.4.10.2 Life cycle inventory

The life cycle inventory includes a mix of foreground and background inventories. The first is based on primary data collected directly from the producer company concerning direct resources consumption ad emissions, including all the water withdrawals and releases as well as all the other kind of information not directly related to water (e.g. energy consumption and raw materials), the second is based mainly on inventory databases where the inventory data have been determined and processed according to ISO 14046 (2014) to account for all the water flows involved.
In this paragraph all the data collected are reported, according to the different life cycle stages investigated.

Packaging

In this stage the packaging used by the company in relation to the service under study have been modeled, in particular focusing on the primary packaging adopted by the company to transport the clean linen to the hospitals. It was considered the packaging production process and next transport to the company plant according to the cradle to industry gate approach.
According to the primary information from the company the total amount of packaging, which was equal to 314.420 kg for the reference year, is substantially made only of PE plastic sealed bags, which have been modeled through the dataset “Polyethylene, linear low density, granulate {RER}| production | Cut-off, U” including also the production process “Extrusion, plastic film {RER}| production | Cut-off, U”.
The transport has been also modeled, adopting the dataset “Transport, freight, lorry 16-32 metric ton, EURO 4 {RER} | transport, freight, lorry 16-32 metric ton, EURO 4 | Alloc Rec, U” and assuming a distance of 10 km from the supplier according to the primary information form the company.

Production

The main fluxes involved in the laundry operation performed at the plant concern energy and chemicals consumption, water resources consumption and production of wastes.

Considering the main sources of energy involved in the process, electricity and methane gas for the production of heat, they have been modeled as follows:

- Electricity energy from national supply network: it has been modeled through the dataset "Electricity, medium voltage {IT}| market for | Cut-off, U".
- Electricity energy from photovoltaic plant: it has been modeled through the dataset "Electricity, low voltage {IT}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, U".
- Heat from natural gas industrial boiler: it has been modeled through the dataset "Heat, district or industrial, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler condensing modulating >100kW | Cut-off, U".

Considering the consumption of water at the plant, which is equal to 25.723 m^3 for the reference year, its withdrawal from the groundwater well has been modeled with the dataset "Tap water {Europe without Switzerland}| tap water production, underground water without treatment | Cut-off, U" modified to account for the specific country of origin which is Italy.

Additionally, since it was not possible to have primary data about the water leaks during the drying operations, according to assumptions and estimations made by the company it has been assumed a flat percentage of water lost due to the evaporation at the plant equal to 5%.

Considering the chemicals involved in the hospital laundry service, they were modeled according to primary information from company and adopting datasets as reported in Table 3.45, where they are grouped in three main classes.

For each chemical it was considered the production process and the transport to the company plant modeled through the dataset "Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4 | Cut-off, U".

Table 3.45 *Data on chemicals and related datasets adopted in the modeling of the hospital laundry service.*

Function	Type of chemical	Dataset
Whitening	Sodium hydroxide	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U
Detergents	Hydrogen peroxide	Hydrogen peroxide, without water, in 50% solution state {RER}| hydrogen peroxide production, product in 50% solution state | Cut-off, U
	Mulan spirit	Ethoxylated alcohol (AE7) {GLO}| market for | Cut-off, U Ethoxylated alcohol (AE11) {GLO}| market for | Cut-off, U Chemical, organic {GLO}| production | Cut-off, U Water, unspecified natural origin, IT
	Puratex	Alkylbenzene sulfonate, linear, petrochemical {RER}| production | Cut-off, U Ethoxylated alcohol (AE7) {GLO}| market for | Cut-off, U Sodium silicate, without water, in 48% solution state {GLO}| market for | Cut-off, U Sodium percarbonate, powder {RER}| production | Cut-off, U Water, unspecified natural origin, IT
	Power uno	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U Chemical, organic {GLO}| production | Cut-off, U Water, unspecified natural origin, IT
	Dual ecodet	Soap {RER}| production | Cut-off, U
	Sanoxy	Acetic acid, without water, in 98% solution state {GLO}| market for | Cut-off, U Hydrogen peroxide, without water, in 50% solution state {RER}| hydrogen peroxide production, product in 50% solution state | Cut-off, U Chemical, organic {GLO}| production | Cut-off, U Water, unspecified natural origin, IT
	Selox	Ethoxylated alcohol (AE7) {GLO}| market for | Cut-off, U Chemical, organic {GLO}| production | Cut-off, U Water, unspecified natural origin, IT
Ecolabel	Green'r ultra-wash	Ethoxylated alcohol (AE7) {GLO}| market for | Cut-off, U Alkylbenzene sulfonate, linear, petrochemical {RER}| production | Cut-off, U 1-propanol {RER}| production | Cut-off, U Chemical, organic {GLO}| production | Cut-off, U Water, unspecified natural origin, IT

The different fluxes of waste generated during the operation of laundry have been modeled according to primary data from the company and, when this was not possible, adopting secondary data from the literature (ISPRA 2017a), considering different treatments and relative datasets according to the information listed in Table 3.46.

Table 3.46 *Datasets adopted in modeling of treatment of wastes produced at plant.*

Type of waste	Code	Dataset
Wastewater	-	Wastewater, average {CH}| treatment of, capacity 5E9l/year | Cut-off, U
Textiles	040222	Waste textile soiled {CH}| treatment of, municipal incineration | Cut-off, U Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U Generic dataset for the recycling.
Paper and carton	150101	Waste paperboard {CH}| treatment of, municipal incineration | Cut-off, U Waste paperboard {CH}| treatment of, sanitary landfill | Cut-off, U Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U
Plastic	150102	Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, U Waste plastic, mixture {CH}| treatment of, sanitary landfill | Cut-off, U Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U
Wood	150103	Waste wood, untreated {CH}| treatment of, municipal incineration | Cut-off, U Waste wood, untreated {CH}| treatment of, sanitary landfill | Cut-off, U Generic dataset for the recycling.
Mix materials	150106	Municipal solid waste {IT}| treatment of, incineration | Cut-off, U Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U Generic dataset for the recycling.
Metals	160117	Scrap steel {CH}| treatment of, municipal incineration | Cut-off, U Scrap steel {CH}| treatment of, inert material landfill | Cut-off, U Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Cut-off, U
Iron/steel	170405	Scrap steel {CH}| treatment of, municipal incineration | Cut-off, U Scrap steel {CH}| treatment of, inert material landfill | Cut-off, U Steel and iron (waste treatment) {GLO}| recycling of steel and iron | Cut-off, U
Recycled paper	200101	Paper (waste treatment) {GLO}| recycling of paper | Cut-off, U
Recycled textile	200111	Generic dataset for the recycling.
Recycled wood	200138	Generic dataset for the recycling.
Green	200201	Biowaste {CH}| market for | Cut-off, U

For all the above described waste treatments it was also included the transport process from the company plant to the final destination, modeled through the dataset “Municipal waste collection service by 21 metric ton lorry {CH}| processing | Cut-off, U”, considering the specific distances according to primary information given by the company and contained into the waste register.

Distribution

This life cycle stage has been modeled considering all the transports needed to collect the dirty linen to the plant, as well as the transport needed to deliver the clean linen to the different hospitals, which are all within the national context.

The transport, which occurs only by vans with a global fuel consumption of 467.553 liters of fuel in the reference year, has been modeled through a mix of datasets according to the different type of vehicle used by the company (n°9 vans EURO4 and n°8 vans EURO5), adopting the datasets “Transport, freight, lorry 3.5-7.5 metric ton, EURO4 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO5 | Cut-off, U” and “Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO4 | Cut-off, U”.

End of life

In the last life cycle stage, the packaging used to transport the clean linen to the hospital are subjected to the final disposal, with different treatments applied according to secondary data (ISPRAb, 2017).

Since the packaging is made only of plastic material, thus percentage of treatment applied have been 82,1% for recycling that was modeled through the dataset “Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U”, 2,8% for incineration that was modeled through the dataset “Waste plastic, mixture {CH}| treatment of, municipal incineration | Cut-off, U”, 15,1% for landfill that was modeled through the dataset “Waste plastic, mixture {CH}| treatment of, sanitary landfill | Cut-off, U”.

Starting from the whole inventory data described above and adopting the LCA software SimaPro to process all the information, the water inventory results for the system product under study in terms of input (raw materials) and outputs (water, air, soil) listed in the Table 3.47.

Table 3.47 *Water inventory data of the whole life cycle of the hospital laundry service.*

Substance	Compartment	Unit	Value
Water, AR	Water	m3	2,35E-18
Water, AT	Water	m3	4,82E-02
Water, AU	Water	m3	2,66E-03
Water, BA	Water	m3	3,90E-03
Water, BE	Water	m3	4,04E-04
Water, BG	Water	m3	3,44E-03
Water, BR	Water	m3	7,61E-03
Water, CA	Water	m3	8,77E-03
Water, CH	Water	m3	1,02E-01
Water, CL	Water	m3	2,32E-03
Water, CN	Water	m3	1,16E-01
Water, CO	Water	m3	1,35E-06
Water, cooling, unspecified natural origin, AT	Raw material	m3	1,41E-05
Water, cooling, unspecified natural origin, AU	Raw material	m3	3,36E-05
Water, cooling, unspecified natural origin, BA	Raw material	m3	1,03E-05
Water, cooling, unspecified natural origin, BE	Raw material	m3	5,29E-05
Water, cooling, unspecified natural origin, BG	Raw material	m3	4,87E-05
Water, cooling, unspecified natural origin, BR	Raw material	m3	1,71E-05
Water, cooling, unspecified natural origin, CA	Raw material	m3	5,94E-05
Water, cooling, unspecified natural origin, CH	Raw material	m3	2,29E-04
Water, cooling, unspecified natural origin, CL	Raw material	m3	4,62E-06
Water, cooling, unspecified natural origin, CN	Raw material	m3	5,66E-04
Water, cooling, unspecified natural origin, CY	Raw material	m3	5,96E-07
Water, cooling, unspecified natural origin, CZ	Raw material	m3	4,58E-04
Water, cooling, unspecified natural origin, DE	Raw material	m3	5,73E-04
Water, cooling, unspecified natural origin, DK	Raw material	m3	1,19E-05
Water, cooling, unspecified natural origin, EE	Raw material	m3	1,62E-05
Water, cooling, unspecified natural origin, ES	Raw material	m3	1,31E-04
Water, cooling, unspecified natural origin, Europe without Switzerland	Raw material	m3	2,56E-04
Water, cooling, unspecified natural origin, FI	Raw material	m3	3,78E-05
Water, cooling, unspecified natural origin, FR	Raw material	m3	8,36E-04
Water, cooling, unspecified natural origin, GB	Raw material	m3	1,31E-04
Water, cooling, unspecified natural origin, GLO	Raw material	m3	3,29E-05
Water, cooling, unspecified natural origin, GR	Raw material	m3	1,14E-04
Water, cooling, unspecified natural origin, HR	Raw material	m3	6,54E-06
Water, cooling, unspecified natural origin, HU	Raw material	m3	3,23E-05
Water, cooling, unspecified natural origin, ID	Raw material	m3	2,34E-05
Water, cooling, unspecified natural origin, IE	Raw material	m3	1,28E-05
Water, cooling, unspecified natural origin, IN	Raw material	m3	1,71E-04
Water, cooling, unspecified natural origin, IR	Raw material	m3	4,33E-05
Water, cooling, unspecified natural origin, IS	Raw material	m3	4,07E-09
Water, cooling, unspecified natural origin, IT	Raw material	m3	1,66E-03
Water, cooling, unspecified natural origin, JP	Raw material	m3	8,00E-05
Water, cooling, unspecified natural origin, KR	Raw material	m3	6,61E-05
Water, cooling, unspecified natural origin, LT	Raw material	m3	3,32E-06
Water, cooling, unspecified natural origin, LU	Raw material	m3	1,55E-06
Water, cooling, unspecified natural origin, LV	Raw material	m3	4,54E-06
Water, cooling, unspecified natural origin, MA	Raw material	m3	8,14E-08
Water, cooling, unspecified natural origin, MK	Raw material	m3	4,88E-06
Water, cooling, unspecified natural origin, MT	Raw material	m3	2,52E-06
Water, cooling, unspecified natural origin, MX	Raw material	m3	2,27E-05
Water, cooling, unspecified natural origin, MY	Raw material	m3	1,76E-05
Water, cooling, unspecified natural origin, NL	Raw material	m3	7,58E-05
Water, cooling, unspecified natural origin, NO	Raw material	m3	2,25E-06
Water, cooling, unspecified natural origin, NP	Raw material	m3	1,45E-10
Water, cooling, unspecified natural origin, PE	Raw material	m3	3,09E-06
Water, cooling, unspecified natural origin, PH	Raw material	m3	1,10E-05
Water, cooling, unspecified natural origin, PL	Raw material	m3	5,25E-04
Water, cooling, unspecified natural origin, PT	Raw material	m3	1,39E-05
Water, cooling, unspecified natural origin, RER	Raw material	m3	7,95E-03
Water, cooling, unspecified natural origin, RNA	Raw material	m3	3,62E-13

Substance	Compartment	Unit	Value
Water, cooling, unspecified natural origin, RO	Raw material	m3	9,47E-05
Water, cooling, unspecified natural origin, RoW	Raw material	m3	1,76E-03
Water, cooling, unspecified natural origin, RS	Raw material	m3	1,11E-04
Water, cooling, unspecified natural origin, RU	Raw material	m3	3,98E-04
Water, cooling, unspecified natural origin, SA	Raw material	m3	3,98E-05
Water, cooling, unspecified natural origin, SE	Raw material	m3	7,99E-05
Water, cooling, unspecified natural origin, SI	Raw material	m3	2,73E-04
Water, cooling, unspecified natural origin, SK	Raw material	m3	6,77E-05
Water, cooling, unspecified natural origin, TH	Raw material	m3	1,43E-05
Water, cooling, unspecified natural origin, TR	Raw material	m3	2,62E-05
Water, cooling, unspecified natural origin, TW	Raw material	m3	2,32E-05
Water, cooling, unspecified natural origin, TZ	Raw material	m3	6,26E-07
Water, cooling, unspecified natural origin, UA	Raw material	m3	1,78E-04
Water, cooling, unspecified natural origin, US	Raw material	m3	3,77E-04
Water, cooling, unspecified natural origin, WEU	Raw material	m3	6,91E-10
Water, cooling, unspecified natural origin, ZA	Raw material	m3	3,62E-05
Water, CY	Water	m3	5,92E-07
Water, CZ	Water	m3	1,76E-03
Water, DE	Water	m3	1,76E-02
Water, DK	Water	m3	1,66E-05
Water, EE	Water	m3	1,59E-05
Water, ES	Water	m3	1,90E-02
Water, Europe without Switzerland	Water	m3	2,28E-05
Water, FI	Water	m3	6,49E-03
Water, FR	Water	m3	9,24E-02
Water, GB	Water	m3	1,37E-04
Water, GLO	Water	m3	2,46E-04
Water, GR	Water	m3	3,01E-03
Water, HR	Water	m3	5,16E-04
Water, HU	Water	m3	2,65E-04
Water, IAI Area, Africa	Water	m3	5,85E-08
Water, IAI Area, Asia, without China and GCC	Water	m3	1,08E-07
Water, IAI Area, EU27 & EFTA	Water	m3	1,37E-06
Water, IAI Area, Gulf Cooperation Council	Water	m3	1,31E-07
Water, IAI Area, North America, without Quebec	Water	m3	8,03E-08
Water, IAI Area, Russia & RER w/o EU27 & EFTA	Water	m3	2,03E-07
Water, IAI Area, South America	Water	m3	7,32E-08
Water, ID	Water	m3	3,54E-04
Water, IE	Water	m3	4,86E-04
Water, IL	Water	m3	1,08E-11
Water, IN	Water	m3	8,05E-03
Water, IR	Water	m3	1,61E-03
Water, IS	Water	m3	5,68E-04
Water, IT	Water	m3	2,23E-01
Water, JP	Water	m3	6,04E-03
Water, KR	Water	m3	3,17E-04
Water, lake, CA	Raw material	m3	6,80E-06
Water, lake, CH	Raw material	m3	3,64E-06
Water, lake, CN	Raw material	m3	3,09E-13
Water, lake, DE	Raw material	m3	1,71E-09
Water, lake, Europe without Switzerland	Raw material	m3	2,57E-06
Water, lake, GLO	Raw material	m3	2,46E-13
Water, lake, RER	Raw material	m3	1,56E-08
Water, lake, RNA	Raw material	m3	3,83E-14
Water, lake, RoW	Raw material	m3	5,92E-06
Water, lake, US	Raw material	m3	8,88E-12
Water, LT	Water	m3	1,21E-05
Water, LU	Water	m3	2,30E-04
Water, LV	Water	m3	4,61E-06
Water, MA	Water	m3	5,94E-08
Water, MK	Water	m3	1,97E-04
Water, MT	Water	m3	2,52E-06
Water, MX	Water	m3	3,88E-03

