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Towards Life Cycle Sustainability Assessment: development of a new method to integrate particular matter formation in climate change impact assessment

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ABSTRACT

The concept of sustainability is nowadays one of the principal points for choices about global development and takes into account environmental, economic and social aspects. It is now shared between all stakeholders that the right approach for products and services sustainability analysis must considered the entire life cycle, to individuate all phases and processes that are impactful and so to manage the improvement in the most efficient and effective way, with no risks to forget aspects that could be relevant for the results assessment. For the life cycle assessment some techniques are internationally recognized, between them the more developed is the Life Cycle Assessment (LCA) for the environmental studies. For the social aspects and, even more, for the sustainability assessment the published methods are different and have some methodological limits not yet solved. Today the research field on LCSA (Life Cycle Sustainability Assessment) is differentiated on some aspects, from the definition of a methodology that consider together environmental, economic and social aspects, to the choice of adequate sets of assessment indicators.

The present research focuses on an improvement proposal of an existing characterization method that allows to assess damage to Human Health (social characteristic), that actually do not take into account consequences of the respiratory problems due to the average temperature increase as a climate change phenomena (environmental characteristic).

The research activities were carried out at CESQA (Environmental and Quality Research Centre) of the Department of Industrial Engineering (Dipartimento di Ingegneria Industriale – DII) at the University of Padova (Italy).

The results of the research activities are summarized in five chapters.

Chapter 1: includes a general introduction on the concept of sustainability and on the recent Life Cycle Sustainability Assessment methodology, underlined actual developments and limits. Social Life Cycle Assessment (SLCA) and Life Cycle Assessment (LCA), life cycle methodologies for environmental and social aspects evaluation of products and services are analyzed. It has been underlined how the most know and recent published characterization methods for LCA allow to evaluate the human health damage category: this could be considered an indicator of social type because for the calculation of DALY (disability-adjusted life years, quantifying the burden of disease from mortality and morbidity). From methods analysis arise that characterization methods have also some limits about the human health damage evaluation: they don’t take into account, for example, consequences of respiratory problems due to climate change and in particular way from average

global temperature, that affects dangerous particles concentration in inhaled air(for example particulate matters).

Chapter 2: reports on materials and methods used in the present research, from the general model description for the damage assessment to the specific model that has been proposed to integrate effects on human health due to the variation of inhalable substance in the air from temperature rise global phenomena.

Chapter 3: presents the results of the research testing model applicability on four different specific case studies, in which has been implemented a life cycle analysis through the application of ReCiPe 2008 assessment method and the method proposed in the present research; difference on results have been evaluated. Sensitivity analysis results have been also reported, considering as variation parameter different values of temperature increase.

Chapter 4: presents the discussions on results and an analysis of results evaluating differences between ReCiPe 2008 method and the proposed one. Results of sensitivity analysis are discussed and deepened.

Chapter 5: reports on the conclusions and perspectives for future researches.

SOMMARIO

Il concetto di sostenibilità è diventato oramai un punto focale nelle scelte di sviluppo globale e include aspetti di tipo ambientale, economico e sociale. É tuttora consolidato che l'approccio corretto per l'analisi di sostenibilità dei prodotti e servizi deve considerare l'intero ciclo di vita, in modo da poter individuare quali fasi e processi risultano più impattanti e poter gestire il miglioramento in maniera più efficente ed efficace, senza il rischio di non considerare aspetti che potrebbero risultare rilevanti per la valutazione. Per tale analisi sono ormai assodate varie tecniche tra le quali la più sviluppata risulta il Life Cycle Assessment per la valutazione della sostenibilità ambientale. Per gli aspetti sociali e, ancor più, per la valutazione della sostenibilità i metodi sviluppati sono diversificati e presentano alcuni limiti metodologici non ancora risolti. Ad oggi il campo di ricerca del cosidetto LCSA (Life Cycle Sustainability Assessment) è diversificato su più aspetti, dalla definizione di una metodologia per la contemporanea valutazione di aspetti ambientalli, economici e sociali, alla definizione di adeguati set di indicatori di valutazione.

La presente ricerca si focalizza sulla proposta di miglioramento di un metodo di caratterizzazione esistente che permette di valutare il danno alla salute umana (caratteristica di tipo sociale), che attualmente non considera le conseguenze dei problemi respiratori dovuti all'innalzamento della temperature media terrestre come fenomeno del cambiamento climatico in atto (caratteristica di tipo ambientale).

Le attività di ricerca sono state condotte presso il CESQA (Centro Studi Qualità e Ambiente) del Dipartimento di Ingegneria Industriale dell'Università di Padova.

I risultati della ricerca sono presentati in cinque capitoli.

Capitolo 1: include un'introduzione generale sul concetto di sostenibilità e sulla recente metodologia Life Cycle Sustainability Assessment per la valutazione della sostenibilità, evidenziandone gli attuali sviluppi e limiti. Vengono analizzate le metodologie Social Life Cycle Assessment (SLCA) e Life Cycle Assessment (LCA) per la valutazione di impatti sociali e ambientali nell'ottica di analisi del ciclo di vita del prodotto. Si è evidenziato come i principali e più recenti metodi di caratterizzazione pubblicati per gli studi di LCA permettano la valutazione della categoria di danno alla salute umana, indicatore con caratteristiche di tipo sociale in quanto permette di misurare gli anni di vita persa per morte prematura o disabilità (DALY). Dall'analisi è emerso come tali metodi di caratterizzazione presentino ancora dei limiti nella valutazione dei danni sulla salute umana, non considerando per esempio le conseguenze dei problemi respiratori dovuti al fenomeno del cambiamento climatico e in modo particolare

all’innalzamento della temperature media globale, che ha effetti sulla concentrazione di particelle pericolose (ad esempio il particolato) nell’aria inalabile.

Capitolo 2: riferisce in merito ai materiali e metodi adottati per la ricerca, dalla descrizione del modello generale per la valutazione del danno al modello specifico proposto per integrare gli effetti sulla salute umana dovuti alla variazione di sostanze inalabili in aria causata dal fenomento dell’innalzamento della temperatura.

Capitolo 3: presenta i risultati della ricerca testando l’applicabilità del modello su quattro differenti casi studio specifici, tramite l’implementazione di un’analisi del ciclo di vita applicando il metodo di caratterizzazione ReCiPe 2008 e il metodo proposto nel presente studio, riportando la differenza di risultato ottenuto. Vengono riportati inoltre i risultati dell’analisi di sensitività sviluppata considerando come parametro di variazione differenti valori di incremento di temperatura possibili.

Capitolo 4: presenta le discussioni l’analisi dei risultati ottenuti valutando la differenza di risultati ottenuti tramite l’applicazione del metodo di caratterizzazione ReCiPe 2008 e il metodo proposto nel presente studio. Sono discussi e approfonditi inoltre i risultati dell’analisi di sensitività effettuata.

Capitolo 5: presenta le conclusioni e gli e spunti per possibili sviluppi futuri della ricerca.

Index

1 INTRODUCTION

1.1 The concept of Sustainability and the Life Cycle Sustainability Assessment methodology

The terms “Sustainability” and “Sustainable Development” are nowadays commonly used in the international and local political discussions but also are concepts increasing considered from people and enterprises. In a globalized word these must been considered as main topics inside social, environmental and economic development policies and, consequently, they became strategic for enterprises in the definition of strategies for their services or products development, in consideration to the actual and future market and consumers. In the definition of policies and strategies, governments and enterprises must consider not only the economic aspects but also the impacts of their strategic choices on the environment and society.

Since the 1980s the concept of “Sustainability” has been used in the general sense of human sustainability on planet Earth, but the specific term has been defined about three decades ago in the Bruntland report (World Commission on Environment and Development, 1987) and it is nowadays known as a term related to the global development: “sustainable development” is development that meets the needs of present without compromising the ability of future generations to meet their needs. Five years later, in the 1992, sustainability was adopted by the United Nations Environment Programme (UNEP) in the Rio de Janeiro Conference, as one of the main political goals for the future development of planet and humankind. In this contest is today globally recognized, from governments to scientific community, from enterprises to consumers, that sustainability is based on three pillars: environment, economic and social. At same time this emerging awareness is supported by another concept that aims to guarantee more sustainable practices into the future: the concept of life cycle thinking approach. The application of the life cycle thinking, or life cycle perspective, to the pillars of sustainability allows to incorporate sustainable development in decision-making processes, both at global than local level.

Putting the attention on the enterprise, in consideration that sustainability is today one of the priority goals to be achieved in both public policies and business strategies in the international market, the ways for a sustainable company to create profit are different and more than one: for example protecting the environment, respecting the workers’ rights and improving the ethical values. It seems so clear that the product development process becomes a critical factor for companies’ competitiveness, particularly in eco-innovation processes. Analyzing literature, several methods discussing sustainable business are available and several tools to support managers in sustainable innovation process exist (Mattioda et al., 2014). In particular two different approaches could be underline and discusses: the Triple Bottom Line (TBL) and the Life Cycle Sustainability Assessment (LCSA). The TBL supports the companies to integrate sustainability goals on the agenda business, balancing traditional economic goals with social and environmental concerns, thereby creating a new corporate performance asset. TBL focuses on company's performance in order to assess the relationship between profit, people and planet in company's activities, processes and products. On the other hand LCSA aims to assess all the environmental, economic and social impacts of the product in a life cycle perspective: it includes indicators of the three dimensions of sustainability. Triple Bottom Line (Elkington, 1997) is a link to the definition of sustainable development that includes the principles of sustainability by measuring the impact of organization's (Savitz and Weber, 2006) activities. In the actual global cultural revolution companies are trying to include the principles of TBL in their activities considering the life cycle stages of a product performance from cradle to grave and, increasingly, from cradle to cradle. In line with the world demands and the searching of the organizations to attend the development of sustainable products, the companies need to adopt sustainability in a systematically way into their strategies. Many possibilities are available for companies to consider the different sustainability pillars in their business agenda: many instruments, operative approaches and standards are available to consider environmental performances of products, costs, social issues, and to implement a quality, environmental and social accountability management system.

The final product or services put in the market should try to meet the concepts related to the TBL and be integrated and optimized at all life cycle stages, starting from design, which must be oriented to the sustainability. The importance to a common vision of sustainability, integrating tools and methods for sustainable product development underline the needing of a methodology to assess sustainability considering together environmental, economic and social: the actual methodology is the so called Life Cycle Sustainability Assessment (LCSA). The results of a bibliographic research, that are show in table 1, could help to better understand the differences between the concepts of sustainable design, triple bottom line and life cycle sustainability assessment.

Table 1 The Concepts of sustainable design, triple bottom line and life cycle sustainability assessment (Mattioda et al., 2014)

	SUSTAINABLE PRODUCT DESIGN	TRIPLE BOTTOM LINE	LIFE CYCLE SUSTAINABILITY ASSESSMENT
Year	1930 / 1971	1997	2008/2011
Authors	Buckminster Fuller / Victor Papanek	Elkington / Savitz	Klöepffer/UNEP/SETAC

	SUSTAINABLE PRODUCT DESIGN	TRIPLE BOTTOM LINE	LIFE CYCLE SUSTAINABILITY ASSESSMENT
Concept	"The technology should improve the human condition and it is necessary a revolution in design in order to make more using less". "In an era of mass production, when everything must be planned and designed, the project has become the most powerful tool which man uses to shape his tools and environments (and, by extension, society and himself). If it is to be environmentally responsible and socially responsive must be revolutionary and radical (going back to the roots) in the true sense	Sustainability Tripod (People, Planet, Profit) is a tool to integrate sustainability into the business agenda, balancing traditional economic goals for social and environmental concerns by creating a new dimension of corporate performance. Triple Bottom Line (TBL) captures the essence of sustainability by measuring the impact of an organization's activities in the world.	Refers to the evaluation of all environmental, social and economic negative impacts and benefits of a product throughout its life cycle and how to use the result to support decision-making processes.
Typology / Application	Hystorical	Organisational tool	Tool for assessing the life cycle of the product

TBL and LCSA have many similitudes, since both are based on the three different dimensions of the sustainability (environmental, economic and social); but as a difference, the TBL refers to the business agenda of an organization and LCSA refers to assessing the benefits and negative impacts of a product by analyzing its lifecycle. When discussing product design and development, it is important to insert the TBL concept in order to include the role of the strategic sustainability in the process of the product life cycle assessment and LCSA should not exclude this concept. Sustainability is part of the organizational strategy and product development process as well as the use of LCSA tool must be connected to the concept of strategy or management.

If an approach towards sustainability development could be strategic about all decisional levels, from Institutions to enterprises, as underline before this vision must be development taking into account a complete overview applying the life cycle perspective analysis. The Life Cycle Thinking represents the basic concept of considering the whole product system life cycle from the "cradle to the grave" (Finkbeiner et al., 2010). It aims to prevent individual parts of the life-cycle from being addressed in a way that just results in the environmental burden being shifted to another part: Life Cycle Thinking is a qualitative concept and could be applied considering environmental, economic, social and also sustainability issues. Focusing in particular on the environmental one, in the last decades many assessment methods and tools have been development, showed in figure 1, the so called "Maslow's

Pyramid": as it is possible to see on the bottom side of the scheme, the Life Cycle Thinking is the basis of every instrument or approach.

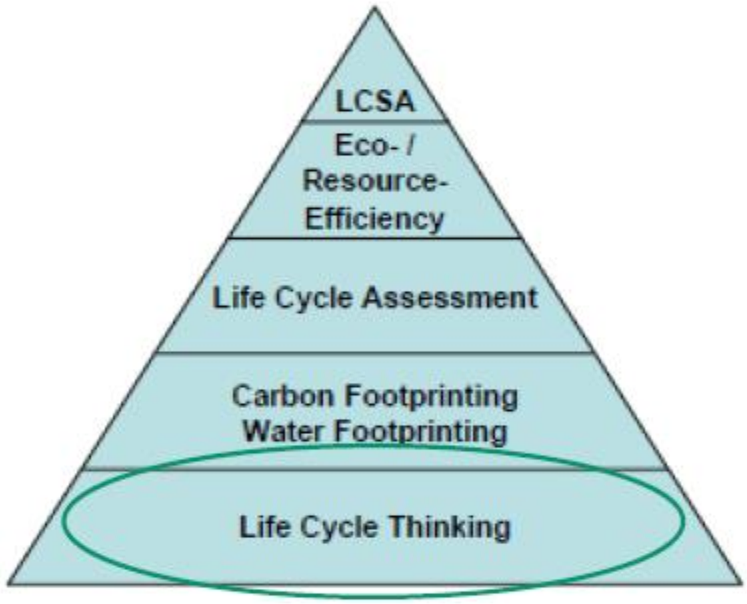


Figure 1 Maslow's Pyramid adapted for environmental and sustainability life cycle assessment approaches (Finkbeiner et al., 2010)

Starting from a qualitative idea, the other levels in the pyramid start to be quantitative. First of all, considering the more recent development, methodologies for single environmental issues like Carbon Footprinting and Water Footprinting have received considerable attention. In this sense, international standards have been published and used by companies to evaluate their performances considering a single issue: impacts of their product, processes, activities or services on climate change (carbon footprint) and on water resource (water footprint). ISO 14067 (ISO, 2013) and ISO 14046 (ISO, 2014) take into account the life cycle concept but address only one environmental impact, climate change or water quality.

The next level in the pyramid is represented by Life Cycle Assessment (LCA). LCA (see next § 1.3) is built around the principle of comprehensiveness and therefore aims to address all environmental interventions; this methodology is based on principles and requirement of ISO 14040 (ISO, 2006,a) and ISO 14044 (ISO 2006, b) and allow to check and to evaluate environmental burdens of a product or service, considering the entire life cycle, in terms of impact or damage categories.

Then, after LCA, the concept of eco-efficiency represents a further step towards sustainability: the purely environmental focus is left and economic or other aspects come into play. Both resource efficiency and eco-efficiency assessment approaches combine environmental indicators with economic or other performance indicators. In the last 2012, ISO published a standard to regulate eco-efficiency analysis: the standard ISO 14045 "Environmental management – Eco-Efficiency assessment pf product systems – principles and guidelines” describes the principles, requirements and guidelines” for eco- efficiency assessment of product systems including, other than environmental assessment (similar to LCA) a product-system-value assessment (worth or desirability ascribed to a product system) that represent another characteristic of the product system (ISO, 2012a). So, in this way, an “environmental aspect” is considered, linked and analyzed in comparison with another product characteristic that could be social or economic for example. The standard give some suggestions to consider for the product system value and the for eco-efficiency calculation, to take in account functional, monetary or other product values; in the next table is shows an example coming from the standard, referred to a mobile phone (product system).

Table 2 Example of product System Values for a mobile phone product system (ISO, 2012a. Annex A)

Terms	**Example**	**Value indicator (unit)**
Product system	Mobile Phone	
Function	To use the product for a long time	
Functional value	Durability	Warranty lifetime (Years)
Monetary value	Depreciation	Trade-in value (USD)
Other values	Aesthetics	Colour preference by consumer Value (numerical from 1-5)

To calculate eco-efficiency of this product system, the system value (functional, monetary or other) are compared and considering together with environmental indicator (e.g. greenhouse gas emission).

At the end, on top of the pyramid, the last missing sustainability dimension, i.e., the social one, is added to the other dimensions as part of a full life cycle based sustainability assessment. LCSA is actually the proposed methodology, nowadays under study and development, that allows to consider together the three dimension of sustainability in a product analysis, based on the life cycle perspective.

This wide and complete approach for the product/system/process analysis could give several benefits in an optic of performance improvement, for potential and future decision-makers, stakeholders, enterprises and consumers, as suggest by Ciroth at al., 2011. In particular LCSA: a) allows *practitioners* to organize complex environmental, economic and social information and data in a structured form; b) helps to put together the three sustainability pillars, life cycle stages and impacts, products and generations by providing a more comprehensive picture of the positive and negative impacts along the product life cycle; c) helps *enterprises* to become more responsible for their business by taking into account all types of impacts associated with their products and services; helps to stimulate innovation along all the value chain; help to made a more transparent communication and information to raise credibility d) allows to improve awareness in value chain actors supporting enterprises and value chain actors to identify weaknesses and potential further improvements of their product life cycle; e) supports *decision-makers* in prioritizing resources and investing them where there are more chances of positive impacts and less chance of negative ones and helps to choose sustainable technologies and products; f) support *consumers* in determining which products are not only cost-efficient, eco-efficient or socially responsible, but also more sustainable.