Substance	Compartment	Unit	Value
Water, MY	Water	m3	4,21E-04
Water, NL	Water	m3	1,66E-04
Water, NO	Water	m3	1,89E-03
Water, NORDEL	Water	m3	5,08E-09
Water, NP	Water	m3	3,78E-04
Water, PE	Water	m3	4,12E-05
Water, PG	Water	m3	6,43E-08
Water, PH	Water	m3	6,30E-04
Water, PL	Water	m3	2,09E-03
Water, PT	Water	m3	8,01E-03
Water, RAF	Water	m3	8,05E-06
Water, RAS	Water	m3	1,86E-06
Water, RER	Water	m3	6,13E-03
Water, river, AU	Raw material	m3	2,39E-07
Water, river, BR	Raw material	m3	1,17E-05
Water, river, CH	Raw material	m3	1,02E-05
Water, river, CN	Raw material	m3	1,14E-04
Water, river, DE	Raw material	m3	2,46E-06
Water, river, ES	Raw material	m3	6,15E-06
Water, river, Europe without Switzerland	Raw material	m3	8,42E-05
Water, river, FR	Raw material	m3	8,01E-07
Water, river, GLO	Raw material	m3	3,91E-06
Water, river, IN	Raw material	m3	3,11E-05
Water, river, KR	Raw material	m3	8,29E-07
Water, river, MY	Raw material	m3	1,51E-04
Water, river, NL	Raw material	m3	2,77E-08
Water, river, PE	Raw material	m3	6,34E-10
Water, river, PH	Raw material	m3	9,88E-04
Water, river, RAS	Raw material	m3	3,78E-06
Water, river, RER	Raw material	m3	9,05E-05
Water, river, RLA	Raw material	m3	9,90E-07
Water, river, RNA	Raw material	m3	1,76E-06
Water, river, RO	Raw material	m3	3,38E-06
Water, river, RoW	Raw material	m3	3,71E-04
Water, river, RU	Raw material	m3	1,90E-07
Water, river, SE	Raw material	m3	4,83E-09
Water, river, TN	Raw material	m3	4,62E-07
Water, river, TZ	Raw material	m3	9,61E-09
Water, river, US	Raw material	m3	3,21E-05
Water, river, WEU	Raw material	m3	7,11E-14
Water, river, ZA	Raw material	m3	3,01E-08
Water, RLA	Water	m3	6,58E-07
Water, RME	Water	m3	7,92E-05
Water, RNA	Water	m3	2,52E-06
Water, RO	Water	m3	1,38E-02
Water, RoW	Water	m3	1,36E-01
Water, RS	Water	m3	6,90E-03
Water, RU	Water	m3	2,64E-02
Water, SA	Water	m3	4,00E-05
Water, salt, ocean	Raw material	m3	2,27E-04
Water, salt, sole	Raw material	m3	4,89E-05
Water, SE	Water	m3	4,10E-02
Water, SI	Water	m3	3,75E-04
Water, SK	Water	m3	3,02E-03
Water, TH	Water	m3	1,16E-04
Water, TR	Water	m3	2,68E-03
Water, turbine use, unspecified natural origin, AT	Raw material	m3	4,82E-02
Water, turbine use, unspecified natural origin, AU	Raw material	m3	2,63E-03
Water, turbine use, unspecified natural origin, BA	Raw material	m3	3,89E-03
Water, turbine use, unspecified natural origin, BE	Raw material	m3	3,51E-04
Water, turbine use, unspecified natural origin, BG	Raw material	m3	3,40E-03
Water, turbine use, unspecified natural origin, BR	Raw material	m3	7,62E-03
Water, turbine use, unspecified natural origin, CA	Raw material	m3	8,74E-03

Substance	Compartment	Unit	Value
Water, turbine use, unspecified natural origin, CH	Raw material	m3	1,02E-01
Water, turbine use, unspecified natural origin, CL	Raw material	m3	2,32E-03
Water, turbine use, unspecified natural origin, CN	Raw material	m3	1,16E-01
Water, turbine use, unspecified natural origin, CZ	Raw material	m3	1,31E-03
Water, turbine use, unspecified natural origin, DE	Raw material	m3	1,71E-02
Water, turbine use, unspecified natural origin, DK	Raw material	m3	1,20E-05
Water, turbine use, unspecified natural origin, ES	Raw material	m3	1,89E-02
Water, turbine use, unspecified natural origin, FI	Raw material	m3	6,46E-03
Water, turbine use, unspecified natural origin, FR	Raw material	m3	9,16E-02
Water, turbine use, unspecified natural origin, GB	Raw material	m3	4,48E-06
Water, turbine use, unspecified natural origin, GLO	Raw material	m3	2,54E-08
Water, turbine use, unspecified natural origin, GR	Raw material	m3	2,90E-03
Water, turbine use, unspecified natural origin, HR	Raw material	m3	5,18E-04
Water, turbine use, unspecified natural origin, HU	Raw material	m3	2,33E-04
Water, turbine use, unspecified natural origin, ID	Raw material	m3	2,13E-04
Water, turbine use, unspecified natural origin, IE	Raw material	m3	4,73E-04
Water, turbine use, unspecified natural origin, IN	Raw material	m3	7,88E-03
Water, turbine use, unspecified natural origin, IR	Raw material	m3	1,56E-03
Water, turbine use, unspecified natural origin, IS	Raw material	m3	5,70E-04
Water, turbine use, unspecified natural origin, IT	Raw material	m3	2,19E-01
Water, turbine use, unspecified natural origin, JP	Raw material	m3	5,96E-03
Water, turbine use, unspecified natural origin, KR	Raw material	m3	2,52E-04
Water, turbine use, unspecified natural origin, LT	Raw material	m3	9,01E-06
Water, turbine use, unspecified natural origin, LU	Raw material	m3	2,29E-04
Water, turbine use, unspecified natural origin, MK	Raw material	m3	1,92E-04
Water, turbine use, unspecified natural origin, MX	Raw material	m3	3,85E-03
Water, turbine use, unspecified natural origin, MY	Raw material	m3	2,86E-04
Water, turbine use, unspecified natural origin, NL	Raw material	m3	9,64E-05
Water, turbine use, unspecified natural origin, NO	Raw material	m3	1,95E-03
Water, turbine use, unspecified natural origin, NP	Raw material	m3	3,78E-04
Water, turbine use, unspecified natural origin, PE	Raw material	m3	3,95E-05
Water, turbine use, unspecified natural origin, PL	Raw material	m3	1,63E-03
Water, turbine use, unspecified natural origin, PT	Raw material	m3	7,99E-03
Water, turbine use, unspecified natural origin, RER	Raw material	m3	1,06E-03
Water, turbine use, unspecified natural origin, RNA	Raw material	m3	3,00E-11
Water, turbine use, unspecified natural origin, RO	Raw material	m3	1,37E-02
Water, turbine use, unspecified natural origin, RoW	Raw material	m3	1,35E-01
Water, turbine use, unspecified natural origin, RS	Raw material	m3	6,80E-03
Water, turbine use, unspecified natural origin, RU	Raw material	m3	2,60E-02
Water, turbine use, unspecified natural origin, SE	Raw material	m3	4,09E-02
Water, turbine use, unspecified natural origin, SI	Raw material	m3	1,08E-04
Water, turbine use, unspecified natural origin, SK	Raw material	m3	2,96E-03
Water, turbine use, unspecified natural origin, TH	Raw material	m3	1,02E-04
Water, turbine use, unspecified natural origin, TR	Raw material	m3	2,65E-03
Water, turbine use, unspecified natural origin, TZ	Raw material	m3	5,52E-05
Water, turbine use, unspecified natural origin, UA	Raw material	m3	5,54E-03
Water, turbine use, unspecified natural origin, US	Raw material	m3	2,29E-02
Water, turbine use, unspecified natural origin, ZA	Raw material	m3	3,57E-05
Water, TW	Water	m3	2,31E-05
Water, TZ	Water	m3	5,57E-05
Water, UA	Water	m3	5,72E-03
Water, UCTE	Water	m3	6,94E-11
Water, UCTE without Germany	Water	m3	4,33E-11
Water, UN-OCEANIA	Water	m3	7,79E-08
Water, unspecified natural origin, AU	Raw material	m3	1,36E-18
Water, unspecified natural origin, CA	Raw material	m3	1,84E-07
Water, unspecified natural origin, CH	Raw material	m3	1,48E-04
Water, unspecified natural origin, CL	Raw material	m3	1,15E-10
Water, unspecified natural origin, CN	Raw material	m3	5,94E-07
Water, unspecified natural origin, DE	Raw material	m3	3,47E-10
Water, unspecified natural origin, Europe without Switzerland	Raw material	m3	2,46E-07
Water, unspecified natural origin, GLO	Raw material	m3	3,33E-05
Water, unspecified natural origin, IAI Area, Africa	Raw material	m3	4,40E-08

Substance	Compartment	Unit	Value
Water, unspecified natural origin, IAI Area, Asia, without China and GCC	Raw material	m3	8,17E-08
Water, unspecified natural origin, IAI Area, EU27 & EFTA	Raw material	m3	4,77E-07
Water, unspecified natural origin, IAI Area, Gulf Cooperation Council	Raw material	m3	9,83E-08
Water, unspecified natural origin, IAI Area, North America, without Quebec	Raw material	m3	6,22E-08
Water, unspecified natural origin, IAI Area, Russia & RER w/o EU27 & EFTA	Raw material	m3	1,45E-07
Water, unspecified natural origin, IAI Area, South America	Raw material	m3	5,84E-08
Water, unspecified natural origin, IT	Raw material	m3	2,35E-05
Water, unspecified natural origin, PG	Raw material	m3	7,85E-09
Water, unspecified natural origin, PH	Raw material	m3	2,76E-06
Water, unspecified natural origin, RAF	Raw material	m3	9,47E-06
Water, unspecified natural origin, RER	Raw material	m3	1,04E-04
Water, unspecified natural origin, RME	Raw material	m3	9,32E-05
Water, unspecified natural origin, RNA	Raw material	m3	3,27E-07
Water, unspecified natural origin, RoW	Raw material	m3	1,73E-04
Water, unspecified natural origin, RU	Raw material	m3	1,33E-05
Water, unspecified natural origin, TH	Raw material	m3	5,10E-10
Water, unspecified natural origin, UN-OCEANIA	Raw material	m3	5,87E-08
Water, unspecified natural origin, US	Raw material	m3	1,26E-07
Water, unspecified natural origin, WEU	Raw material	m3	8,60E-11
Water, US	Water	m3	2,33E-02
Water, well, in ground, AT	Raw material	m3	3,28E-15
Water, well, in ground, AU	Raw material	m3	1,18E-06
Water, well, in ground, BR	Raw material	m3	2,72E-06
Water, well, in ground, CA	Raw material	m3	2,98E-07
Water, well, in ground, CH	Raw material	m3	7,99E-06
Water, well, in ground, CN	Raw material	m3	7,04E-05
Water, well, in ground, DE	Raw material	m3	2,29E-06
Water, well, in ground, ES	Raw material	m3	3,63E-06
Water, well, in ground, Europe without Switzerland	Raw material	m3	9,24E-06
Water, well, in ground, FR	Raw material	m3	6,45E-07
Water, well, in ground, GLO	Raw material	m3	6,64E-06
Water, well, in ground, ID	Raw material	m3	1,44E-06
Water, well, in ground, IN	Raw material	m3	5,39E-05
Water, well, in ground, IS	Raw material	m3	1,71E-11
Water, well, in ground, IT	Raw material	m3	3,47E-03
Water, well, in ground, JP	Raw material	m3	8,57E-12
Water, well, in ground, MA	Raw material	m3	1,44E-08
Water, well, in ground, MX	Raw material	m3	1,91E-11
Water, well, in ground, MY	Raw material	m3	1,31E-05
Water, well, in ground, NORDEL	Raw material	m3	5,98E-09
Water, well, in ground, PE	Raw material	m3	1,03E-09
Water, well, in ground, PG	Raw material	m3	6,78E-08
Water, well, in ground, PH	Raw material	m3	1,54E-04
Water, well, in ground, PL	Raw material	m3	2,40E-06
Water, well, in ground, PT	Raw material	m3	4,80E-13
Water, well, in ground, RER	Raw material	m3	5,72E-05
Water, well, in ground, RLA	Raw material	m3	1,89E-07
Water, well, in ground, RNA	Raw material	m3	9,75E-07
Water, well, in ground, RoW	Raw material	m3	1,86E-04
Water, well, in ground, RU	Raw material	m3	6,64E-07
Water, well, in ground, SE	Raw material	m3	8,40E-10
Water, well, in ground, TH	Raw material	m3	3,28E-15
Water, well, in ground, TN	Raw material	m3	7,10E-07
Water, well, in ground, TR	Raw material	m3	3,54E-11
Water, well, in ground, US	Raw material	m3	4,89E-05
Water, well, in ground, WEU	Raw material	m3	2,18E-06
Water, well, in ground, ZA	Raw material	m3	3,75E-07
Water, WEU	Water	m3	2,42E-06
Water, ZA	Water	m3	7,28E-05
Water/m3	Air	m3	5,77E-03

3.4.11 Life cycle impact assessment

Starting from the life cycle inventory above described, in this paragraph results of the life cycle impact assessment are reported, particularly referring to the monetary assessment of water scarcity impacts related to the product under study.

According to the comments reported in the same life cycle impact assessment phase of the other case studies, the monetary assessment has been performed through the application of the new monetary characterization factors developed in this research work to the method proposed by Pfister et al. (2009), which has been assumed as reference.

The sensitivity analysis performed in this case study, as in the previous case studies, were aimed to evaluate the effects on final results from the application of the new proposed method to 4 existing water scarcity impact assessment methods, and also to evaluate the effects on final results from the adoption of the modified monetary base constant MK (§ 3.3) in the calculation of the new monetary characterization factors.

The next Table 3.48 reports the results from the application of the new proposed method in absolute terms according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.48 *Monetary impact assessment resulting from the application of the new proposed method to the hospital laundry service. Results are expressed in US$/FU and characterized according to the life cycle stages.*

Method	Packaging	Production	Distribution	End of life	Total
I_{eco} - Pfister based (MCFi - SET EQ)	0,007	0,031	0,003	0,000	**0,041**
I_{eco} - Pfister based (MCFi - SET 1)	0,008	0,047	0,003	0,000	**0,059**
I_{eco} - Pfister based (MCFi - SET 2)	0,014	0,047	0,004	0,000	**0,065**
I_{eco} - Pfister based (MCFi - SET 3)	0,014	0,056	0,005	0,000	**0,075**
I_{eco} - Pfister based (MCFi - SET 4)	0,012	0,048	0,004	0,000	**0,064**
I_{eco} - Pfister based (MCFi - SET 5)	0,007	0,034	0,003	0,000	**0,044**
I_{eco} - Pfister based (MCFi - SET 6)	0,011	0,047	0,004	0,000	**0,062**

The results listed in Table 3.46 show a variability in the absolute values obtained from the application of the 7 different proposed set of characterization factors developed according to the weighting approaches described in the previous chapter 2 (§ 2.2.1.1).

The total value of the monetary assessment of water scarcity impacts of the hospital laundry service resulted to be in the range between 0,041 US$/FU, from $I_{eco\text{ - Pfister based}}$ when applying $MCF_{i\text{ - SET EQ}}$, and 0,75 US$/FU from $I_{eco\text{ - Pfister based}}$ when applying $MCF_{i\text{ - SET 3}}$, confirming what observed in the previous case studies where the same sets were responsible respectively of the minimum and the maximum absolute value of the monetary impact among all the 7 sets applied.

As already observed in the life cycle impact assessment phase of the other case studies, analyzing the incidence of the results in percentage terms throughout the different life cycle stages is fundamental for a properly identification of the hotspots along the whole supply chain of the production system under study. Thus, the values in absolute terms listed in the previous Table 3.48 have been reported also in percentage terms in the next Table 3.49 and Figure 3.26 in order to allow a better understanding of the incidence of the final impact results.