So both practitioners than enterprises, decision-makers and consumer could have benefits from the awareness of LCSA potentialities, but considering that the focus of this analysis is on the *product* the actor that is firstly involved in this new approach is, obviously, the company. It is in the middle between decision-makers and consumers and it must take into account, especially in this modern globalized market where sustainability is becoming a key point for competitiveness, inputs and expectations from them to give an output with the best performances required, also in terms of sustainability ones.

1.1.1 The origins of LCSA

From many years the theme of sustainability is a fundamental topic in the governmental policy of all development Nations in the world and also inside the scientific community this is one of the main arguments under investigation and research. An interesting analysis about the development of the sustainability concept comes from the works of Bettencourt and Kaur (2011). Authors made a literature research considering the period 1974 – 2010 using as key-search the word "sustainability" and "sustainable development" in abstract, title and keywords sections. The results shown a great number of publications founded, almost 20.000; integrating the research strategy with the word "LCA" the result was 600 publications. These numbers confirmed the growing interest on sustainability assessment, where in this time Environmental life cycle assessment play yet a principal role in comparison of economic and social analysis.

After the Brundtalnd definition many ideas have arose to try give concrete solution for the sustainability assessment. The first conceptual ideas in the optical of the modern LCSA approach could be attribute to the Oeko Institute with the "Product Lyne Analysis" (Oeko-Institut,1987), while O'Brien (1996) was one of the first research to consider the social dimension inside a life cycle assessment. He underlined that integration of social and environmental aspects and results could give a more deep and complete evaluation of the potential impacts but, on the other hand, O'Brien recognized the difficulties of this integration, and suggested as future development the research of a way of a methodology that allow to meet together both social and environmental performances indicators. Another interesting works was published after two years, with the aim to examine and discuss the feasibility of including four Socio-Ecological Principles, as criteria for sustainability, in the LCA methodology (Andersson et al., 1998). In this work, inside all phases of LCA implemented methodology (see § 1.3), the socio-ecological principles was considered: a) substances from the lithosphere must not systematically accumulate in the ecosphere; b) society-produced substances must not systematically accumulate in the ecosphere; c) the physical conditions for production and diversity within the ecosphere must not be systematically deteriorated; and d) the use of resources must be efficient and just with respect to meeting human needs. This work represents one of the first efforts made with the objective to build a concrete solution for the integration of social aspects in a life cycle assessment analysis.

Concluding this brief overview on Life Cycle Sustainability Assessment history, and in particular considering the methodology to implement to conduct the analysis, the formulation given by Klopffer (2008) could be consider the starting point in this sense. The work published aimed to give a proposition how to quantify sustainability, restricting the attention to the assessment of products, goods and services. It confirmed that for achieving or assessing sustainability, the environmental, economic and social aspects have to be tuned and checked against and together and so the following scheme for LCSA was proposed:

LCSA = LCA + LCC + SLCA,

Where LCA is the environmental life cycle assessment (§ 1.3), LCC (Life Cycle Costing) is similar to the LCA approach but take into account economic evaluations and SLCA stands for societal or social life cycle assessment. Considering the LCA as a well know and reference methodology, Klopffer in its research suggest at least two options to include LCC and SLCA in the sustainability assessment of product:

- Option 1, LCSA = LCA + LCC + SLCA, based on three separate life cycle assessment with the same system boundaries, excluding a formal weighting between the three pillars: there isn't any compensation between the three sustainability sphere and so transparency in results is ensured.
- Option 2, LCSA = "LCA new", including LCC and SLCA as additional impact categories in Life Cycle Impact Assessment, with the advantage to do an univocal analysis of the system products under study, considering the same input and output or, in other terms, the same life cycle inventory data.

From the definition of sustainability the principal critical point has been to understand how it is possible "to measure sustainability": LCSA methodology is "the idea", many efforts have been made to create and standardize a recognized assessment methodology but nowadays a solution is not yet be found.

1.1.2 LCSA: state of the art, critical points, proposals and future developments

In this paragraph is reported an overview of some publications that have been considered of relevant importance to understand the intrinsic limits of LCSA that are and will be analyzed by scientific community with the aim to create a general and diffuse consensus around this approach.

A through collection of all aspects about LCSA on which research must put attention have been given in the book "Toward a Life Sustainability Assessment" (Ciroth et al., 2011), edit by UNEP. In this publication are underlined the principal areas of intervention to improve the methodology and to allows its applicability:

- Considering the Option 1 gives by Klopffer, a greatest number of case study will allow to test the methodology and to achieve a better consensus between practitioners;
- Development of technical competences, for conducting analysis on product based on life cycle perspective;
- Development of data inventory on appropriate database to support system analysis and assessment;
- Communication of results, in consideration to the three different sustainability analysis (environmental, economic and social), evaluating the probabilities to give separate or differentiate evaluations;
- Punctual definition of the so called "areas of protections" (Human Health, Ecosystem Quality and Resources) inside a sustainability assessment.
- Consideration of needs of future generations, to prevent the risk of wrong analysis, choices and compromises in these choices;
- Consideration about the interrelationship between the three sustainability dimensions;
- User-friendly approach, to be simply used by many stakeholders and practitioners;
- Formulation of a guideline, a sort of reference standard as for environmental LCA (ISO, 2006 a, b)
- Research to avoid double counting in the application of the three different analysis and consideration of the time dimension, avoiding the exclusion of impact effects on the future.

Another interesting view on the state of the art of LCSA is made by Cinelli (2013), that consist in a report from a Workshop made in Copenhagen in the last November, 2012. The aims of the meeting were to discuss the different schools of thoughts on LCSA and to outline a research agenda framework for enabling/improving LCSA. Different research presentations about LCSA possibilities and perspectives have been made, that could be summarized as follow:

- LCSA = "LCA new" (Klopffer, 2008); LCC and SLCA should be included as additional impact categories in the life cycle impact assessment, following the LCA standard ISO, 2006 a, b);

- LCSA = Eco-efficiency + SLCA. Starting from Eco-efficiency standard (ISO, 2012a) can be added to LCA results a “monetary” component. The addition of SLCA is required to cover social impacts;
- LCSA = LCA + socioeconomic analysis. Framework proposed by the German Institute for Energy and Environmental Research, in which results from environmental impact indicators are combined with socioeconomic evaluations;
- LCSA = LCA_{mod} and $SLCA_{mod.}$ A combination of an LCA and SLCA: both methodologies should be revised and expanded in order to account for those aspects that are currently not covered, for example including a way to evaluate how product life cycles affect poverty in the present generation and how affect the stock of capital should be included in presented LCA and SLCA methodologies.

This last formula has been suggested by Jørgensen et al. (2013): the authors, starting from the Brundtland definition of sustainability, and made a research with the objective to analyze the claim that in order to assess the sustainability of products, a combination of the results from a life cycle assessment (LCA), social life cycle assessment (SLCA) and life cycle costing (LCC) is needed. Considering the definition in WCED (1987), the product's sustainability assessment should addressing the extent to which product life cycles affect poverty levels among the current generation, changes in the level of natural, human and social capital available for the future population. In some cases existing SLCA approaches allows to extend the focus analysis on which product life cycles affect poverty; in the same way, LCA is a mean to understand which product life cycles affect natural capital and human capital is a topic covered by both LCA and SLCA in different ways. Considering the actual level of scientific research, it is difficult to relate good or causes that create and destroys social capital which the existing life cycle methodology. LCC is relevant for sustainability analysis if it is an instrument to evaluate monetary gains or losses for the poor, taking into account that this issue is, in some cases, considered in the SLCA approaches. The conclusion of this work made by the authors was that LCSA should include both an LCA and an SLCA considering how product life cycles affect poverty and produced capital; furthermore LCC may be taken into account if it helps assessing income gains for the poor.

One of the more recent publication and interesting analysis about the start of life cycle sustainability assessment has given from Zamagni et al. (2013); in a worldwide contest where sustainability has become quite a keyword in any decisional context and where from scientific community many efforts are making to provide guidelines and methodologies to assess sustainability basing on the life cycle approach as methodological support to integrate sustainability into design, innovation and evaluation products and services, different aspects need to be take into account and improved. Authors underline these analytical aspects to be discussed:

- The scale of the assessment (from the global level in which geopolitical implication are involved, to the continental, country, up to the regional and local scale);
- The time frame, considering how actual impacts could have effects in future and how certain present problems may be solved in the future by choosing now a certain strategy
- The ways how mechanisms could be addressed (e.g. considering link between activities, processes and different product systems);
- How different stakeholders and actors should be involved in the analysis, considering the different perspectives guides about the choice of the modeling techniques to be applied and to define the value system from which sustainability indicators are derived.

A very interesting question that arose from this publication is "*are the methods and tools developed so far able to address sustainability questions in business and policy context?".* This question is emblematic in consideration of the sustainability assessment methodologies actually developed and, at the end of discussion, it is underline as "*there will be a continued need to further refine and develop measures of each of the pillars of sustainability, while at the same time promoting social processes to encourage learning and adaptation from inadequately modeled and understood dependencies between the pillars*" (Zamagni et al., 2013).

Some years ago Finkebeiner et al. (2010), exploring the current status of Life Cycle Sustainability Assessment for products and processes affirmed that while for the environmental dimension well established tools like Life Cycle Assessment are available, for the economic and social dimension, there is still need for consistent and robust indicators and methods. A part interesting of this research was, in particular, the purpose of two ways to conduct the assessment phase to give sustainability indications. The first has been the so called "Life Cycle Sustainability Triangle" (LCST) where environmental, economic and social aspects are considered together. This method, that is an adaptation of the representation used for chemical mixtures, can be applied to the weighting of any three parameters. Applying this model the utility values social, economic and environmental aspects are to be weighted and these utility values are the input variables for the weighting procedure. The sustainability utility value or total utility value of an alternative is calculated by normalizing these three values, multiplying them by a weighting factor and then adding them together. The LCST (show the example in figure 2) represent the way to choose the different weighting values linking to the different type of indicators: this could be seen as a decisional tool that allows comparisons between different products, basing on the same decisional rules.

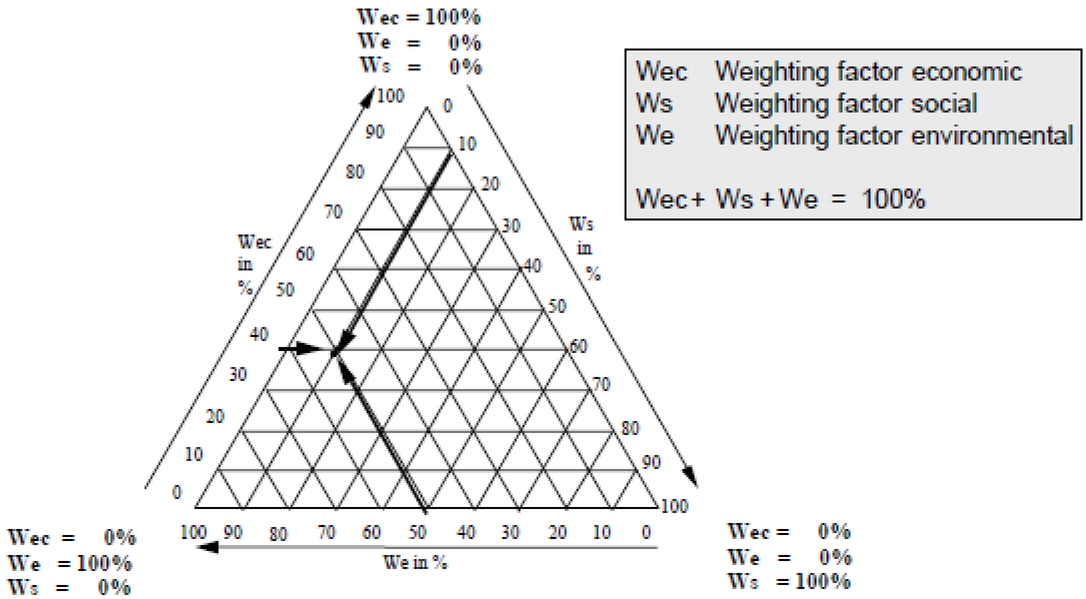


Figure 2 Example of weighting set based on LCST scheme (Finkebeiner et al., 2010)

The second approach for impact assessment and results communication proposed was the so called Life Cycle Sustainability Dashboard (LCSD). The methodology and the related software on the basis of this evaluation scheme (Traverso and Finkbeiner, 2009) were established by a research group of the Joint Research Centre of Ispra (Italy). In the LCSD software a certain number of indicators and their values can be inserted and these indicators are grouped into a limited number of topics: in a specific way for the application to LCSA the indicator sets used for LCA, LCC and SLCA can be used and implemented together. All indicator values for each considered product or service can be used and, for each indicators, a weighting factors could be considered. In the next figure (fig. 3) an example of LCSD graphical scheme is show for a specific case study on different hard floor coverings.

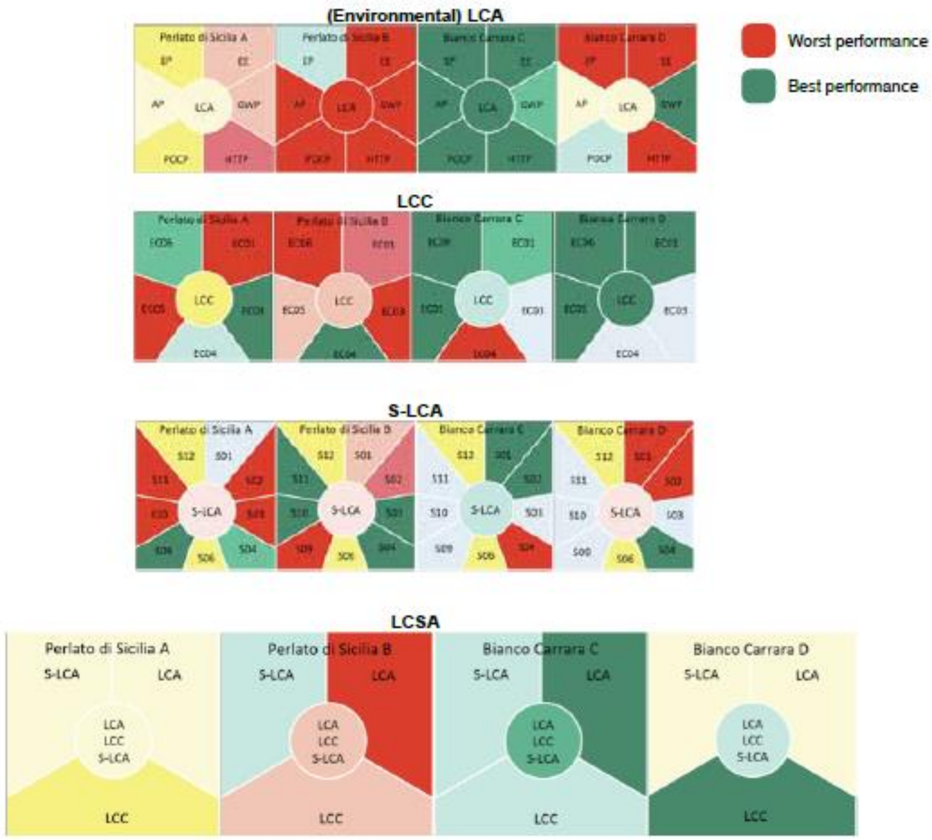


Figure 3 Example of Sustainability Dashboard (Ciroth et al., 2011)

In this way it is possible to see the different comparisons between single sustainability issues (LCA, LCC, SLCA) and have also a general results in terms of sustainability performances of each products in comparison to the other ones.

Considering the topic of sustainability assessment methodology, another interesting contribute to the research comes from Ostermeyer et al. (2013). In this study was applied the multidimensional Pareto optimization methodology to evaluate sustainability performances of a specific product case study, the building technologies. Beyond the specific application, this research underlines another different possibility for the assessment phase: considering LCC and LCA indicators come from different solutions, with the proposed methodology (under specific considerations and assumptions) it is possible to realize a Pareto-optimal curve that allow to individuate the best possible solutions. The results of the calculation could be visualized in a diagram with economic indicator on Y-axis and ecological indicator on X-axis how shown, as example, in the figure 4 where red line represent the optimum.

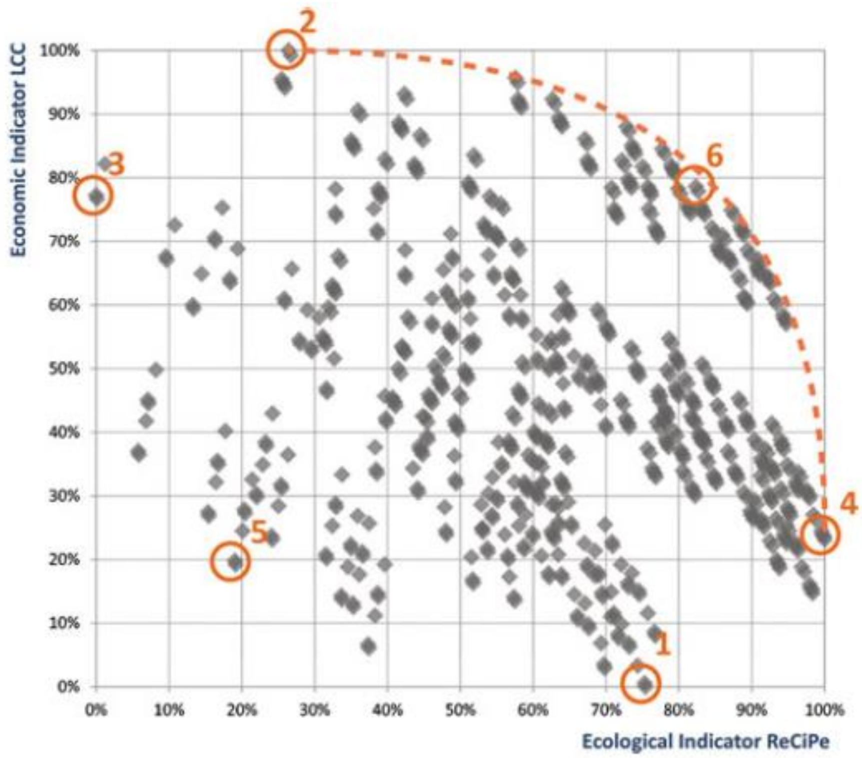


Figure 4 Example of Multidimensional Pareto Optimization results for sustainability assessment application.