Table 3.49 *Monetary assessment of water scarcity impacts resulting from the application of the new proposed method to the hospital laundry service. Results are expressed in % and characterized according to the life cycle stages.*

Method	Packaging	Production	Distribution	End of life
I_{eco} - Pfister based (MCFi - SET EQ)	17,9	75,7	6,4	0,0
I_{eco} - Pfister based (MCFi - SET 1)	14,3	79,7	5,9	0,0
I_{eco} - Pfister based (MCFi - SET 2)	21,0	72,0	6,9	0,0
I_{eco} - Pfister based (MCFi - SET 3)	18,6	74,6	6,8	0,0
I_{eco} - Pfister based (MCFi - SET 4)	18,6	74,8	6,6	0,0
I_{eco} - Pfister based (MCFi - SET 5)	16,8	76,9	6,2	0,0
I_{eco} - Pfister based (MCFi - SET 6)	17,8	75,7	6,4	0,0

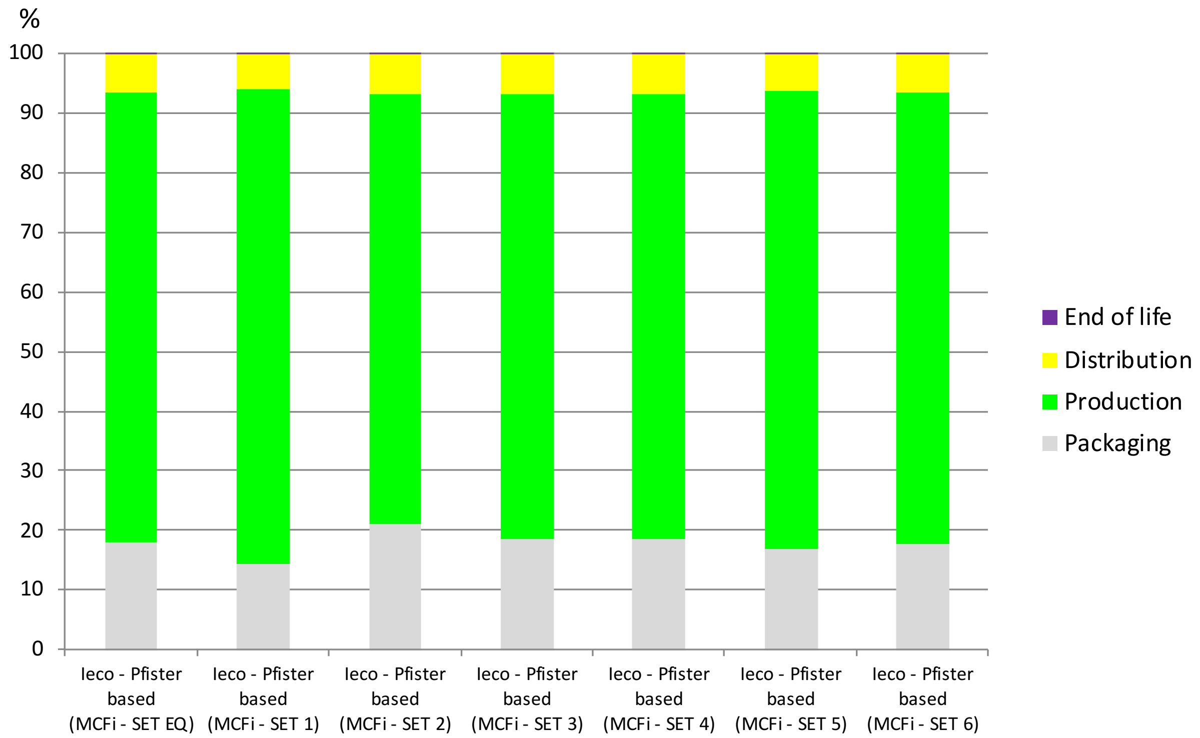

Figure 3.26 *Graphical representation of results from the application of the new proposed method to the hospital laundry service. Results are represented in % and characterized according to the life cycle stages.*

Observing the results expressed in percentage terms along the whole supply chain it was possible to observe that the application of the 7 different proposed sets of characterization factors, unlike the previous case studies, resulted to have a slightly higher variability in the incidence on the different life cycle stages among the 7 proposed sets of characterization factors.

Moreover, despite this effect on final results from the application of the 7 different proposed sets of characterization factors, all of them confirmed that raw materials is the most impactful life cycle stage with an average incidence of more than 75% on the overall impact, followed by packaging that is the second most important contribution with an average incidence of about 18%, and by distribution with an average incidence of about 6,5%. The end of life stage, instead, is characterized by an almost null impact.

3.4.12 Life cycle interpretation and hotspots analysis

In this stage results are analyzed in order to highlight the hotspots related to the impact assessment performed in this case study.

According to the research objectives and to the same approach adopted in the life cycle interpretation phase of the previous case studies, some sensitivity analysis have been performed in order to investigate: (i) the effects on the final results from the application of the new proposed method to different existing water scarcity impact assessment methods, including the one from Pfister et al. (2009) adopted as reference in the previous stage; (ii) the effects on the final results from the adoption of the modified monetary base constant MK (§ 3.3) in the calculation of the new monetary characterization factors.

Results from the monetary assessment of water scarcity impacts of the hospital laundry service under study, performed applying different sets of proposed monetary characterization factors, substantially confirmed that production is the most impactful life cycle stage, with an average incidence to the total overall impact of about 75%.
Considering the life cycle stage of packaging, which is the second most important contribution to the overall impact with an average incidence of about 18%, it was possible to observe that the total contribution to this stage is due to the PE plastic bags used to transport the clean linen to the hospitals. Moreover, a deep analysis of production, which is the most impactful life cycle stage, showed that detergents are responsible for the most part of the impact, particularly considering those based on soap, with an incidence on the total impact of more than 60%.
For this reason, according to the high incidence of these kind of chemical, so it has been also performed an additional sensitivity analysis in order to investigate the potential effects on the results from the change of the datasets adopted to model the detergents.

Sensitivity analysis 1: adoption of alternative water scarcity impact assessment methods
According to the research objectives in this analysis the effects on results from the application of new proposed method for the monetary assessment to different existing water scarcity impact assessment methods have been investigated.
The same methods selected to perform the analysis in the other case studies have been also adopted in this sensitivity analysis, considering thus the criteria described in the chapter 2 (§ 2.2.1.3).
According to the results from the life cycle impact assessment phase of this case study (§ 3.4.11), which was characterized by a not so high variation in the percentage incidence of the final results from the application of the 7 different proposed set of characterization factors, adopting the same

approach of the other case studies also in this sensitivity analysis it was assumed one single set of monetary characterization factors as reference, in particular $MCF_{i\text{ - SET 1}}$.
The next Table 3.50 contains results in absolute terms from the sensitivity analysis according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.50 *Results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are expressed in US$/FU and characterized according to the life cycle stages of the hospital laundry service.*

Method	Packaging	Production	Distribution	End of life	Total
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 1)	0,008	0,047	0,003	0,000	**0,059**
$I_{eco\text{ - Hoekstra based}}$ (MCFi - SET 1)	0,014	0,106	0,007	0,000	**0,127**
$I_{eco\text{ - Berger based}}$ (MCFi - SET 1)	0,010	0,039	0,004	0,000	**0,053**
$I_{eco\text{ - Boulay based}}$ (MCFi - SET 1)	0,842	2,007	0,247	0,001	**3,097**

From the results in Table 3.50 it was possible to observe a high variability in the absolute values obtained from the application of the $MCF_{i\text{ - SET 1}}$ to different existing water scarcity impact assessment methods.
The minimum total value of the monetary assessment of water scarcity impacts of the hospital laundry service resulted to be 0,053 US$/FU when applying the new proposed method to the water scarcity impact assessment method from Berger et al. (2014), while the maximum resulted to be 3,097 US$/FU when applying the method from Boulay et al. (2016).
As already explained in the other case studies, this is due to the different approach adopted by the authors in developing the water scarcity index (WSI) of each method (§ 2.2.1.3), with different resulting range of minimum and maximum values of the characterization factors.
Thus, in order to have a better comprehension about the variability of the incidence on final results when adopting different existing water scarcity impact assessment methods, it was important to analyze impact values in percentage terms, as reported in the next Table 3.51 and Figure 3.27.

Table 3.51 *Results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are expressed in % and characterized according to the life cycle stages of the hospital laundry service.*

Method	Packaging	Production	Distribution	End of life
Ieco - Pfister based (MCFi - SET 1)	14,3	79,7	5,9	0,0
Ieco - Hoekstra based (MCFi - SET 1)	11,3	83,0	5,6	0,0
Ieco - Berger based (MCFi - SET 1)	19,4	73,2	7,3	0,0
Ieco - Boulay based (MCFi - SET 1)	27,2	64,8	8,0	0,0

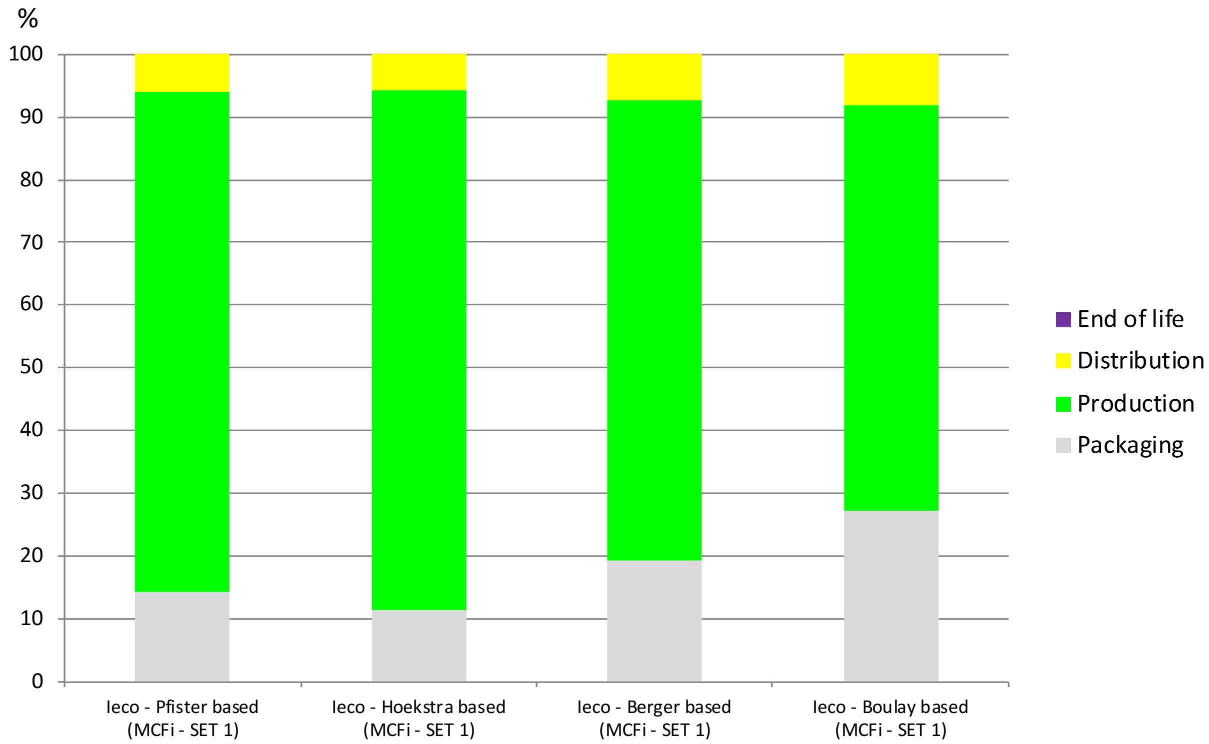

Figure 3.27 *Graphical representation of results from the sensitivity analysis performed applying the new prosed method for the monetary assessment of water scarcity impacts to 4 different existing water scarcity impact assessment methods. Results are represented in % and characterized according to the life cycle stages of the Parma ham P.D.O.*

The analysis of results expressed in percentage terms confirmed that production is the life cycle stage characterized by the higher incidence on the overall impact, followed by packaging which is the second most important contribution. Moreover, as observed in the life cycle impact phase of this case study (§ 3.4.11), when comparing results within the same life cycle stage from the application of the new proposed method to the different existing water scarcity impact assessment methods it was possible to highlight that each method is characterized by a discordant variation of the incidence on the life cycle stage analyzed.
Considering raw materials, which is the most impactful life cycle stage, it was possible to highlight that applying the new proposed method to Boulay et al. (2016) the resulting incidence is equal to 64,8%, while when considering the application to the method of Hoekstra et al. (2012) the incidence raised up to 83%, with a significant increment of about 18%.
This confirm what partially observed in the sensitivity analysis 1 of the other case studies, which is that when performing this kind of assessment, it is highly recommended to be careful in interpreting results, especially when adopting different methods to perform the assessment.

Sensitivity analysis 2: adoption of the modified monetary base constant MK
According to the review of the monetary base constant MK (§ 2.2.1.2) performed in this research work, this sensitivity analysis is aimed to confirm the observations reported in the chapter 2 (§ 2.2.1.2) about the expected very low variation in final results when applying the new proposed monetary characterization factors calculated adopting the modified monetary base constant MK.
Considering the information obtained from the life cycle impact assessment phase of this case study (§ 3.4.11) that highlight a not so high variation of the incidence in percentage terms of the final results from the application of the 7 different proposed set of characterization factors, so it was assumed only one set of monetary characterization factors to perform the assessment, particularly $MCF_{i\text{ - SET }1}$, adopting the same approach of the other case studies.
The next Figure 3.28 reported the results graphically in order to highlight the differences between the application of $MCF_{i\text{ - SET }1}$ to Pfister et al. (2009) method and the application of $MCF_{i\text{ - SET }1*}$, which has been calculated considering the monetary base constant MK modified, to the same water scarcity impact assessment method adopted as reference.
As expected, the final water scarcity impact expressed in monetary terms showed a low variation, with values equal to 0,059 US$/FU and 0,061 US$/FU when applying respectively $MCF_{i\text{ - SET }1}$ and $MCF_{i\text{ - SET }1*}$.

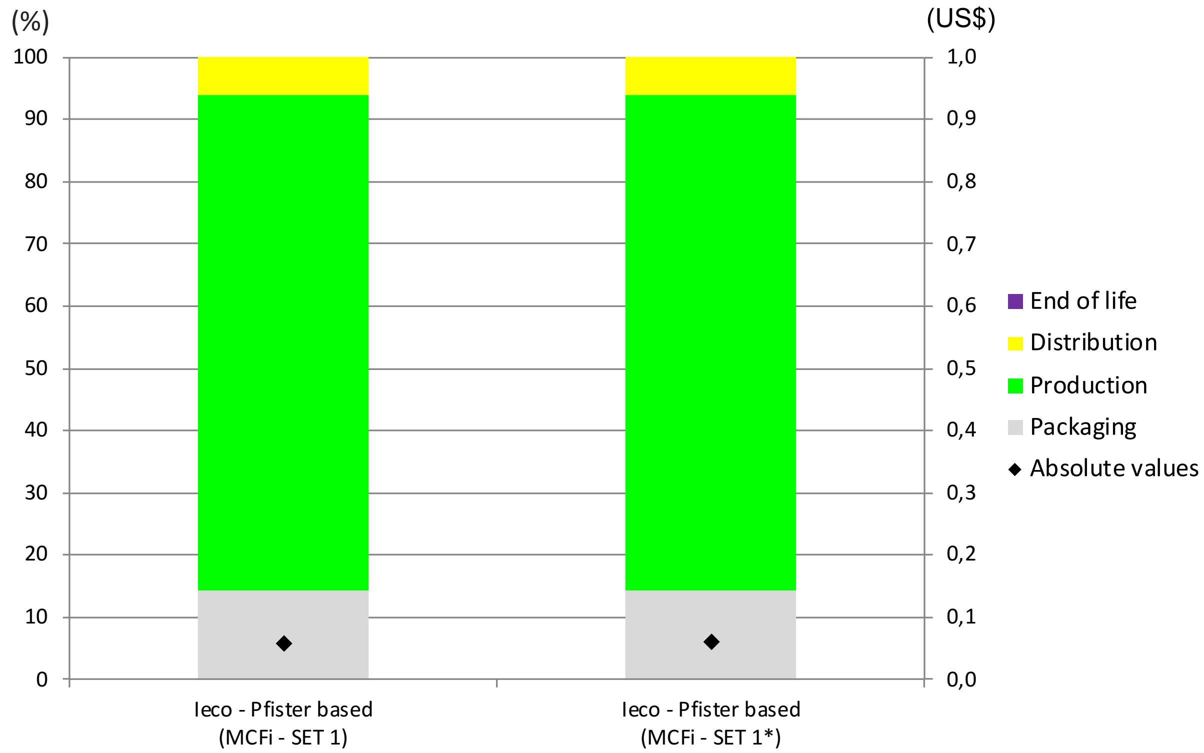

Figure 3.28 *Graphical representation of results from the sensitivity analysis performed to evaluate effects on final results from the application of the monetary base constant MK modified. Results are represented in % and characterized according to the life cycle stages of the hospital laundry service, with black squares in the middle of the columns representing total values in absolute terms.*

Sensitivity analysis 3: change of water related datasets adopted in the farm stage

According to the outcome of the hotspots analysis, which showed a consistent incidence of chemicals within the production life cycle stage on the final impact, particularly because of the detergents, thus this analysis was aimed to assess the effects on final results from the change of the datasets adopted to model this kind of chemicals.