The authors also concluding that the development in the field of social indicators has to be strengthened in order to come up with a holistic sustainability picture. Another dimension (social one) should be considered applying this methodology: a three-dimensional analysis might be done that gives as result a Pareto-optimal surface as reference to sustainability evaluation on products under analysis and comparison.

The multidimensional analysis has been also suggested by Vinyes et al. (2013) that applied the methodology for the LCSA study used cooking oil waste management. In this case study LCSA was implemented as the combination of LCA, LCC and S-LCA results without formal weighting between them, considering that weighting problem exists on the weighting of individual indicators within each of the three sustainability dimensions, and weighting among the three dimensions of sustainability. So single and separate life cycle analysis were conducted (considering the same product system and the same reference unit). To relate different indicators and their impact to the functional unit (reference unit) authors assumed that each dimension (environmental, economic and social) has the same weight, but the indicators chosen have different percentages of contribution to the global sustainability of the systems studied: positive and negative indicators has been distinguished. Negative indicators are those that have a negative contribution to sustainability (economic and environmental indicators) and positive indicators are those that have a positive contribution to sustainability (social indicators). In this way, to apply multi-criteria approach, the indicators used in LCA, LCC and S-LCA have been grouped in three sustainability factors (SF), firstly transforming all indicators into contribution percentages (calculated by comparing the values that each system have obtained for the same indicator, assuming a value of 100% the highest indicator value) and then assuming scores index from 1 to 5 for each indicator according to the percentage of contribution assigned (a differentiation has been made between negative indicators, as the case of economic and environmental assessment, and positive indicators, as the case of social assessment). Finally, for each sustainability dimension a total score was calculate through the sum of different impact categories indicators considered; an example of results obtain is shown in figures 5.

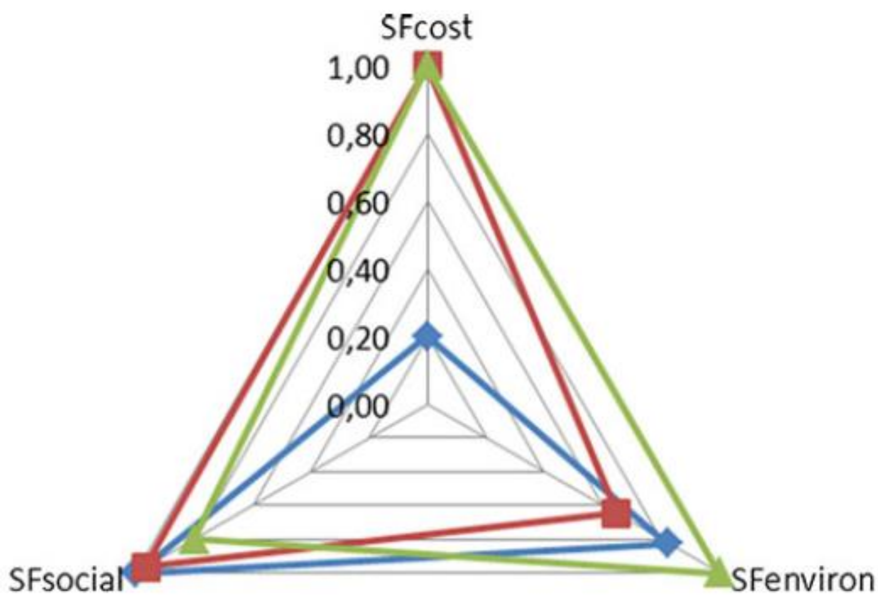


Figure 5 Example of LCSA results (Vinyes et al., 2013)

It is clear as, in the graph, the different colored lines represent results for each single system considered in the comparison study.

The analysis of all these publications help to understand from which contest the concept and the idea of Life Cycle Sustainability Assessment methodology was born and in which way it has developed over time. Many critical points emerged during this methodology development process, especially in relation to a defined and shared methodology to conduct the assessment phase. This relevant problem is linked to the different type of indicators individuate for each specific sustainability dimension and to the difficulties, or maybe the impossibility, to find a functional relationship between each environmental, economic and social indicator. Taking into account the cited publications, Table 3 summarized a more deepened analysis made with the aim to check the aspects that should be improved for a future development of the LCSA approach and in particular have been individuate this general critical area of investigation:

- Effective communication and comprehensibility of the results;
- The role of LCC in LCSA
- Development of S-LCA and integration inside LCSA
- Sustainability assessment (calculation of indicators)
- Double counting for some impact categories
- Temporal dimension in the assessment

For each analyzed publications, the red box in the table represent topics that are relevant for authors.

Table 3 Aspects to be improved for the development of LCSA methodology (underline in red)

	Topic					
Ref.	Effective communication and comprehensibility of the results	The role of LCC in LCSA	Development of S-LCA and integration inside LCSA	Sustainability assessment (calculation of indicators)	Double counting for some impact categories	Temporal dimension in the assessment
Ciroth et al., 2011						
Cinelli et al., 2013						
Jorghensen et al., 2013						
Zamagni et al., 2013						
Finkbeiner at al., 2010						
Ostemayer et al., 2013						
Vinyes et al., 2012						

Results coming from Table 3 underline as one of the more relevant problem is the definition of a well-defined sustainability assessment methodology and a specific sustainability indicators. The problem of the assessment method is also discussed by Zijp et al. (2015) where, in consideration that sustainability assessment could play a key role in decision making, the choice of the adequate methodology for assessment analysis represents a strategic and fundamental step. In literature there is a lack about the way to perform a problem analysis that guide to the choice of the assessment method, maybe due to a lack of systematic and versatile approaches to do it. Another relevant topic that needs future development is the field of social sustainability, where SLCA methodology (§1.2) is not yet well defined between stakeholders and practitioners and a general consensus must be developed. These results are in line with analysis of Valdivia et al. (2013) that punctually described area that need more future enhances: from data production and acquisition, methodological development, discussion about LCSA criteria (e.g. cutoff rules), to the definitions and formats of communication and dissemination of LCSA results and the expansion of research and applications combining (environmental) LCA, LCC and S-LCA. In this sense, authors underlined the importance for available software and database, so providers are called for in order to facilitate user-friendly and accessible tools to promote LCSA studies. Always in this sense also Sala et al. (2013) affirm that progress towards sustainability require development on methodologies for integrated assessment; LCSA represents an interesting and promising approach for developing a transparent, robust and comprehensive assessment but developments are necessaries: LCSA should be hierarchically different from LCA, LCC and SLCA representing an holistic approach which integrates, and not substitute, the reductionist approaches of the single part of the analysis (Sala et al., 2013).

1.1.3 LCSA in specific activity sectors: energy and food

Starting from previous considerations about LCSA and taking in mind the general concepts regarding LCA (about environmental impact assessment), LCC (for economic life cycle analysis) and SLCA (to evaluate life cycle social aspects related to a system product) in this paragraph is reported and analyzed a research made by Fedele et al. (2015a) with the aim to delineate the development and the implementation of the LCC, S-LCA and LCSA methodologies, through a literature review of scientific papers. In particular the objective of that research was focused on the specific food and energy sectors, with the objective to underline what have been the energy products and services on which case studies have been applied. The choice to put and focus the attention on these specific sectors is in line with the overall research study reported in this Thesis: how it will be possible to see in the next sections (Chapter 3) case studies have been applied in these sectors, in line with the choices and observation explained in the next paragraphs (§1.4.3, §1.4.3 and §2.2.2).
The analysis conducted by Fedele et al. (2015a) was an exploratory qualitative based on a bibliographic research review: starting from the experience of LCA development the research has been made on three relevant editors that have published many researches in the environmental sustainability field (Springer, Elsevier and Wiley) and has been performed searching specific keywords on books, texts and on relevant scientific papers published. The sections analyzed have been the “Title”, “Abstract” or “Keywords” and the specific chosen for the literature research were “life cycle costing”, “social life cycle assessment”, “life cycle sustainability assessment” and the relative

acronyms combined, respectively, with the words “food” and “energy”. All publications founded have been singularly analyzed considering the following features: source, year of publication, research field (LCA, LCC, S-LCA, LCSA or combination of them) and principal topic (sector of application or specific product/service/process analyzed). The general results was that scientific literature is not yet well developed in the topics analyzed and although many papers underline the relevance of these approaches for product analysis, specific case studies and applications are not so common. Moreover, results about cost analysis (LCC) shown that, although all studies have been referred to the entire product/services, a well-defined common approach is not shared between different applications. For SLCA and LCSA approaches are still under development and only a few case studies have been identified: the analysis shown that this conclusion is particularly valid for agricultural and food production sectors unlike the energy one. Considering the food sector the research has given as result 25 publications (Table 4), of which 17 papers published on scientific journal: about the 90% of the founded research had been published starting from 2010.

Table 4 Bibliographic research results for food sector (Fedele et al.,2015a)

Topic	Number of Publications	Life Cycle approach	Specific Applications
Food Packaging	3	LCC, S-LCA	
Specific Food Products	10	LCC, S-LCA, LCSA	Sugar, Wine, Milk, Olive, Citrus, Fish, Animals
End Of Life	4	LCC, S-LCA, LCSA	Waste Management, Disposal, Food Recycling
Other Products/ Processes linked to Food Sector	8	LCC, S-LCA	Chemical Product, Supply Chain, General Methodological Approach to Food Sector

About energy sector the analysis shown a higher number of scientific published research compared to the food sector, with 82 papers published (Table 5). A significant development on these research topics, similar to the food case, started in the last years, with a percentage of publication of about 65% in the last five years. Similar to the previous case, also in this one results underlined a relevant development of economic studies, with 61 LCC analysis founded but, despite this, a relevant number (16) of LCSA applications has been founded and only 5 applications of the SLCA methodology.

Table 5 Bibliographic research results for energy sector (Fedele et al.,2015a)

Topic	Number of Publications	Life Cycle approach	Specific Applications
Alternative electric energy production	18	LCC, SLCA, LCSA	Energy from wind, biomass, geothermal and solar source, photovoltaic, nuclear power, hybrid energy systems
Traditional and alternative fuels	26	LCC, SLCA, LCSA	Gasoline, diesel oil, biodiesel, biogas, hydrogen, cassava-based ethanol, biogas from algae, bioethanol, gas storage
Buildings and component	15	LCC, LCSA	Net-zero, retrofitting and commercial buildings, residential furnaces and boilers, smart window
Specific energy product/process	15	LCC, SLCA, LCSA	Insulation, electronic devices and motor, clothes dryers, fan, alternators, wind turbine, fluorescent lamp, WEEE, energy storage system
Traditional Electric Energy Production	4	LCC, LCSA	Electricity cost, gas fired combined cycle plant, power generation technologies, electric power generation
Transport applications	4	LCC	Electrical/electronic components in Automotive, electric drivers, energy and transportation technologies, electrified vehicles

In this case are interesting the results obtained for the fuels (traditional and alternative), in consideration to the use of these products in the transport services. In all this specific cases, in a life cycle perspective, other than the extraction and production(refinery) phases, the very impactful (especially in terms of environmental and social burdens) is the use phase, in which is considered the combustion phase and so the emissions to the air (that gives both environmental than human health problems).

As general results, in comparison with the development of LCA in the food and energy sector it has been possible to declare that the number of papers founded about LCC, S-LCA and LCSA is still small. The analysis showed that a consistent number of LCC, S-LCA and LCSA analysis are combined in the same study with LCA application and similar (e.g. carbon footprint), in particular in the food sector where more than half studies reported this combination.

This introduction underlines how sustainability is an aspect and a characteristic of products, process and service increasingly considered between the different stakeholders in the actual globalized market and world, but many efforts will be done especially to define a shared approach on the methodology to measure sustainability. Sustainability assessment could help companies to improve the performances of their products or services, as a logical consequence of the analysis, the assessment and so the improving of each life cycle phase or where this actions could be more efficient. A study of UN Global Compact and Accenture (Johnson et al., 2013) has reported that, on a sample of 1000, 93% of CEOs (Chief Executive Officers) from around the world view sustainability as a crucial part of their company's future success. Sustainable product development is become a core issue for the manufacturing industry and should be a target of designers to make products more sustainable (Chang et al., 2014). Moreover this instrument could give companies opportunities in terms of visibility in a market where, with the advent of social media, consumers who are supposed to receive, understand and act upon sustainability information have also become communicators of such information, which has become an important concern and driver for companies (Goedkoop et al., 2015).

1.2 Social issues in a life cycle perspective: the Social LCA (SLCA) methodology

Social Life cycle analysis includes a range of purposed methodologies that are still under analysis and that are different in terms of approach and for the nature of the results that they allow to obtain (Bocum et al., 2015). At conceptual level SLCA is a social impact assessment methodology that should be implemented with the aims to assess the social aspects (and socio-related aspects as socio-economic and socio-environment ones) and potential and real impacts of products and services along their entire life cycle, trying to include also that all remote stages of the life cycle where companies are however involved (e.g. all phases inherent to supply chain). As has been wrote by Jørgensen (2012) "a common logic behind, assuming that the use of SLCA in decision support will lead to improvements in the product life cycle is that it allows decision makers to choose the alternative among several, which leads to the most beneficial social impacts". This sentence underline as SLCA could be taking into account from decision makers especially in the comparison between different alternative products with the same function or, also, to evaluate different alternatives for the same product, for example in the design phase.

The discussion about the way to deal with social aspects in the already development life cycle assessment started about 25 years ago: the work of Fava et al. (1993), a publication of the SETAC (Society of Environmental Toxicology and Chemistry) titled "A Conceptual Framework for Life Cycle Impact Assessment", included the proposal of a "social welfare impact category" inside LCA; in this report has been underlined the strictly links between environmental and social aspects, where the primary emphasis should be on environmental impacts that arise directly or indirectly from other social impacts. Starting from this assumption initiated the discussion among LCA methodology developers and researchers on how and in which way to include social aspects into the environmental life cycle assessment of products and systems (Benoît et al., 2010). Analyzing the progress in the methodology and literature on this time period until now it is possible to see how several authors had addressed the social aspects with a life cycle approach but it is possible to affirm that the publication “Guidelines for Social Life Cycle Assessment of Products” (Andrews at al., 2009), that come from a UNEP/SETAC Life Cycle Initiative group, represent the first complete reference that suggests a general approach and a set of indicators to assess social aspects in the life cycle assessment framework. Since Guidelines Publications, the literature available and the social life cycle assessment case studies conducted were booming (Benoît et al., 2010); before that it is possible to find some studies and presentations, between them the most relevant in this development process are reported in the following table (Table 6).

Table 6 Main publications or presentations on SLCA methodology

Author	Title of paper/presentation	Main topic of research
Casado Cañeque F., (2002)	Evaluación de la situación laboral de empresas: El análisis del ciclo de vida como herramienta para el desarrollo sostenible.	Development of social company performance indicators for use in LCA
Norris G.,2004	Life cycle sustainable consumption analysis: evaluating the health impacts of income changes and development in life cycle assessments	Assessment of socioeconomic pathways to worker health impacts in the US economy and in global supply chains
Weidema B.P., 2006	Social impact categories, indicators, characterization and damage modelling.	Social impact assessment in LCA, including determination of damage categories, impact categories, and suggestions for category indicators or inventory data
Dreyer et al., 2006	A framework for social life cycle impact assessment.	
Benoît et al., 2007	Developing a methodology for social life cycle assessment	
Norris G., 2006	Social impacts in product life cycles: towards life cycle attribute assessment	Context-dependent life cycle attribute assessment over traditional forms of life cycle inventory information for conducting social life cycle assessment.
Swarr T., 2009	Societal life cycle assessment—could you repeat the question?	Methodologies differences between social life cycle assessment of a product and usual environmental LCA

As already mentioned, the 2009 with the Guidelines for Social Life Cycle Assessment of Products publication, could be considered the reference starting point for SLCA applications. This report has been made with the objective to provide to the all stakeholders a reference guide to work in the assessment of social and socio-economic impacts of products life cycle, describing the context, the key concepts, the broader field in which tools and techniques could be developed and their scope of application. The SLCA methodology helps practitioners to assess social and socio-economic impacts considering all the life cycle, from supply chain to the use phase and disposal, basing results on both generic and site specific data (Andrews at al., 2009). Positive or negative aspects could be linked to the behaviors of enterprises, to socio-economic processes, or to impacts on social capital and, in relation to the scope of the study, indirect impacts on stakeholders may also be considered. A SLCA analysis provides information on social and socio-economic aspects for decision making, instigating dialogue on the social and socio-economic aspects of production and consumption, in the prospect to improve performance of organizations and ultimately the well-being of stakeholders (Andrews at al., 2009). Kloepffer (2008) underlined interesting observation and proposal about SLCA:

- One of the biggest problem of SLCA impact assessment is the definition of indicators and in particular the scaling of some indicators: for example considering the payment of the workers, in a macro-economy contest, cheap labor could be an advantage for developing countries considering their situation in a global market;
- Taking into account the different published proposals, a process of harmonization could be achieved, especially in a perspective of studies comparison. The possibility to have different indicators measuring various aspects of SLCA with a standardized methodology could be an interesting, or maybe necessary, idea to develop. In a more deepened analysis these critical points emerged: relation between qualitative indicators and functional unit (unit of reference) of the study; methods to obtain specific inventory data for local SLCA; individuation of correct indicators and their quantification; social impacts quantifications; results evaluation.

In a some way Guideline (Andrews at al., 2009) are been write for giving answers to all these emerging doubts, difficulties and problems. Firstly, in this report to contextualize social analysis has been identified three specific dimensions:

- <u>Behaviors</u>. Particular behaviors or decision are the main cause of some social impacts.
- <u>Socio-economic processes</u>: social impacts are the downstream effect of socio-economic decisions, for example an investment decision could affect the life style ore the quality of life of a community.

- <u>Capitals</u>: human, social and cultural capitals of a population must been considered as the original context in comparisons to the choices that will be made, that could give positive or negative effects.