The analysis has been done modifying where possible all the datasets linked to the production of the soaps. This was done in particular changing the reference country for the production of the coconut oil, which is the main element used in the production of the soaps, resulting in a change of all the water flows involved in this process, thus irrigation, water withdrawals and releases.

Starting from the available dataset, characterized by a mix of coconut oil from India (15%), Philippines (20%), Indonesia (35%) and rest of the world (30%), it was assumed that all the production take place all in the Philippines, which is one of the most producer in the world.

According to what explained in the sensitivity analysis 3 of the other case studies, also in this case it is important to clarify that the choice to modify in that way the dataset for the production of the soap is only a hypothesis made in order to assess the potential effects on final results.
Moreover, the analysis has been performed applying the $MCF_{i\text{ - SET 1}}$ to 4 different existing water scarcity impact assessment methods as already done in the other case studies.
In the next Table 3.52 results from the sensitivity analysis are listed in absolute terms according to the functional unit (FU) and characterized for each life cycle stage of the product under study.

Table 3.52 *Results from the sensitivity analysis performed modifying the water related datasets adopted in the modeling of the soaps and applying the new prosed method to 4 different existing water scarcity impact assessment methods. Results are expressed in US$/FU and characterized according to the life cycle stages of the hospital laundry service.*

Method	Packaging	Production	Distribution	End of life	Total
I_{eco} - Pfister based (MCFi - SET 1)	0,008	0,015	0,003	0,000	**0,027**
I_{eco} - Hoekstra based (MCFi - SET 1)	0,014	0,018	0,007	0,000	**0,040**
I_{eco} - Berger based (MCFi - SET 1)	0,010	0,011	0,004	0,000	**0,025**
I_{eco} - Boulay based (MCFi - SET 1)	0,842	0,819	0,247	0,001	**1,909**

As observed in the sensitivity analysis 2, the results show a high variability in the absolute values obtained from the application of the $MCF_{i\text{ - SET 1}}$ to different existing water scarcity impact assessment methods.
The reason is the same already explained in the previously sensitivity analysis, thus the different approach adopted by the authors in developing the water scarcity index (WSI) of each method (§ 2.2.1.3).
Moreover, as observed in the sensitivity analysis 3 of the case studies 2# and #3, the most significant result from this sensitivity analysis is that final impacts are highly reduced if compared to the results from the sensitivity analysis 2 of this case study, with a reduction in the range between -38% and -69% according to the different method considered.

This was because of the changes applied to the soap production, particularly change the irrigation processes linked to countries like India that has a high impact factor, with the country of reference of Philippines that has a lower characterization factor.

Because of the importance to better understand how this variation may affect the hotspots analysis, results have been also reported in percentage terms, according to the next Table 3.53 and Figure 3.29. Results confirmed that production still remains the life cycle stage characterized by the most incidence on the total final impact, as well as that a reduction in the incidence of the life cycle stage itself occurred for all the different methods applied, with a consistent variation in the range between the minimum of about -22%, when applying $MCF_{i\text{ - SET 1}}$ to Boulay et al. (2016) method, and the maximum of about -37%, when applying $MCF_{i\text{ - SET 1}}$ to Hoekstra et al. (2012) method.

Table 3.53 *Results from the sensitivity analysis performed modifying the water related datasets adopted in the modeling of soaps and applying the new prosed method to 4 different existing water scarcity impact assessment methods. Results are expressed in % and characterized according to the life cycle stages of the hospital laundry service.*

Method	Packaging	Production	Distribution	End of life
$I_{eco\text{ - Pfister based}}$ (MCFi - SET 1)	31,6	55,2	13,1	0,1
$I_{eco\text{ - Hoekstra based}}$ (MCFi - SET 1)	36,3	45,6	18,1	0,1
$I_{eco\text{ - Berger based}}$ (MCFi - SET 1)	41,4	42,9	15,6	0,1
$I_{eco\text{ - Boulay based}}$ (MCFi - SET 1)	44,1	42,9	13,0	0,1

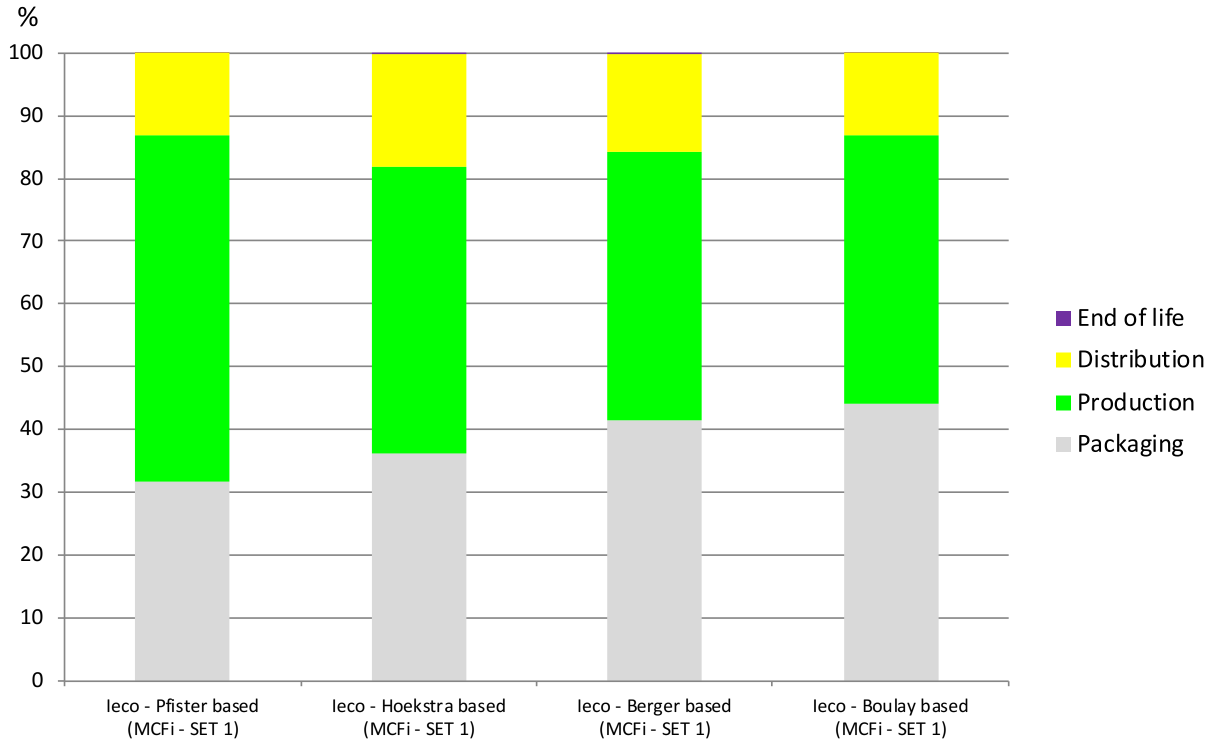

Figure 3.29 *Graphical representation of results from the sensitivity analysis 3. Results are represented in % and characterized according to the life cycle stages of the hospital laundry service.*

4. Discussions

Considering on the one hand the increasing awareness of both public and private companies on the necessity to promote sustainable environmental management practices, particularly focusing on the area of high concerns represented by water scarcity (Vörösmarty et al., 2013; Davidson, 2014; Jiménez et al., 2014), and on the other hand the emerging trend in the scientific community to investigate the possibility to perform assessment of environmental impacts and aspects in monetary terms (Nguyen et al., 2016; Morel et al., 2018) in order to better support organizations and policy makers in the development of consistent sustainable business models and strategies (Risz et al., 2012; ISO/DIS 14008, under development), in this research a new method to assess in monetary terms water scarcity impacts in Life Cycle Assessment (LCA) has been developed and presented.

Focusing on the proposed method, new monetary characterization factors able to convert water scarcity impacts into monetary impacts have been developed, adopting the widely accepted standardized LCA methodology and considering in particular the life cycle impact assessment (LCIA) phase (ISO 14044, 2006) working along the environmental mechanism (also called cause-effect chain) to convert emissions/resources into environmental impacts (Finnveden et al., 2009).

The choice of the LCA theory as basis for the development of the new proposed method is justified by indications from the literature suggesting that this kind of methodology may be considered a valid supporting tool for the implementation of monetary assessments of environmental impacts and aspects (Weidema, 2009; Risz et al., 2012; Le Pochat 2013; Bruel et al., 2016; Nguyen et al., 2016, Morel et al., 2018).

Moreover, the recent publication of the LCA based standard ISO 14046 (2014) that provide a standardize scheme to perform Water Footprint assessment of products, processes and organizations, additionally supported the definition of the new method proposed in this research work aimed to provide monetary assessment of water scarcity impacts.

The development of monetary characterization factors within the new proposed method has started considering the environmental mechanism approach commonly used in the LCA for the development of emission-related impact methods (Van Zelm et al., 2011; Verones et al., 2013; Núñez et al., 2018) that, however, is not fully applied in the assessment of water related impacts since to date available methods are typically based on the analytical approach, with no specific recommendations for the adoption of the mechanistic modeling principle supporting the assessment of water consumption related impacts (Núñez et al., 2018).

For this reason, the proposal of this research has been to develop specific monetary characterization factors, called MCF_i, to perform a monetary assessment converting water scarcity impact into monetary impact (called I_{eco}) in a way similar to the one adopted in LCA where elementary flows are characterized into environmental impacts (called I_{env}).

The approach adopted in the calculation of the new proposed MCF_i allowed to account (i) for environmental water related aspects, introducing new environmental-related dimensionless indexes based on information collected from existing water impact assessment methods at midpoint and endpoint level according to the three common LCA areas of protection (AoP) human health, ecosystem quality, resources (Udo de Haes et al., 1999), and (ii) for economic water related aspects, developing new economic-related dimensionless indexes calculated through the adoption of information provided by existing parameters such as Water Tariff, Gross National Income and Water Productivity.

The combination of these aspects in a unique monetary characterization factor allowed to tackle some significant limits of the available monetary methods within the LCA, the most important of all the absence of a method to specifically assess water scarcity impacts into monetary terms (Pizzol et al., 2015; Weidema et al., 2015).

The choice to develop new economic-related indexes to be used in the calculation of the proposed MCF_i, which have been derived from some existing parameters assumed as proxy for the effects of water consumption, rather than the application of existing common economic valuation techniques is justified by the fact that the latter are highly affected by limitations in their application within the LCA, with no recommended valuation method for water impacts (Weidema et al., 2013). In fact, despite a general need by decision-makers for economic assessment tools in order to evaluate environmental impacts and aspects, many limits still persist in the existing monetary valuation methods within the LCA, such as the impossibility to have monetary characterization factors widely adaptable to any kind of context under study, coherently thus with the LCA approach where emissions and impacts from different processes and activities are aggregated over space and time (Pizzol et al., 2015).

Therefore, the new monetary characterization factors proposed in this work have been developed considering some criteria described in the chapter 2 (§ 2.2) in order to meet the research needs as follows:

- The new MCF_i have to be based on the general principle of the characterization pathway (cause-effect chain), accounting particularly for the effects of water consumption on the three LCA areas of protection human health, ecosystems and resources;
- The development of the MCF_i have to be based on information as much as possible homogeneous, particularly when considering the existing water related impact methods in order to avoid the risk of double counting;
- The new proposed MCF_i have to be applicable in many different contexts, particularly in the different countries worldwide.

Focusing on the new proposed monetary characterization factors, the adoption of the three parameters W_{HH}, W_{ECO} and W_R, introduced in the proposed equation Eq. 2.2 (§ 2.2) representing the weighting factors for each effect of water consumption on the different LCA areas of protection human health, ecosystems and resources has led to the development in this research work of different weighing sets according to the criteria described in chapter 2 (§ 2.2.1.1) with the consequent definition of some sets of monetary characterization factors.

To evaluate the applicability and the effectiveness of the new proposed method, all the different sets of MCF_i (7 in total) have been tested in 4 different real case studies adopting the LCA based framework described in chapter 2 (§ 2.3).

Moreover, through the sensitivity analysis performed in each case study it was possible to investigate the effects on the final results from the application of the new proposed method to different existing water scarcity impact assessment methods, as well as to investigate some key aspects having an effective contribution to the hotspots analysis.

Focusing on the results from the application of the new proposed method to the 4 real case studies (three concerning food products, one concerning a laundry service), some interesting results emerged as follows.

For the three case studies on food products, considering the application of all the new sets of MCF_i to the method proposed by Pfister et al. (2009) that was assumed as reference for the assessment of water scarcity impacts in monetary terms (§ 3.4.2), it was observed that raw materials is the most impactful life cycle stage with a very high incidence, always over the 90% of the overall impact.

Considering the case study 4#, which referred instead to a laundry service, it emerged that production is the most impactful life cycle stage, with an average incidence on the overall impact of about 75%. According to the fact that the variation in the incidence on final results from the application of the different 7 sets of MCF_i resulted to be low, it has been possible to assume one single set of monetary characterization factors (i.e. $MCF_{i\ -\ SET\ 1}$) as reference to perform the sensitivity analysis aimed to investigate how the hotspots may change when adopting different water scarcity impact methods, avoiding the risk to loss some potentially useful information arising from the same application of the other sets of MCF_i.

What emerged was again that raw materials is the life cycle stage characterized by the most incidence on the overall impact in case study #1, #2 and #3, while production is again the most impactful life cycle stage in case study #4, demonstrating a consistency in the capacity of the new proposed method to identify the same hotspots even if applied to different existing water scarcity impact methods.

However, it is important to specify that even if this was true in the case studies #1, #2, #3 characterized by a variation in the way of each method to give a different importance to the life cycle stage raw materials always lower than 7% between the maximum and the minimum final value, in case study #4 the variation was higher, resulting equal to about 18%.

This outcome highlights the importance in the choice of the method to be applied when performing this kind of assessments, with the necessity to pay attention in the interpretation of results since different existing methods for the assessment of water scarcity impacts may lead to different interpretations.

To further analyze this aspect, in order to confirm the goodness of the new proposed method allowing a consistent hotspots analysis useful in supporting company performance improvement, it was observed the behavior of other methods in the identification of the hotspots along the life cycle stages from their application in all the 4 real case studies investigated.

Since no other similar methods exist in the literature to perform the monetary assessment of water scarcity impacts (Weidema et al., 2013; Pizzol et al., 2015; Weidema et al., 2015), so it was decided to adopt the existing water scarcity impact assessment methods, which were already considered in this research work to test the new proposed method, as reference for the comparison.

Results from the application of the different methods to perform water scarcity impact assessment (I_{env}) and the corresponding monetary impact assessment (I_{eco}) through the application of the new prosed method are showed in the next Figure 4.1, 4.2, 4.3, 4.4 respectively for the case studies from #1 to #4.