The relationships between these three dimensions, that could be effectively very complex to individuate, must be considered for a complete for a complete analysis. Social indicators could help also to define these relationships, but because the complexity and subjectivity about their individuation, in the guidelines has been defined a set of related indicators isolated from the stakeholder context. Different subcategories have been defined, classified according to stakeholder and impact categories and assessed by the use of inventory indicators (with a unit of measurement). Inventory indicators and units of measurement may vary depending of the context of the study. The purpose of the classification into impact categories gives by Guideline is to support the identification of stakeholders, to classify subcategory indicators within groups that have the same impacts, and to support further impact assessment and interpretation (Andrews at al., 2009). The next figure shows an example for the assessment reference framework gives from Guideline.

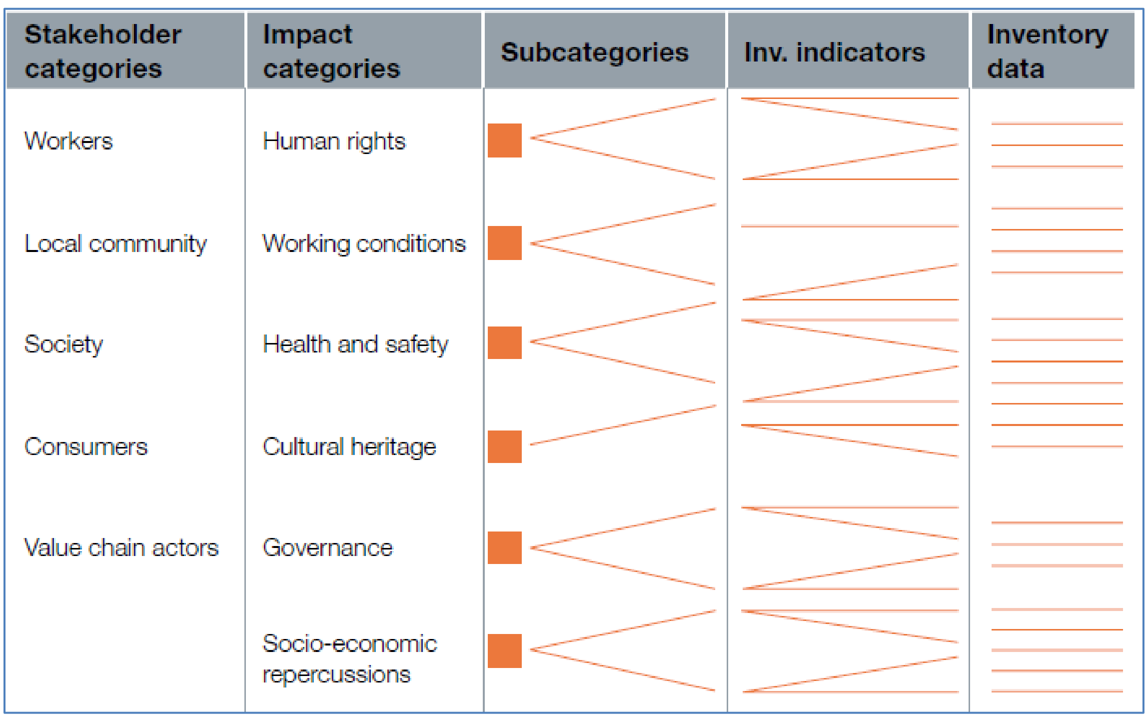


Figure 6 Assessment system for SLCA analysis (Andrews at al., 2009)

For individuation and classification of social and socio-economic subcategories (and obviously then for assessment) two schemes have been proposed: the stakeholder classification and the classification according to impact categories.

Considering the *stakeholders classification,* this proposal is based on the definition of possible stakeholders categories that could be individuate looking at the complete life-cycle (extraction, processing, manufacturing, assembly, marketing, sale, use, recycling, and disposal) of any product. Each of life cycle stages can be associated with geographic locations and conditions, and so for each one of these social and socio-economic impacts may be observed in five main stakeholder categories (Workers/employees; Local community; Society; Consumers; Value chain actors). For each of these categories it is possible to defines punctual subcategories to which associated specific indicators for the SLCA analysis. The figure 7 illustrated a scheme of different stakeholders categories and subcategories to considerate in a SLCA study.

Stakeholder categories	Subcategories
Stakeholder "worker"	Freedom of Association and Collective Bargaining Child Labour Fair Salary Working Hours Forced Labour Equal opportunities/Discrimination Health and Safety Social Benefits/Social Security
Stakeholder "consumer"	Health & Safety Feedback Mechanism Consumer Privacy Transparency End of life responsibility
Stakeholder "local community"	Access to material resources Access to immaterial resources Delocalization and Migration Cultural Heritage Safe & healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Stakeholder "society"	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of armed conflicts Technology development Corruption
Value chain actors* not including consumers	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

Figure 7 Stakeholder categories and subcategories (Andrews at al., 2009)

The other approach proposed is relative to the *classification according to impact categories*: these come from a logical grouping of S-LCA results. Stakeholder categories and subcategories are the basis on which to build impact categories but more efforts and studies needs to be done in order to determine one a common sets of generally accepted impact categories. However, similar to the developed environmental LCA (§1.3), the evaluation of the social impacts should be follow a cause-effect chain from the inventory data and flows to midpoint indicators (that aim to cover social problems that stand somewhere between the inventory data) and then continuing with further cause-effect modeling to assess endpoint results (to evaluate more general Area of Protection). As suggested by Andrews at al. (2009), two types of social and socio-economic impact categories can be identified:

- impact categories aggregate the results for the subcategories within a theme of interest to a stakeholder. These categories should be expressed regarding the stakeholders affected and may cover health and safety, human rights, working conditions, socio-economic repercussions, cultural heritage and governance. Each subcategory indicator results are aggregated into impact category results through a well-defined aggregation formula.
- impact categories model the results for the subcategories that have a causal relationship defined on the criteria. In this case Impact categories correspond to a model of the social impact pathways to a general (endpoints) indicator as human capital, cultural heritage and human well-being.

This second proposal is similar to the methodology on the basis of LCA assessment, where starting data inventory, through the so called classification and characterization phases, is possible to calculate impacts indicator that could be, with a second characterization step, grouped in common damage category.

After this guideline, another work from UNEP SETAC Group could be considered a reference pillar in the field of social analysis and assessment: four years later were published "The Methodological Sheets for Subcategories in Social Life Cycle Assessment" (Benoît et al., 2013). This guide supplement the Guidelines for Social Life Cycle Assessment of Products published in 2009 and were developed as a public resource to guide the application of S-LCA with the aim to provide an hands-on tool for practitioners to design and conduct S-LCA studies and provide detailed information on each of the subcategories introduced in the Guidelines organized by stakeholder category (Benoît et al., 2013). In line with the concepts on the base of Guidelines (Andrews at al., 2009) social life cycle impact assessment is the process by which inventory data is aggregated within subcategories and categories to help understand the magnitude and the significance of the data collected in the Inventory phase. This should be achieved in three steps: selecting impact categories and characterization methods and models, linking inventory data to a particular subcategories and impact categories (classification) and determining (calculating) results for the subcategory indicators (characterization).

The methodological sheets might to help implementation of these processes to correctly conduct a SLCA study. As example in the figure 8 is reported the methodological sheets built for analyzing the stakeholder category "Value Chain" and for the specific subcategory "supplier relationship".

Inventory Indicator	Unit of Measurement	Data Sources
Absence of coercive communication with suppliers	qualitative/semi-quantitative	▪ Interviews with management and procurement department ▪ Interviews with suppliers
Sufficient lead time	qualitative/semi-quantitative	▪ Interviews with management and procurement department ▪ Interviews with suppliers
Reasonable volume fluctuations	qualitative/semi-quantitative	▪ Interviews with management and procurement department ▪ Interviews with suppliers
Payments on time to suppliers	semi-quantitative	▪ Interviews with management and procurement department ▪ Interviews with suppliers

Figure 8 Methodological SLCA sheet for the stakeholder category "Value Chain" - subcategory "supplier relationship" (Benoît et al., 2013)

Considering this example the sheets could be a guide for a company that want to consider the potential social impacts of their activities or unintended consequences of its procurement and purchasing decisions on other organizations, and take due care to avoid or minimize any negative impact. In the inventory phase, data to calculate the indicator could be collected, for example, through Interviews with management, with procurement department and with suppliers.

These UNEP/SETAC Guidelines provide general procedures for implementing a SLCA but lack in terms of SLCA impact assessment methods and, in fact, starting their publication many new SLCA methods have been proposed. All these proposals are substantially different and a common accepted methodology is not yet developed (Chhipi-Shrestha et al., 2015): in general two different SLCA methodologies groups could be identified that are "performance reference point" and "impact pathways methods". Figure 9 shows these two different broad categories, that can be further divided in subcategories.