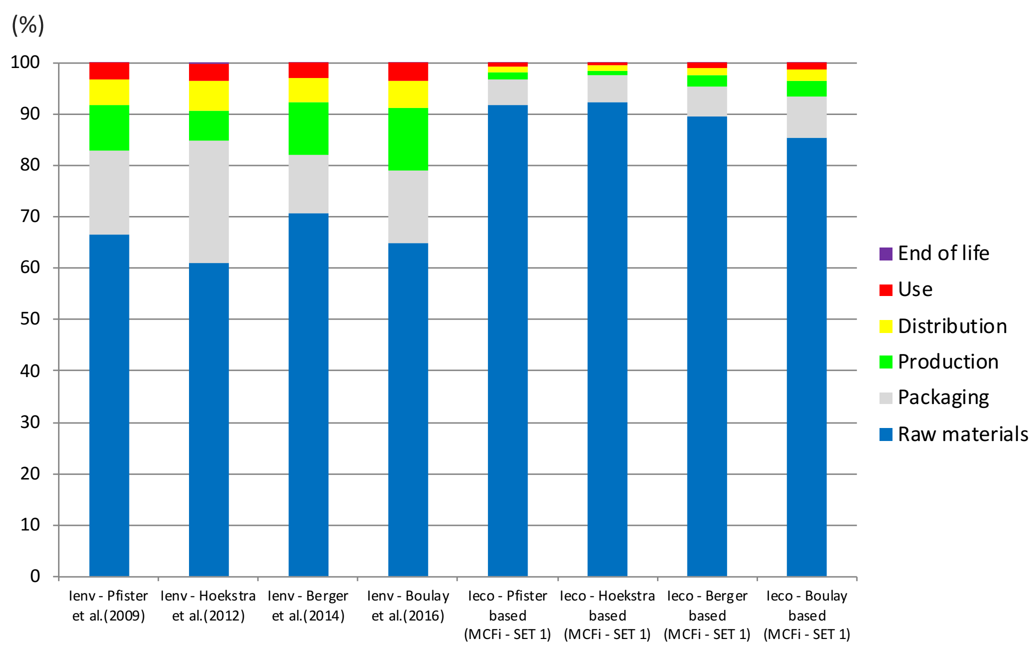

Figure 4.1 *Graphical representation of results from the comparison of the water scarcity impact assessment and the corresponding monetary impact assessment in case study #1. Results are represented in % and characterized according to the life cycle stages of the jar packaged ice cream.*

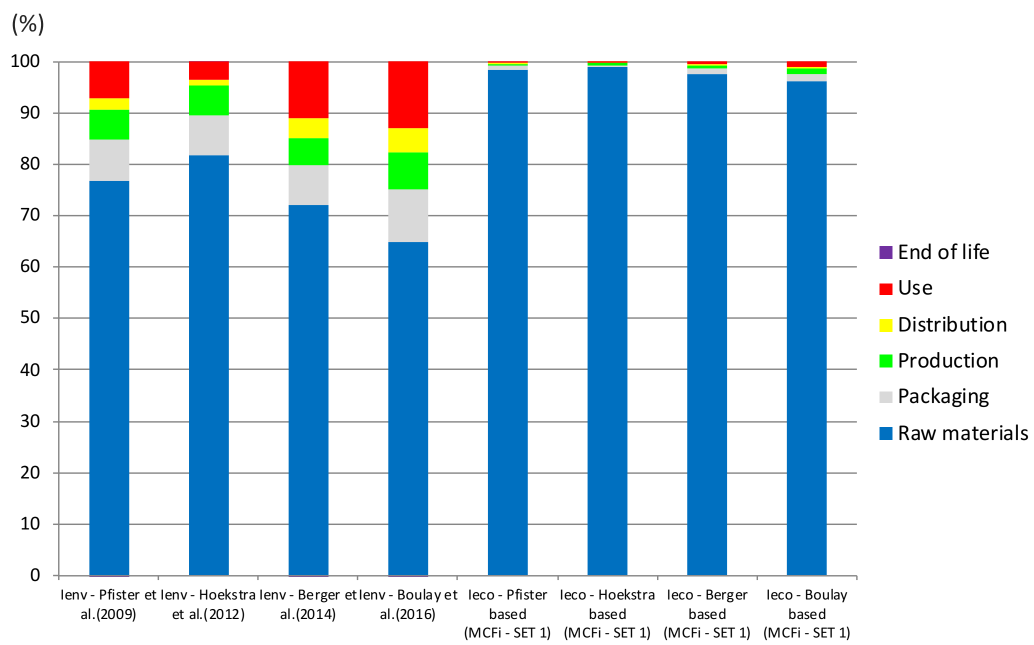

Figure 4.2 *Graphical representation of results from the comparison of the water scarcity impact assessment and the corresponding monetary impact assessment in case study #2. Results are represented in % and characterized according to the life cycle stages of the fresh mozzarella cheese.*

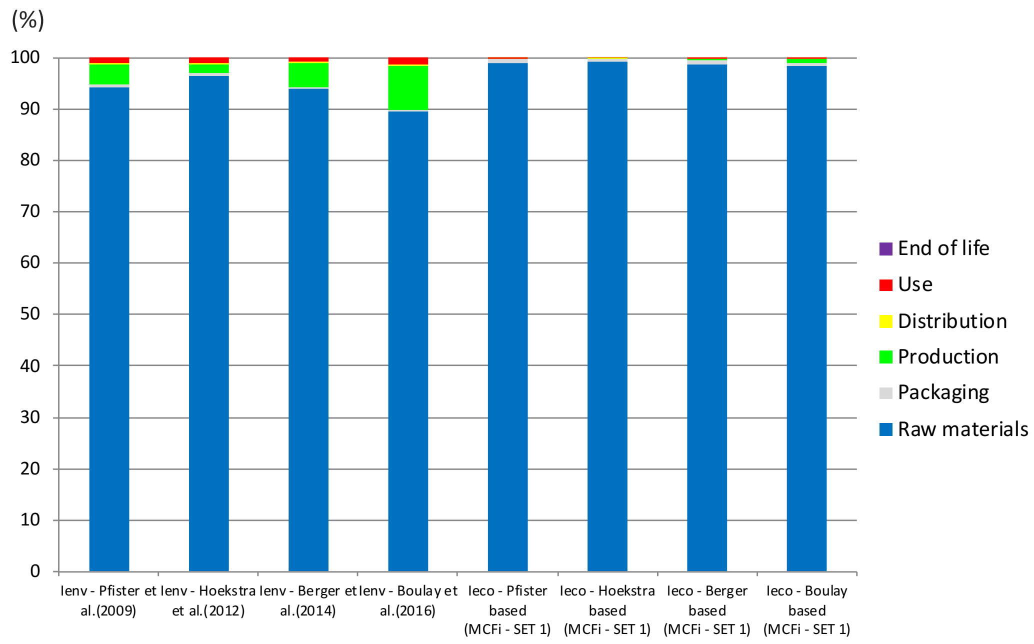

Figure 4.3 *Graphical representation of results from the comparison of the water scarcity impact assessment and the corresponding monetary impact assessment in case study #3. Results are represented in % and characterized according to the life cycle stages of the Parma ham P.D.O.*

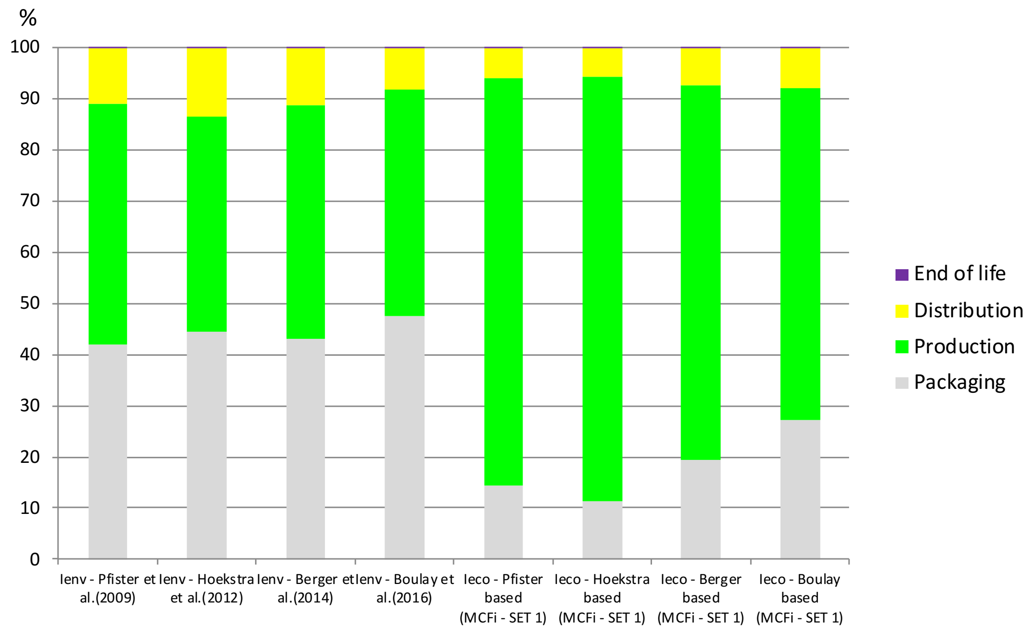

Figure 4.4 *Graphical representation of results from the comparison of the water scarcity impact assessment and the corresponding monetary impact assessment in case study #4. Results are represented in % and characterized according to the life cycle stages of the hospital laundry service.*

From the above results an interesting aspect emerged, in particular the capacity of the new proposed method to provide a clear and well defined indication about the hotspots along the whole supply chain.
Results achieved in case study #1, #2, #3 highlighted that raw material is the life cycle stage responsible of the most part of the total impact, both in environmental terms (water scarcity impact assessment) and in economic terms (monetary impact assessment) for all the applied methods.
However, this was clearer when considering the new proposed method to perform monetary impact assessment rather than when considering the existing water scarcity impact assessment methods, since the hotspots analysis showed a significant increase in the incidence of raw materials up to about 90% and more, intensifying thus the importance of this life cycle stage when compared to the others.
This effect clearly emerged from the case study #4, where it was possible to observe a change in the hotspots arising from the application of the new proposed monetary impact assessment method, resulting in a switch of the most part of the total impact to the production stage if compared to the hotspots resulting from the application of the existing water scarcity impact assessment methods. The latter, indeed, resulted to share the most part of the total impact (about the 90%) more or less equally between packaging and production.
The adoption of the new proposed method as screening tool in the hotspot analysis thus may be useful for companies, particularly in the definition of sustainable water management strategies because of the possibility to focus on a specific and clearly identified hotspot, allowing to allocate in an efficient way financial and human resources.
Another interesting aspect emerged from the comparison of the hotspots identified by the application of the different impact assessment methods was a general trend in the reduction of the variability between the minimum and the maximum incidence of impacts in monetary terms if compared to impacts in environmental terms.
This was clearly evident in the case studies #1, #2 and #3 where, focusing on the variability for the life cycle stage of raw materials representing the most impactful one along the whole supply chain of all the three case studies, it was possible to observe a decrease in the variability of the impact of this life cycle stage from 9,6% to 7,1% for the case study #1, from 16,9% to 2,8% for case study #2, from 6,9% to 0,8% for the case study #3.
These findings allowed demonstrating that the adoption of the new proposed method, beyond the possibility to perform a monetary assessment of water scarcity impacts like no other method before, allowed to have final impacts characterized by a lower variability in their incidence along the whole

life cycle, resulting therefore in a higher accuracy of the hotspots analysis if compared to the one from the adoption of the different existing water scarcity impact assessment methods.

Results from the hotspots analysis allowed to better focus on specific issues to set effective water management strategies by the companies. Thus, in order to evaluate the possibility to reduce the total impacts, a sensitivity analysis (number 3 in each case study) has been performed investigating the potential effects on the results from the change of some key parameters related to the hotspots, the latter identified within the most impactful life cycle stage of each product system under study.

In case study #1, #2 and #3 what emerged was a consistent incidence on the total impact from the life cycle stage raw materials. This was because the farm stage modeled in all the three product systems, which is needed to provide some fundamental raw materials to be used in the final product, such as butter, skimmed powder milk and cream in case study #1, milk in case study #2 and fresh pork meat in case study #3.

More in detail, all these raw materials have one thing in common, which is the high water consumption during the farm phase, especially in relation to the production of the animal feeds. For this reason, the sensitivity analysis has been performed focusing on this key aspect, modifying the country of origin of the above listed raw materials and, in particular, assuming Italy as country of reference for all the processes of irrigation, water withdrawals and releases in water bodies and air involved in the cultivation of the animal feeds.

Observing the results from the adoption of these alternative solutions emerged the possibility to reduce the total impact assessed through the new proposed method, particularly by about 7% on average in case study #1, by more than 70% in case study #2 and by more than 80% in case study #3.

In case study #4, instead, it was observed that production is the life cycle stage characterized by the most part of the total impact. This was mainly due to the presence of detergents, particularly soaps. Thus, the sensitivity analysis in this case study has been performed modifying the country of origin of detergents, specifically modifying the reference country for the production of the coconut oil that is the main element used in the production of the soap, assuming its production totally in the Philippines and changing all the water flows involved in this process such as irrigation, water withdrawals and releases.

What emerged from the results was the possibility to have a benefit from the adoption of this alternative solution, with a total monetary impact reduction by a value ranging between -38% and -69% according to the different water scarcity impact method considered.

Beyond the results highlighted in the sensitivity analysis previously described, with benefits achievable in all the 4 real case studies when adopting alternative improvement solutions in relation to the identified hotspots, another significant result emerged from the comparison between the results of the sensitivity analysis applying both the new proposed monetary impact method according to the 4 existing water scarcity impact assessment methods adopted as reference (§ 2.2.1.3), and the 4 existing water scarcity impact assessment methods themselves.

In the next Table 4.1, 4.2, 4.3 and 4.4 results in absolute terms from the comparison are reported for each case study respectively from #1 to #4, highlighting also the variation in percentage terms achievable in each case study implementing the alternative solutions previously described, according to the different impact methods.

Table 4.1 *Comparison of results from the sensitivity analysis 3 of case study #1 adopting 4 existing methods to perform water scarcity impact assessment (I_{env}) and the corresponding monetary impact assessment (I_{eco}) from the application of the new prosed method. Results are expressed in m^3eq/FU for water scarcity impacts and US$/FU for corresponding monetary impacts.*

Method	Unit	Business as usual	Alternative	Variation (%)
I_{env} - Pfister et al. (2009)	m^3eq/FU	0,016	0,016	-0,5%
I_{env} - Hoekstra et al. (2012)	m^3eq/FU	0,022	0,022	-1,5%
I_{env} - Berger et al. (2014)	m^3eq/FU	0,027	0,027	0,8%
I_{env} - Boulay et al. (2016)	m^3eq/FU	1,565	1,595	1,9%
I_{eco} - Pfister based (MCFi - SET 1)	US$/FU	0,826	0,764	-7,5%
I_{eco} - Hoekstra based (MCFi - SET 1)	US$/FU	1,925	1,805	-6,2%
I_{eco} - Berger based (MCFi - SET 1)	US$/FU	0,724	0,673	-7,0%
I_{eco} - Boulay based (MCFi - SET 1)	US$/FU	35,261	32,878	-6,8%

Table 4.2 *Comparison of results from the sensitivity analysis 3 of case study #2 adopting 4 existing methods to perform water scarcity impact assessment (I_{env}) and the corresponding monetary impact assessment (I_{eco}) from the application of the new prosed method. Results are expressed in m^3eq/FU for water scarcity impacts and US$/FU for corresponding monetary impacts.*

Method	Unit	Business as usual	Alternative	Variation (%)
I_{env} - Pfister et al. (2009)	m^3eq/FU	0,060	0,049	-18%
I_{env} - Hoekstra et al. (2012)	m^3eq/FU	0,120	0,069	-42%
I_{env} - Berger et al. (2014)	m^3eq/FU	0,076	0,081	7%
I_{env} - Boulay et al. (2016)	m^3eq/FU	4,284	5,505	29%
I_{eco} - Pfister based (MCFi - SET 1)	US$/FU	9,480	2,230	-76%
I_{eco} - Hoekstra based (MCFi - SET 1)	US$/FU	23,575	5,293	-78%
I_{eco} - Berger based (MCFi - SET 1)	US$/FU	7,544	1,974	-74%
I_{eco} - Boulay based (MCFi - SET 1)	US$/FU	322,092	98,127	-70%

Table 4.3 *Comparison of results from the sensitivity analysis 3 of case study #3 adopting 4 existing methods to perform water scarcity impact assessment (I_{env}) and the corresponding monetary impact assessment (I_{eco}) from the application of the new prosed method. Results are expressed in m^3eq/FU for water scarcity impacts and US$/FU for corresponding monetary impacts.*

Method	Unit	Business as usual	Alternative	Variation (%)
I_{env} - Pfister et al. (2009)	m^3eq/FU	0,077	0,088	15%
I_{env} - Hoekstra et al. (2012)	m^3eq/FU	0,132	0,084	-36%
I_{env} - Berger et al. (2014)	m^3eq/FU	0,132	0,171	30%
I_{env} - Boulay et al. (2016)	m^3eq/FU	5,302	11,750	122%
I_{eco} - Pfister based (MCFi - SET 1)	US$/FU	7,957	1,171	-85%
I_{eco} - Hoekstra based (MCFi - SET 1)	US$/FU	19,457	2,153	-89%
I_{eco} - Berger based (MCFi - SET 1)	US$/FU	6,603	1,447	-78%
I_{eco} - Boulay based (MCFi - SET 1)	US$/FU	282,685	92,046	-67%

Table 4.4 *Comparison of results from the sensitivity analysis 3 of case study #4 adopting 4 existing methods to perform water scarcity impact assessment (I_{env}) and the corresponding monetary impact assessment (I_{eco}) from the application of the new prosed method. Results are expressed in m^3eq/FU for water scarcity impacts and US$/FU for corresponding monetary impacts.*

Method	Unit	Business as usual	Alternative	Variation (%)
I_{env} - Pfister et al. (2009)	m^3eq/FU	0,002	0,002	0%
I_{env} - Hoekstra et al. (2012)	m^3eq/FU	0,004	0,003	-14%
I_{env} - Berger et al. (2014)	m^3eq/FU	0,003	0,003	-7%
I_{env} - Boulay et al. (2016)	m^3eq/FU	0,208	0,201	-4%
I_{eco} - Pfister based (MCFi - SET 1)	US$/FU	0,059	0,027	-55%
I_{eco} - Hoekstra based (MCFi - SET 1)	US$/FU	0,127	0,040	-69%
I_{eco} - Berger based (MCFi - SET 1)	US$/FU	0,053	0,025	-53%
I_{eco} - Boulay based (MCFi - SET 1)	US$/FU	3,097	1,909	-38%

From the results listed in the previous tables what emerged is a clear discrepancy in the capacity to clearly identify the potential benefits achievable when adopting alternative solutions between the new method proposed in this research work and the existing water scarcity impact assessment methods adopted as reference for the comparison.

The latter, in fact, totally disagreed to each other in the identification of the final impact variation potentially achievable from the adoption of solutions alternative to the business as usual scenario in each case study.

Moreover, observing the variations in percentage terms, it was not possible to identify a general common rule to explain the behavior of the water scarcity impact assessment methods, since each of them provides different results in terms of positive/negative variations among all the 4 case studies. The variation arising from the application of the method from Pfister et al. (2009), for example, is mostly null in case study #1 and #4, while it is negative (-18%) and positive (+15%) respectively in case study #2 and #3. Methods from Berger et al. (2014) and from Boulay et al. (2016) were also not able to give coherent information about the variations achievable in the different case studies, with very different positive and negative percentage values.

Only the method from Hoekstra et al. (2012) showed a trend more or less coherent among the different case studies, giving always a negative variation, thus a benefit, in all the case studies.

Considering the new proposed method, instead, it has been possible to observe its effectiveness and accuracy in measuring the potential benefit achievable from the adoption of alternative solutions in relation to the hotspots of all the case studies, as demonstrated by the values in the previous tables.

Results from the application of the new proposed method for the monetary assessment of water scarcity impacts, in fact, clearly established that the adoption of the alternative solutions may lead to potential benefits in terms of total impact reduction in all the case studies, highlighting also a less variability among the minimum and the maximum value of the final variation resulting from the application of the new proposed method to the 4 existing water scarcity impact assessment methods adopted as reference.

This may help companies to reduce uncertainties in the decision-making process, identifying the best alternative solutions to be implemented ensuring a high level of effectiveness.

Despite the impossibility to make a comparison with other similar existing monetary valuation methods aimed to specifically address water scarcity related impacts, the new proposed LCA based method for the assessment of water scarcity impacts in monetary terms resulted to be useful when compared to other existing methods aimed to perform environmental evaluation about the water scarcity impacts. In particular emerged a higher accuracy in the capacity of the new proposed model to provide consistent hotspots analysis and, moreover, to clearly identify the potential benefits achievable from the adoption of alternative solutions related to the identified hotspots.

5. Conclusions

Population growth and increasing depletion of natural resources are only some example of the phenomena that have progressively affected the health status of the planet in the last decades, as demonstrated by the constant degradation of ecosystems and loss of biodiversity (Millennium Ecosystem Assessment, 2005; Global Footprint Network, 2016; WWF, 2016).

In order to tackle this negative trend some important initiatives have been undertaken by the scientific community at the international level, aimed to promote a sustainable development for the next years (UN DESA, 2014; Steffen et al., 2015; United Nation, 2015).

Within this context, the management of scarce resources like water has been recognized as a key issue to consider in order to contrast the adverse effects from the increasing competition between water users, with an expected situation for the next years where more than a half of the world population will live in areas affected by water scarcity (Vörösmarty et al., 2013; Davidson, 2014; Jiménez et al., 2014).

Water crisis is clearly becoming a top global risk (Bates et al., 2008; Addams et al., 2009; UNEP, 2012; World Economic Forum, 2016), representing a threat not only under the environmental point of view but also for economic growth and the competitiveness of companies, the latter highly exposed to water risks mainly related to physical, regulatory, and reputational aspects (Morrison et al., 2009).

Companies are therefore asked to elaborate policies and strategies aimed at a more sustainable management of water resources, identifying operative targets and strategic actions in a consistent way (Koh et al., 2012; Nielsen, 2017).

This is possible adopting environmental management tools developed in the last decades by the scientific community to support decision-makers and companies in promoting the sustainable development, such as the Life Cycle Assessment methodology that to date is one of the most diffused tool to perform evaluation on potential environmental impacts of a product/process/service along all the whole life cycle (ISO 14040, 2006), and the LCA based tool of Water Footprint (ISO 14046, 2014) developed to assess specifically water related impacts.

The needs for economic valuation of environmental aspects like water resource, in order to support companies in the management of the related risks, is also an emerging challenge, with the possibility to include environmental externalities within the companies' policies that became recently more and more popular (Nguyen et al., 2016).

This led the scientific community to investigate the possibility to perform assessment of environmental impacts and aspects in monetary terms, in order to make LCA results more comprehensible by stakeholder (Risz et al., 2012; Bruel et al., 2016; Nguyen et al., 2016). Monetization of environmental impacts is recognized as an effective practice to better support companies and policy makers in the development of sustainable strategies (ISO/DIS 14008, under publication).

However, the to date available LCA methods almost fail in providing consistent economic information about environmental impacts (Pizzol et al., 2015), mainly because of many limits still persist in the monetary valuation methods within the LCA, with existing methods characterized by low flexibility, low level of abstraction, high degree of subjectivity and high variability in scale and geographical boundaries (Risz et al., 2012; Tekie et al., 2013; Pizzol et al., 2015).

Furthermore, among all the limits the most important one is represented by the total absence of consistent frameworks for the specific monetary assessment of water scarcity related impacts within the LCA (Pizzol et al., 2015, Weidema et al., 2015).

According to the above described framework, the present research work was mainly aimed to try to fill the existent gaps in performing monetary assessment of water scarcity related impacts, developing a new method able to provide information useful for companies and decision makers to better understand LCA outputs in economic terms and to support them in developing more environmentally sustainable strategies. The specific objectives of the research work have been:

- The development of a new method to assess in monetary terms water scarcity impacts in Life Cycle Assessment (LCA), defining new monetary characterization factors (MCF_i) able to convert water scarcity impacts into monetary impacts.
- Testing the new proposed method through its application in 4 different real case studies in the national context investigating its capacity to provide consistent hotspots analysis.

The first part of the research work focused on the definition of new specific monetary characterization factors (called MCF_i), developed adopting a combination of (i) principles from the LCA standardize methodology, in line with literature indications that suggest the adoption of this kind of tool because of its consistency in the implementation of monetary assessments of environmental impacts and aspects (Weidema, 2009; Risz et al., 2012; Le Pochat 2013; Bruel et al., 2016; Nguyen et al., 2016, Morel et al., 2018), particularly focusing on information given by existing water impact assessment methods at midpoint and endpoint level according to the three common LCA areas of protection (AoP) human health, ecosystems, resources (Udo de Haes et al., 1999), and (ii) economic water related aspects considering information from existing parameters such as Water Tariff, Gross National Income and Water Productivity.

The combination of these two strategic dimensions (environmental and economic) led to the definition of the new monetary characterization factors proposed in this research work to be used in order to perform a monetary assessment converting environmental impacts, particularly those of water scarcity, into monetary impacts.

A validation of the new proposed method has been also performed through sensitivity analysis at different levels. Some sets of weighting factors to be applied in the proposed equation for the calculation of the new MCF_i (§ 2.2) have been developed considering two existing commonly used approaches, equal weighting and distance-to-target (Castellani et al., 2016; Sala et al., 2018). This led to the definition of 7 different weighing sets and, consequently, to the definition of 7 different sets of new monetary characterization factors to be applied.

In the second part of the research work, thus, in order to evaluate the applicability and the effectiveness of the new proposed method, the different sets of MCF_i have been tested in 4 different real case studies adopting an LCA based framework (§ 2.3).

The case studies, which have been selected in the national context according to the possibility to investigate production systems characterized by critical water related processes, concerned in particular: (i) a jar packaged ice cream; (ii) a fresh mozzarella cheese; (iii) a Parma ham P.D.O.; (iv) a hospital laundry service.

Applicability of the new developed sets of monetary characterization factors has been confirmed in all the case studies, demonstrating also a low variability in the incidence of final impacts among all the life cycle stages from the application of the 7 different sets of MCF_i.

Results from the adoption of the new proposed method allowed to highlight that raw materials is the most impactful life cycle stage in case study #1, #2 and #3 because of the high dependence from the farm stage necessary to provide the ingredients to be used in the food products analyzed, while production is the most impactful life cycle stage in case study 4#, due to the presence of detergents, particularly soaps.

These findings have been also confirmed by the sensitivity analysis, performed in each case study, aimed to evaluate the effects on the final results from the application of the new proposed method to different existing water scarcity impact assessment methods, particularly those from Pfister et al. (2009), Hoekstra et al. (2012), Berger et al. (2014) and Boulay et al. (2016).

The outcomes of the analysis confirmed again that raw materials is the life cycle stage characterized by the most incidence on the total impact in case study #1, #2 and #3, whereas production is again the most impactful life cycle stage in case study #4, demonstrating thus the consistency of the new proposed method in the identification of the same hotspots even if applied to different existing water scarcity impact assessment methods.

The goodness of the new proposed method in providing consistent hotspots analysis has been furthermore confirmed by a comparison between results from the application in each case study of 4 different existing methods to perform environmental assessment (water scarcity impact), particularly those already adopted in the previously described sensitivity analysis, and the new method proposed to perform monetary impact assessment (monetization of water scarcity impacts).

Results from the comparison highlighted that the new proposed method allows a better definition of the hotspots along the whole supply chain than the existing water scarcity impact assessment methods. In fact, in case study #1, #2 and #3 it was observed an increase in the incidence of the most impactful life cycle stage, i.e. raw materials, when applying the new proposed method to perform monetary impact assessment rather than the existing water scarcity impact assessment methods, intensifying thus the importance of this life cycle stage when compared to the others.

This clearly emerged from the case study #4, where the hotspots, identified by the existing water scarcity impact assessment methods equally shared between the life cycle stage of packaging and production, are subjected to a total switch towards the production life cycle stage when adopting the new proposed method.

Moreover, results from the comparison highlighted a general trend in the reduction of the variability between the minimum and the maximum incidence of impacts in monetary terms if compared to impacts in environmental terms, demonstrating that the adoption of the new proposed method lead to a hotspots analysis characterized by a higher accuracy if compared to the one from the adoption of the different existing water scarcity impact assessment methods.

The possibility given by the new proposed method to clearly identify hotspots along the whole supply chain represents a valid opportunity for the companies in defining strategies for the reduction of water related impacts, in this case assessed in monetary terms.

Sensitivity analysis performed on the basis of the key aspects identified in the hotspots analysis allowed the companies to better evaluate the effects from the adoption of some alternative solutions for the reduction of the final impacts.

According to the raw materials butter, skimmed powder milk and cream in case study #1, milk in case study #2 and fresh pork meat in case study #3 that are responsible for high water consumption, particularly in relation to the production of the animal feeds, the variation of their country of origin assuming Italy as reference for all the processes of irrigation, water withdrawals and releases in water bodies and air led to the possibility to reduce the total impact assessed through the new proposed method by about 7% on average in case study #1, by more than 70% in case study #2 and by more than 80% in case study #3.

Considering the case study #4, instead, the variation of the reference country for the production of the coconut oil that is the main element used in the production of the soap, assuming its production totally in the Philippines changing all the water flows involved in this process such as irrigation, water withdrawals and releases, allowed to a potential reduction ranging between -38% and -69%.

The most interesting aspect, however, clearly emerged from the comparison of these results with those obtained when performing the same sensitivity analysis through the application of the 4 existing water scarcity impact assessment methods already adopted as reference in this research work.

In fact, results from the comparison showed a net difference in the capacity to clearly establish the variation of final impact achievable when adopting solutions alternative to the business as usual scenario.

The existing water scarcity impact assessment methods adopted as reference totally disagreed to each other, providing very discordant variations on final results among all the 4 case studies. For example, the method from Pfister et al. (2009) showed a variation of the final impact close to zero in case study #1 and #4, while it showed negative (-18%) and positive (+15%) variations respectively in case study #2 and #3. Results from Berger et al. (2014) and Boulay et al. (2016) were also incoherent in terms of final variations achievable in the different case studies, highlighting very different positive and negative percentage values. The method from Hoekstra et al. (2012) was the only one showed a trend more or less coherent among the different case studies, leading always to a negative variation, thus a benefit, in all the case studies.

The new proposed method, instead, revealed its effectiveness and accuracy since it allowed to clearly establish that when adopting solutions alternative to the business as usual scenario it is possible to have potential benefits in terms of total impact reduction in all the case studies investigated, showing also a less variability among the minimum and the maximum variations of final results.

The possibility to adopt the new proposed method as screening tool to clearly identify the potential benefits achievable from the adoption of alternative solutions related to the hotspots may be strategic for the reduction of uncertainties within the decision-making process, supporting thus companies in the proper definition of the best alternative solutions to be implemented in order to ensure a high level of effectiveness in reduction of water related impacts.

However, results of this research work open to new research perspectives, with some aspects that could be further investigated in order to increase the accuracy and the completeness of the new proposed method.

First, since the latter has been developed to be applied only to assess water scarcity impacts, considering thus water resource in quantitative terms, the possibility to account also for qualitative aspects should be investigated to improve the final accuracy of the monetary assessment.

Second, despite no general consensus seems to be achievable in the scientific community about the best weighting solution to be used when performing this kind of analysis, in any case it could be useful as a further validation to apply also other weighting schemes (e.g. panel weighting).

Third, since the new proposed method has been applied to 4 different existing water scarcity impact assessment methods adopted as reference in this research work, thus the adoption of other methods should be investigated to assess the effects on final results.

Finally, it would be interesting to investigate different productive contexts (e.g. packaging, wastes, etc.) additional to those considered in this research work in order to confirm the capacity of the new proposed method to generate consistent results and accurate hotspots analysis.

Concluding, even if monetary assessment of environmental impacts within the LCA still remains an approach characterized by a high level of complexity due to a huge amount of data required in the development of consistent characterization factors, with a certain degree of subjectivity that necessarily affects the final results, however this is an emergent topic that is currently being discussed at the international level (Risz et al., 2012; Bruel et al., 2016; Nguyen et al., 2016; ISO/DIS 14008, under publication) mainly because of the possibility to develop tools in order to support companies and decision makers in the definition of more sustainable practices to be implemented within their policies allowing a better resources management, including water, along the whole supply chain.

Annexes

ANNEX A. Economic-related parameter values

Table A.1 *GNI, Water Productivity and Water Supply Tariff, according to each different investigated country, adopted in the development of the dimensionless economic-related indexes.*

Country	GNI[1] (US$/per capita)	Water Productivity[2] (US$/m^3)	Water Supply Tariff[3] (US$/m^3)
Albania	4.250	9,74	0,31
Algeria	4.270	21,71	0,13
Argentina	11.960	11,74	0,38
Armenia	3.760	3,78	0,27
Australia	54.420	64,61	2,70
Austria	45.230	116,63	2,81
Azerbaijan	4.760	4,88	0,21
Bangladesh	1.330	4,10	0,18
Belarus	5.600	41,71	0,14
Belgium	41.860	83,38	2,38
Benin	820	65,97	0,81
Bolivia	3.070	11,72	0,35
Bosnia and Herzegovina	4.880	54,16	0,75
Botswana	6.610	84,67	0,73
Brazil	8.840	32,38	0,89
Bulgaria	7.470	9,64	1,02
Burkina Faso	640	13,33	0,78
Cambodia	1.140	6,80	0,18
Cameroon	1.200	29,77	0,85
Canada	43.660	45,87	1,83
Chile	13.530	7,31	1,20
China	8.260	13,71	0,33
Colombia	6.320	29,61	0,68
Costa Rica	10.840	18,38	0,71
Croatia	12.110	90,40	1,83
Cyprus	23.680	90,08	1,82
Czech Republic	17.570	129,77	1,88
Denmark	56.730	514,76	3,60
Dominican Republic	6.390	9,01	0,52
Ecuador	5.820	8,72	0,57
Estonia	17.750	13,26	1,52
Finland	44.730	37,65	1,80
France	38.950	90,91	2,40

Country	GNI[1] (US$/per capita)	Water Productivity[2] (US$/m^3)	Water Supply Tariff[3] (US$/m^3)
Gabon	7.210	128,21	0,79
Germany	43.660	109,99	2,79
Ghana	1.380	45,57	1,09
Greece	18.960	25,43	1,20
Guatemala	3.790	14,41	0,32
Honduras	2.150	11,29	0,36
Hungary	12.570	27,43	1,17
Iceland	56.990	4,84	2,36
India	1.680	2,80	0,08
Indonesia	3.400	8,32	0,24
Iran	6.530	4,97	0,10
Israel	36.190	138,56	1,41
Italy	31.590	38,02	1,59
Jamaica	4.660	16,62	1,76
Japan	38.000	72,61	0,93
Jordan	3.920	31,35	0,69
Kazakhstan	8.710	8,71	0,21
Kenya	1.380	15,38	0,60
Kuwait	41.680	150,19	0,52
Lebanon	7.680	31,06	0,18
Liberia	370	12,64	0,38
Lithuania	14.770	69,35	1,24
Macedonia	4.980	18,54	0,49
Madagascar	400	0,58	0,32
Malawi	320	6,09	0,49
Malaysia	9.850	28,07	0,15
Mali	750	2,31	0,65
Mexico	9.040	14,68	0,52
Morocco	2.850	10,39	0,67
Mozambique	480	15,18	0,44
Namibia	4.620	48,65	2,23
Nepal	730	2,02	1,22
Netherlands	46.310	79,44	2,63
New Zealand	39.070	31,22	1,58
Niger	370	7,50	5,60
Norway	82.330	151,23	2,08
Oman	18.080	51,37	1,14
Panama	12.140	38,51	0,43
Paraguay	4.070	10,22	0,41
Peru	5.950	13,21	0,36
Philippines	3.580	3,08	0,58
Poland	12.680	46,65	1,29
Portugal	19.850	24,48	1,63
Romania	9.470	28,41	0,97
Russia	9.720	27,53	0,44
Rwanda	700	50,88	0,47
Senegal	950	6,68	0,60

Country	GNI[1] (US$/per capita)	Water Productivity[2] (US$/m³)	Water Supply Tariff[3] (US$/m³)
Slovakia	16.810	174,12	1,75
Slovenia	21.660	41,49	1,19
South Africa	5.480	26,65	1,07
Spain	27.520	36,70	1,28
Sudan	2.140	2,57	0,62
Suriname	7.070	7,96	0,28
Swaziland	2.830	5,08	0,84
Sweden	54.630	193,14	2,17
Switzerland	81.240	309,57	2,03
Tajikistan	1.110	0,65	0,05
Tanzania	900	7,89	0,48
Thailand	5.640	6,67	0,50
Tunisia	3.690	14,38	0,20
Turkey	11.180	24,41	0,81
Turkmenistan	6.670	1,25	-
Uganda	660	39,25	0,86
UK, England and Wales	42.390	319,54	1,99
Ukraine	2.310	9,05	0,32
United States	56.180	33,31	1,68
Uruguay	15.230	12,95	0,85
Uzbekistan	2.220	0,96	0,04
Vietnam	2.050	1,77	0,33
Zambia	1.300	16,11	0,50
Zimbabwe	940	4,03	1,13

1. Goss national income per capita (The World Bank, 2017a).
2. Water productivity in Gross Domestic Production (GDP) per cubic meter of total freshwater withdrawal (The World Bank, 2017b)
3. Average water supply tariff per county weighted by population served, based on a consumption of 15m³ per month. (IBNET, 2017).

ANNEX B. Datasets adopted for the definition of the weighting factors

Table B.1 *Global Health Data Exchange database. Indicator 3.9.2: Age-standardized death rate attributable to unsafe water, sanitation, and hygiene (WaSH) per 100.000 people (GHDx, 2017).*

Country	Year 2005	Year 2030
Afghanistan	44,4	12,6
Albania	0,7	0,2
Algeria	3,6	1,2
Andorra	0,2	0,2
Angola	233,7	53,1
Antigua and Barbuda	3,5	2,0
Argentina	2,1	0,9
Armenia	1,8	0,2
Australia	0,2	0,3
Austria	0,1	0,1
Azerbaijan	6,8	0,8
Bahrain	2,9	1,4
Bangladesh	74,4	14,8
Barbados	3,0	2,1
Belarus	0,4	0,1
Belgium	0,5	0,6
Belize	9,2	5,2
Benin	150,3	87,7
Bhutan	33,7	6,1
Bolivia	20,9	3,0
Bosnia and Herzegovina	0,3	0,1
Botswana	76,6	25,5
Brazil	8,1	1,9
Brunei	0,7	0,7
Bulgaria	0,5	0,2
Burkina Faso	176,7	91,1
Burundi	234,3	130,3
Cambodia	54,3	7,3
Cameroon	135,4	55,2
Canada	0,5	0,5
Cape Verde	25,0	9,5
Central African Republic	230,6	215,4
Chad	209,2	119,6
Chile	1,3	0,6
China	2,4	0,2
Colombia	4,1	0,8
Comoros	162,3	81,4
Congo	163,9	100,7
Costa Rica	2,3	0,8
Cote d'Ivoire	108,8	66,7
Croatia	0,3	0,1
Cuba	3,5	1,8

Country	Year 2005	Year 2030
Cyprus	0,4	0,2
Czech Republic	0,3	1,0
Democratic Rep. of Congo	150,7	84,4
Denmark	0,4	0,4
Djibouti	104,7	37,7
Dominica	4,4	2,8
Dominican Republic	10,8	4,0
Ecuador	6,3	1,1
Egypt	13,9	3,8
El Salvador	11,5	2,4
Equatorial Guinea	52,4	18,4
Eritrea	172,2	91,3
Estonia	0,3	0,1
Ethiopia	182,2	72,7
Federated St. of Micronesia	12,1	6,1
Fiji	15,3	8,0
Finland	0,2	0,1
France	0,4	0,3
Gabon	87,2	33,7
Georgia	1,4	0,3
Germany	0,2	0,3
Ghana	70,3	25,8
Greece	0,1	0,1
Grenada	5,2	3,3
Guatemala	41,3	9,0
Guinea	160,4	55,7
Guinea-Bissau	164,5	71,3
Guyana	20,4	7,3
Haiti	70,5	23,4
Honduras	26,9	7,4
Hungary	0,2	1,5
Iceland	0,2	0,2
India	180,8	54,2
Indonesia	48,5	16,5
Iran	2,8	0,9
Iraq	10,2	3,5
Ireland	0,3	0,2
Israel	0,5	0,5
Italy	0,1	0,1
Jamaica	4,6	3,1
Japan	0,5	0,4
Jordan	2,1	0,7
Kazakhstan	2,2	0,2
Kenya	354,8	186,5
Kiribati	83,8	47,1
Kuwait	1,3	0,9
Kyrgyzstan	5,5	1,1
Laos	51,1	8,0
Latvia	0,4	0,1

Country	Year 2005	Year 2030
Lebanon	2,5	0,7
Lesotho	212,7	108,5
Liberia	204,3	80,1
Libya	2,6	0,8
Lithuania	0,4	0,2
Luxembourg	0,3	0,2
Macedonia	0,6	0,1
Madagascar	152,3	99,2
Malawi	190,0	87,4
Malaysia	3,2	1,8
Maldives	3,5	0,8
Mali	219,6	91,5
Malta	0,2	0,1
Marshall Islands	14,3	3,6
Mauritania	121,8	41,3
Mauritius	1,8	1,2
Mexico	5,0	1,3
Moldova	1,7	0,3
Mongolia	3,1	0,4
Montenegro	0,2	0,1
Morocco	12,5	2,3
Mozambique	103,8	42,1
Myanmar	53,0	9,0
Namibia	84,3	31,1
Nepal	128,5	17,0
Netherlands	0,3	0,4
New Zealand	0,2	0,3
Nicaragua	10,4	2,0
Niger	218,5	108,0
Nigeria	167,4	59,6
North Korea	4,7	2,0
Norway	0,4	0,3
Oman	3,8	0,7
Pakistan	66,6	22,3
Palestine	3,9	3,7
Panama	5,8	2,1
Papua New Guinea	130,4	55,0
Paraguay	9,7	1,9
Peru	9,8	2,8
Philippines	18,3	8,6
Poland	0,3	0,3
Portugal	0,4	0,3
Qatar	0,6	0,4
Romania	1,1	0,2
Russia	0,9	0,3
Rwanda	136,8	52,1
Saint Lucia	3,2	1,3
St. Vincent and Grenadines	6,1	3,6
Samoa	6,6	3,6

Country	Year 2005	Year 2030
Sao Tome and Principe	66,2	14,2
Saudi Arabia	7,2	1,4
Senegal	103,5	62,5
Serbia	0,3	0,2
Seychelles	3,1	1,8
Sierra Leone	213,7	131,7
Singapore	0,9	0,5
Slovakia	0,4	0,2
Slovenia	0,3	0,1
Solomon Islands	53,9	15,9
Somalia	180,2	118,2
South Africa	60,4	17,5
South Korea	0,6	0,6
South Sudan	188,1	143,5
Spain	0,2	0,1
Sri Lanka	7,2	1,1
Sudan	48,8	14,3
Suriname	13,8	6,2
Swaziland	126,1	58,3
Sweden	0,3	0,4
Switzerland	0,2	0,1
Syria	1,2	0,5
Taiwan	0,7	0,5
Tajikistan	20,7	5,3
Tanzania	161,0	67,9
Thailand	9,4	4,4
The Bahamas	2,6	2,1
The Gambia	84,5	51,0
Timor-Leste	73,0	7,6
Togo	130,2	68,8
Tonga	8,5	3,7
Trinidad and Tobago	3,5	1,8
Tunisia	3,0	1,8
Turkey	3,0	0,5
Turkmenistan	10,7	0,4
Uganda	112,2	71,5
Ukraine	0,6	0,2
United Arab Emirates	2,9	1,7
United Kingdom	0,5	0,3
United States	0,4	0,5
Uruguay	1,6	0,8
Uzbekistan	3,3	0,4
Vanuatu	52,7	17,3
Venezuela	5,9	2,3
Vietnam	6,6	1,3
Yemen	52,5	9,1
Zambia	258,2	59,0
Zimbabwe	82,0	84,5

Table B.2 *AQUASTAT database. Indicator 6.2.1: total population with access to safe drinking-water in % (FAO, 2016).*

Country	Year 2003-2007
Afghanistan	42,6
Albania	95,9
Algeria	87
Andorra	100
Angola	46,4
Antigua and Barbuda	97,9
Argentina	97,7
Armenia	96,7
Australia	100
Austria	100
Azerbaijan	80,2
Bahamas	97,6
Bahrain	100
Bangladesh	81,3
Barbados	98,7
Belarus	99,6
Belgium	100
Belize	93,5
Benin	72
Bhutan	92,7
Bolivia	84,6
Bosnia and Herzegovina	98,7
Botswana	95,5
Brazil	95,9
Bulgaria	99,6
Burkina Faso	72,8
Burundi	73,8
Cabo Verde	86,9
Cambodia	57,4
Cameroon	69
Canada	99,8
Central African Republic	65,7
Chad	48,2
Chile	97,3
China	88,5
Colombia	90,7
Comoros	90,1
Congo	72,8
Cook Islands	99,9
Costa Rica	96,6
Côte d'Ivoire	79,8
Croatia	98,9
Cuba	92,7
Cyprus	100
Czechia	99,9
Democratic People's Republic of Korea	99,8

Country	Year 2003-2007
Democratic Republic of the Congo	49,7
Denmark	100
Djibouti	87,1
Dominica	94,4
Dominican Republic	86,3
Ecuador	83,3
Egypt	97,6
El Salvador	87,7
Equatorial Guinea	47,4
Eritrea	54,8
Estonia	99,3
Ethiopia	42
Fiji	93,8
Finland	100
France	100
Gabon	89,3
Gambia	87,1
Georgia	94,6
Germany	100
Ghana	79,5
Greece	99,7
Grenada	96,6
Guatemala	88,7
Guinea	69,8
Guinea-Bissau	64,3
Guyana	91,8
Haiti	60,2
Honduras	85,9
Hungary	99,7
Iceland	100
India	87,4
Indonesia	82,6
Iran (Islamic Republic of)	95,4
Iraq	83,7
Ireland	97,1
Israel	100
Italy	100
Jamaica	93,7
Japan	100
Jordan	96,9
Kazakhstan	93,4
Kenya	57,7
Kiribati	63,5
Kuwait	99
Kyrgyzstan	83,8
Lao People's Democratic Republic	61,2
Latvia	98,7
Lebanon	94,1
Lesotho	80,3

Country	Year 2003-2007
Liberia	68,5
Lithuania	93,8
Luxembourg	100
Madagascar	44
Malawi	75,5
Malaysia	96,4
Maldives	97,5
Mali	60,8
Malta	100
Marshall Islands	93,9
Mauritania	50,7
Mauritius	99,6
Mexico	92,5
Micronesia (Federated States of)	89,5
Monaco	100
Mongolia	61,5
Montenegro	98,3
Morocco	81,9
Mozambique	46,3
Myanmar	74,6
Namibia	84,8
Nauru	94,9
Nepal	84,1
Netherlands	100
New Zealand	100
Nicaragua	83,1
Niger	50,8
Nigeria	60,1
Niue	98,7
Norway	100
Occupied Palestinian Territory	76
Oman	89,4
Pakistan	89,9
Palau	94,8
Panama	92,1
Papua New Guinea	37,9
Paraguay	85,4
Peru	83,3
Philippines	89,2
Poland	97,1
Portugal	99,1
Qatar	99,9
Republic of Korea	97,1
Republic of Moldova	86,7
Romania	93,5
Russian Federation	95,9
Rwanda	71,1
Saint Kitts and Nevis	98,3
Saint Lucia	95,2

Country	Year 2003-2007
Saint Vincent and the Grenadines	95,1
Samoa	96,3
Sao Tome and Principe	90,4
Saudi Arabia	97
Senegal	72,6
Serbia	99,3
Seychelles	95,7
Sierra Leone	54,3
Singapore	100
Slovakia	99,9
Slovenia	99,6
Solomon Islands	80,2
Somalia	30,7
South Africa	89,8
Spain	100
Sri Lanka	87,6
Suriname	92,6
Swaziland	64,8
Sweden	100
Switzerland	100
Syrian Arab Republic	89,1
Tajikistan	66,6
Thailand	95,2
The former Republic of Macedonia	99,3
Timor-Leste	63,8
Togo	57,9
Tokelau	97,4
Tonga	98,9
Trinidad and Tobago	94,5
Tunisia	94,1
Turkey	96,9
Turkmenistan	60,4
Tuvalu	96,9
Uganda	67,7
Ukraine	97
United Arab Emirates	99,6
United Kingdom	100
United Republic of Tanzania	54,9
United States of America	99
Uruguay	98,4
Uzbekistan	87,5
Vanuatu	84,7
Venezuela (Bolivarian Republic of)	92,2
Viet Nam	87,3
Yemen	55
Zambia	59
Zimbabwe	78,4

Table B.3 *Global Sustainable Development Goals Indicators Database. Indicator 15.1.2: average proportion of freshwater key biodiversity areas (KBAs) covered by protected areas in terms of % (UNDP, 2018).*

Country	Year 2005	Year 2010
Afghanistan	0,1	0,1
Albania	68,3	68,6
Algeria	47,2	47,2
Angola	33,3	33,3
Argentina	32,9	43,1
Armenia	25,1	26,9
Australia	29,0	31,2
Austria	68,9	68,9
Azerbaijan	24,5	24,5
Bangladesh	20,8	20,8
Belarus	39,7	39,7
Belgium	91,1	91,2
Belize	18,3	18,3
Bhutan	23,1	29,9
Bolivia	61,6	61,6
Bosnia and Herzegovina	20,0	40
Botswana	46,0	46,0
Brazil	14,0	15,6
Brunei Darussalam	50	50
Bulgaria	49,0	98,6
Burkina Faso	50,2	63,0
Burundi	52,1	52,1
Cambodia	30,8	33,0
Cameroon	28,4	28,4
Canada	20,4	20,5
Central African Republic	94,8	95,9
Chad	70,2	70,2
Chile	38,7	38,7
China	35,4	35,5
Colombia	12,0	17,2
Congo	100,0	100,0
Costa Rica	31,8	36,8
Côte d'Ivoire	87,4	87,4
Croatia	23,1	23,1
Czechia	86,2	92,1
Democratic Republic of Korea	0	0
Democratic Republic of Congo	29,4	32,8
Denmark	100,0	100,0
Djibouti	0	0
Dominican Republic	97,8	97,8
Ecuador	70,9	70,9
Egypt	28,5	28,5
El Salvador	48,6	81,6
Eritrea	0,0	0,0
Estonia	93,4	93,4
Ethiopia	16,0	16,0

Country	Year 2005	Year 2010
Fiji	0,1	0,1
Finland	74,0	74,0
France	68,3	77,2
Gabon	93,6	93,6
Georgia	3,8	3,8
Germany	73,6	80,9
Greece	70,8	88,4
Guatemala	49,6	49,6
Guinea	100,0	100,0
Haiti	0	0
Honduras	31,8	36,8
Hungary	81,6	84,8
Iceland	31,6	31,6
India	15,2	15,2
Indonesia	38,9	38,9
Iran (Islamic Republic of)	38,9	40,4
Iraq	1,0	1,9
Ireland	97,7	97,7
Israel	23,2	26,1
Italy	80,9	84,7
Japan	66,2	66,8
Kazakhstan	8,4	15,6
Kenya	31,0	37,8
Kyrgyzstan	30,7	30,7
Lao	19,9	19,9
Latvia	97,5	97,5
Lebanon	21,1	21,1
Liberia	48,6	48,6
Lithuania	95,2	95,2
Luxembourg	37,1	37,1
Madagascar	55,1	55,3
Malawi	35,9	35,9
Malaysia	76,6	76,6
Mali	43,7	43,7
Mayotte	100	100
Mexico	8,5	9,2
Mongolia	36,7	38,8
Montenegro	0	0
Morocco	21,7	27,7
Mozambique	45,0	45,0
Myanmar	18,5	18,5
Namibia	53,6	77,4
Nepal	35,7	36,5
Netherlands	91,0	91,1
New Zealand	20,9	25,8
Nicaragua	65,8	65,8
Niger	45,3	45,3
Nigeria	12,3	59,1
Norway	54,8	54,9

Country	Year 2005	Year 2010
Pakistan	37,0	37,0
Paraguay	24,5	24,5
Peru	31,8	36,8
Philippines	48,1	48,1
Poland	73,8	91,8
Portugal	57,0	64,0
Republic of Korea	29,7	36,8
Republic of Moldova	10,8	10,8
Romania	11,5	58,4
Russian Federation	27,4	27,4
Rwanda	47,8	47,8
Saudi Arabia	17,7	17,7
Senegal	31,5	31,6
Serbia	26,2	30,7
Sierra Leone	50,0	72,5
Slovakia	81,3	81,3
Slovenia	93,0	93,1
Somalia	0	0
South Africa	31,5	31,6
South Sudan	45,2	58,8
Spain	43,9	44,1
Sri Lanka	72,6	72,6
State of Palestine	4,7	4,7
Sudan	0	0
Suriname	49,4	49,4
Swaziland	31,5	31,6
Sweden	61,3	61,5
Switzerland	57,4	60,1
Syrian Arab Republic	4,3	4,3
Tajikistan	33,4	33,4
Thailand	43,6	43,6
The Republic of Macedonia	85,8	86,0
Tunisia	15,6	22,1
Turkey	3,6	4,0
Turkmenistan	12,7	13,1
Uganda	43,3	60,8
Ukraine	16,9	16,9
United Kingdom	86,4	86,7
United Republic of Tanzania	28,4	33,9
United states of America	20,4	20,5
Uruguay	1,1	2,3
Uzbekistan	2,9	10,4
Venezuela	85,8	85,8
Viet Nam	23,6	23,6
Yemen	7,7	7,7
Zambia	52,8	56,2
Zimbabwe	60,5	60,5

Table B.4 *Global Sustainable Development Goals Indicators Database. Indicator 15.5.1: red list index for change in aggregate global extinction risk of species. Values scaled to the max of 1 (UNDP, 2018).*

Country	Year 2005
Afghanistan	0,838
Albania	0,883
Algeria	0,906
American Samoa	0,863
Andorra	0,920
Angola	0,936
Anguilla	0,928
Antigua and Barbuda	0,917
Argentina	0,864
Armenia	0,850
Aruba	0,944
Australia	0,865
Austria	0,896
Azerbaijan	0,912
Bahamas	0,716
Bahrain	0,882
Bangladesh	0,813
Barbados	0,920
Belarus	0,954
Belgium	0,984
Belize	0,774
Benin	0,910
Bermuda	0,594
Bhutan	0,801
Bolivia	0,875
Bonaire, Sint Eustatius and Saba	0,871
Bosnia and Herzegovina	0,903
Botswana	0,981
Brazil	0,909
British Virgin Islands	0,760
Brunei Darussalam	0,844
Bulgaria	0,941
Burkina Faso	0,991
Burundi	0,921
Cabo Verde	0,865
Cambodia	0,860
Cameroon	0,837
Canada	0,975
Cayman Islands	0,826
Central African Republic	0,944
Chad	0,924
Chile	0,807
China	0,791
China, Hong Kong Region	0,823
China, Macao Region	0,972
Colombia	0,763

Country	Year 2005
Comoros	0,817
Congo	0,984
Cook Islands	0,789
Costa Rica	0,838
Côte d'Ivoire	0,893
Croatia	0,900
Cuba	0,666
Curaçao	0,818
Cyprus	0,983
Czechia	0,969
Democratic People's Republic of Korea	0,925
Democratic Republic of the Congo	0,893
Denmark	0,975
Djibouti	0,852
Dominica	0,707
Dominican Republic	0,753
Ecuador	0,745
Egypt	0,943
El Salvador	0,846
Equatorial Guinea	0,815
Eritrea	0,939
Estonia	0,986
Eswatini	0,819
Ethiopia	0,841
Falkland Islands (Malvinas)	0,674
Faroe Islands	0,878
Fiji	0,693
Finland	0,990
France	0,911
French Guiana	0,972
French Polynesia	0,749
Gabon	0,962
Gambia	0,982
Georgia	0,878
Germany	0,983
Ghana	0,846
Greece	0,847
Greenland	0,927
Grenada	0,766
Guadeloupe	0,634
Guam	0,559
Guatemala	0,740
Guinea	0,901
Guinea-Bissau	0,961
Guyana	0,926
Haiti	0,745
Holy See	0,989
Honduras	0,764
Hungary	0,927

Country	Year 2005
Iceland	0,879
India	0,730
Indonesia	0,819
Iran (Islamic Republic of)	0,877
Iraq	0,849
Ireland	0,923
Israel	0,748
Italy	0,919
Jamaica	0,744
Japan	0,821
Jordan	0,960
Kazakhstan	0,878
Kenya	0,837
Kiribati	0,805
Kuwait	0,912
Kyrgyzstan	0,986
Lao People's Democratic Republic	0,816
Latvia	0,988
Lebanon	0,918
Lesotho	0,966
Liberia	0,896
Libya	0,971
Liechtenstein	0,992
Lithuania	0,988
Luxembourg	0,986
Madagascar	0,837
Malawi	0,806
Malaysia	0,786
Maldives	0,891
Mali	0,985
Malta	0,882
Marshall Islands	0,877
Martinique	0,767
Mauritania	0,980
Mauritius	0,472
Mayotte	0,924
Mexico	0,709
Micronesia (Federated States of)	0,740
Monaco	0,752
Mongolia	0,953
Montenegro	0,846
Montserrat	0,701
Morocco	0,894
Mozambique	0,859
Myanmar	0,843
Namibia	0,967
Nauru	0,808
Nepal	0,824
Netherlands	0,960

Country	Year 2005
New Caledonia	0,695
New Zealand	0,687
Nicaragua	0,869
Niger	0,951
Nigeria	0,876
Niue	0,889
Northern Mariana Islands	0,604
Norway	0,949
Oman	0,915
Pakistan	0,910
Palau	0,865
Panama	0,760
Papua New Guinea	0,880
Paraguay	0,950
Peru	0,729
Philippines	0,703
Poland	0,957
Portugal	0,858
Puerto Rico	0,700
Qatar	0,883
Republic of Korea	0,821
Republic of Moldova	0,965
Réunion	0,599
Romania	0,946
Russian Federation	0,958
Rwanda	0,849
Saint Kitts and Nevis	0,748
Saint Lucia	0,871
Saint Vincent and the Grenadines	0,777
Samoa	0,831
San Marino	0,992
Sao Tome and Principe	0,786
Saudi Arabia	0,938
Senegal	0,952
Serbia	0,954
Seychelles	0,703
Sierra Leone	0,917
Singapore	0,897
Sint Maarten (Dutch part)	0,997
Slovakia	0,961
Slovenia	0,939
Solomon Islands	0,810
Somalia	0,937
South Africa	0,808
South Sudan	0,935
Spain	0,848
Sri Lanka	0,633
State of Palestine	0,787
Sudan	0,966

Country	Year 2005
Suriname	0,990
Sweden	0,993
Switzerland	0,982
Syrian Arab Republic	0,950
Tajikistan	0,984
Thailand	0,836
The former Republic of Macedonia	0,971
Timor-Leste	0,929
Togo	0,855
Tokelau	0,868
Tonga	0,729
Trinidad and Tobago	0,828
Tunisia	0,974
Turkey	0,879
Turkmenistan	0,977
Turks and Caicos Islands	0,844
Tuvalu	0,868
Uganda	0,788
Ukraine	0,941
United Arab Emirates	0,899
United Kingdom	0,831
United Republic of Tanzania	0,757
United States of America	0,849
United States Virgin Islands	0,795
Uruguay	0,838
Uzbekistan	0,975
Vanuatu	0,705
Venezuela (Bolivarian Republic of)	0,847
Viet Nam	0,792
Western Sahara	0,923
Yemen	0,913
Zambia	0,880
Zimbabwe	0,794

Table B.5 *Global Sustainable Development Goals Indicators Database. Indicator 6.4.2: level of water stress, freshwater withdrawal as a proportion of available freshwater resources in terms of % (UNDP, 2018).*

Country	Year 2014-2015
Afghanistan	43,7
Albania	6,5
Algeria	88,0
Andorra	0,0
Angola	0,7
Antigua and Barbuda	8,5
Argentina	6,6
Armenia	66,0
Australia	4,6
Austria	7,6
Azerbaijan	53,1
Bahamas	0,0
Bahrain	205,8
Bangladesh	3,8
Barbados	87,5
Belarus	4,5
Belgium	56,5
Belize	0,7
Benin	0,7
Bermuda	4,2
Bhutan	0,6
Bolivia	0,5
Bosnia and Herzegovina	1,4
Botswana	2,1
Brazil	1,3
Brunei Darussalam	1,9
Bulgaria	41,9
Burkina Faso	9,5
Burundi	3,1
Cabo Verde	9,0
Cambodia	0,6
Cameroon	0,5
Canada	2,2
Central African Republic	0,1
Chad	2,4
Chile	5,5
China	29,4
Colombia	0,9
Comoros	1,2
Congo	0,0
Costa Rica	3,1
Côte d'Ivoire	2,7
Croatia	1,0
Cuba	25,6
Cyprus	37,6
Czechia	24,0

Country	Year 2014-2015
Democratic People's Republic of Korea	15,9
Democratic Republic of the Congo	0,1
Denmark	20,7
Djibouti	7,9
Dominica	10,0
Dominican Republic	43,7
Ecuador	3,7
Egypt	159,9
El Salvador	11,4
Equatorial Guinea	0,1
Eritrea	10,1
Estonia	22,5
Eswatini	32,4
Ethiopia	11,6
Fiji	0,5
Finland	10,5
France	22,8
French Guiana	0,0
Gabon	0,1
Gambia	1,5
Georgia	4,6
Germany	41,5
Ghana	2,8
Greece	19,7
Grenada	7,1
Guatemala	3,8
Guinea	0,3
Guinea-Bissau	0,7
Guyana	0,9
Haiti	15,6
Honduras	2,5
Hungary	8,2
Iceland	0,2
India	44,5
Indonesia	9,2
Iran (Islamic Republic of)	90,0
Iraq	93,1
Ireland	2,4
Israel	110,5
Italy	44,8
Jamaica	11,3
Japan	28,5
Jordan	150,9
Kazakhstan	28,1
Kenya	14,3
Kuwait	2603,5
Kyrgyzstan	44,0
Lao People's Democratic Republic	1,4
Latvia	1,1

Country	Year 2014-2015
Lebanon	33,3
Lesotho	2,1
Liberia	0,1
Libya	1072,0
Lithuania	4,0
Luxembourg	2,5
Madagascar	5,8
Malawi	11,1
Malaysia	3,4
Maldives	15,7
Mali	5,8
Malta	44,4
Mauritania	15,9
Mauritius	26,4
Mexico	25,9
Mongolia	2,4
Morocco	49,0
Mozambique	0,9
Myanmar	3,7
Namibia	0,9
Nepal	5,9
Netherlands	21,1
New Zealand	2,8
Nicaragua	1,4
Niger	3,8
Nigeria	5,8
Norway	1,2
Oman	106,2
Pakistan	102,5
Panama	1,1
Papua New Guinea	0,1
Paraguay	0,9
Peru	1,2
Philippines	25,1
Poland	37,8
Portugal	17,1
Puerto Rico	21,3
Qatar	472,5
Republic of Korea	57,6
Republic of Moldova	13,2
Réunion	22,5
Romania	5,1
Russian Federation	2,0
Rwanda	1,4
Saint Kitts and Nevis	51,3
Saint Lucia	14,3
Saint Vincent and the Grenadines	11,2
Sao Tome and Principe	0,5
Saudi Arabia	1242,6

Country	Year 2014-2015
Senegal	7,2
Serbia	4,3
Sierra Leone	0,2
Singapore	31,7
Slovakia	1,9
Slovenia	6,1
Solomon Islands	0,0
Somalia	30,3
South Africa	42,9
South Sudan	1,3
Spain	49,7
Sri Lanka	34,1
State of Palestine	48,8
Sudan	93,7
Suriname	1,0
Sweden	2,9
Switzerland	7,4
Syrian Arab Republic	109,4
Tajikistan	71,4
Thailand	17,5
The Republic of Macedonia	13,2
Timor-Leste	14,3
Togo	1,8
Trinidad and Tobago	12,3
Tunisia	94,0
Turkey	27,5
Turkmenistan	162,8
Uganda	1,3
Ukraine	13,9
United Arab Emirates	2346,5
United Kingdom	9,7
United Republic of Tanzania	7,5
United States of America	22,6
Uruguay	3,5
Uzbekistan	138,8
Vanuatu	0,0
Venezuela (Bolivarian Republic of)	2,6
Viet Nam	12,8
Yemen	227,7
Zambia	2,1
Zimbabwe	24,3

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