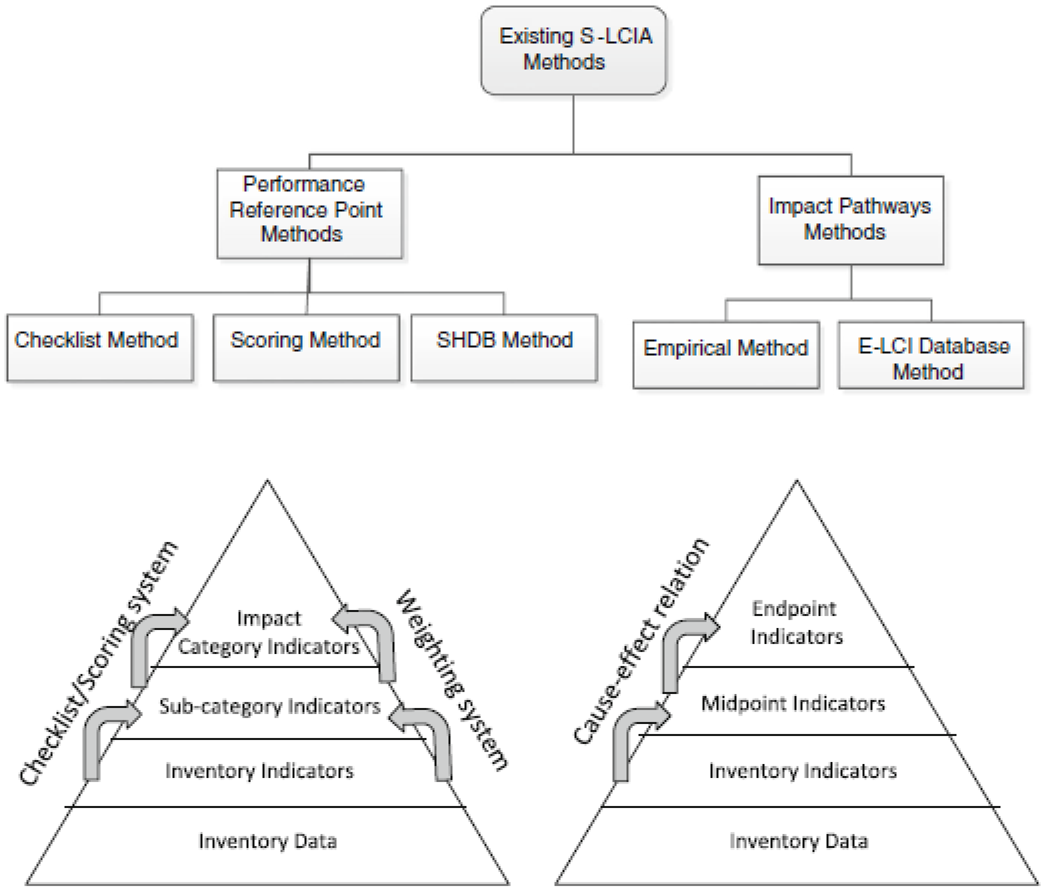


Figure 9 SLCA Impact Assessment methods (Chhipi-Shrestha et al., 2015)

Performance reference point method is based on target references based on internationally accepted minimum performance levels (as far example that give from ILO-International Labour Organization or from OECD-Organization for Economic Co-operation and Development). This method use colour scheme, scoring and weighting system to qualitatively or quantitatively aggregate data to a same impact indicator. The second type of social impact assessment method is based indeed on the concept of cause-effect chain to calculate impacts. This characterization model is similar in the structure to that implemented for environmental LCA (§ 1.3.2) and allows to calculate quantitative indicators (Chhipi-Shrestha et al., 2015). An interesting application of this second method category for social life cycle impact assessment is that proposed from Arvidsson at al. (2016). Similarly to the focus of this research (as will be possible to understand after these introduction sections - § 1.6), the Authors highlighted the importance of the human health indicator and so the needs of further development of impact assessment method to better described this indicator. In that research, based on different case studies on the specific knowledge of the product systems analyzed, a generic human health impact assessment was assessed, that entails the assessment of both positive and negative human health impacts quantified in terms of DALY (disability-adjusted life years) (Arvidsson at al.,

2016). This damage category is also taken into account in the existing impact assessment model that has been proposed for LCA (§1.3.2 and 1.3.3). Considering that, it is reasonable to think that starting from this existing structure, using DALY as reference unit, this could be an interesting staring point on which improve o built social characterization factors.
To conclude this general overview on social impacts and SLCA, one on the last study published (Zamagni et al., 2016) help to delineate possible future development to do in this field. An interesting observation is also reported in this publication, about the consistency between SLCA and LSCA: social impacts are mainly connected to a company and no to the function delivered by a given product (Zamagni et al., 2016). LCSA include a product-oriented perspective and in the same way also a SLCA must consider the specific product or service under study and the entire, but specific, life cycle. Other specific issues that need development in the future are the follow: the definition of what to assess and the way to choose indicators; the framework to define how to assess social impacts and respective indicators; the development of additional impact assessment models; the development of different approaches to define aggregation models and weighting rules; the development of database where inventory data are defined and differentiated for sectors, product groups and are geographically differentiate.

1.3 Environmental LCA: methodology and applications

The choice done in this research introduction to start the discussion with LCSA and then SLCA topics might seem unusual in comparison with similar and already published researches. In fact LCA is the most common and developed methodology that, in some cases, has given many suggestions and ideas to the others life cycle methodology for their development. But the proposed structure is effectively in line with the research path followed, which is started trying to give some contributions for the development of sustainability assessment considering LCSA methodology. Lacks founded in the LCSA and SLCA has been a sort of guide to deepened analyze LCA and understand if, also inside this methodology, improvement are useful in a sustainability (and social too) perspective. In this contest must to be read the choice to put LCA discussion after LCSA and SLCA ones.
Historically the study of environmental impacts of products started between the 1960s and 1970s, especially for comparative evaluations. The first researches that are recognized as similar LCA were relative to energy analysis while the first study, quantifying the resource requirements, emission loadings and waste flows, was applied to different beverages container and was conducted by the Midwest Research Institute for the Coca Cola Company (Guinée et al., 2011). In the years later, the

importance of addressing the LCA of a product or compared products became relevant. Governments started to encourage the use of LCA and so LCA has become a key point in the environmental policies and in voluntary actions, especially in the European Union, USA, Japan, Canada, Australia, and in developing economies as India and China. Life Cycle Assessment aims to track environmental impacts and assess them from a system perspective, identifying strategies for improvements without burden shifting. LCA is so a technique principally used and conducted to support corporate internal decision-making, such as for eco-design of products, process optimizations, supply chain management, marketing and strategic decisions (Hellweg and Milà I Canals, 2014). Shifting from company dimension to higher political and decisional levels, LCA is also considered and used to support the definition of sustainable consumption, production and development. International and national economy and development policies are supported from LCA analysis and results: for example the European Commission's Energy-using Product Directive (EU, 2005) was built basing on LCA studies that in that specific case identified the phase of use of household appliances as the main impactful. Other examples of environmental policies at European level which are based on the life cycle approach are the following (Zamagni, 2012):

- Sustainable Consumption and Production Action Plan (CEC, 2008),
- Waste Framework Directives,
- Thematic Strategy on the Sustainable Use of Natural Resources (CEC, 2005),
- Environmental Technologies Action Plan (CEC, 2004).

Since the start of this decade, LCA has been see as the framework to the development of LCSA, in particular in the development of inventory analysis and impact assessment methodologies: some impact and damage assessment models as Eco-Indicator 99 and Recipe 2008 (§ 1.3.2) include for example human adaptation scenarios in their endpoint models of climate change, but they do not include the environmental implications of these adaption scenarios such as the production of electricity to run additional air conditioners, as a consequence of global warming (Guinée et al., 2011). Staying focused on this specific aspect, one way to improve LCA to LCSA could be trough integration of social aspects in LCA, similarly to the "LCA new" proposal (§1.1.2). When integrating into LCA all the different social aspects that are treated in the different basic texts on social impact assessment it is essential to treat each aspect according to the different damage categories identified as the different aspects of human life that has intrinsic value: Life and longevity; Health; Autonomy; Safety, security and tranquility; Equal opportunities; Participation and influence (Weidema, 2006). Considering "Life and longevity" thise characteristics are intimately connected, since all humans die once in a lifetime, so that the damage to life is in fact not additional deaths, but a change in the timing of deaths (i.e. loss of live-years through premature deaths). Changes in the expected length of life are measured by the damage indicator Years of Life Lost (YLL) while non-fatal impacts on human health are measured in terms of the type of disability (disease or injury) and the duration of the condition: The unit of the damage indicator is therefore disability-years and the indicator is define a healthy Years Lost due to Disability (YLD) (Weidema, 2006). Combining YLL and YLD it is possible to calculate damage in terms of DALY, in a similar way that is follower in the LCA impact assessment model to evaluate the Human Health endpoint damage indicator. Shifting to a more general field, considering in a global way the LCA methodology, Chang et al. (2014) underlined as with respect to the operations of LCA, problems could be individuated about the definition, inventory, impact and interpretation: all four phase that are included in the standardized methodology (§ 1.3.1). Considering each phase, various kinds of obstacles exist: vague definitions, uncertain data, environmental impact and inaccurate interpretation are identified as the most significant problems and deserve deeper learning.

All these observations mean that efforts, starting to the environmental and environmental-related impacts assessment models improvement, should be done in a broader perspective of sustainability assessment.

1.3.1 Standard for LCA

In comparison to the other life cycle methodologies (economic, social and obviously sustainability), LCA is the only one that could be based on reference international standards:

- ISO 14040:2006 Environmental management -- Life cycle assessment -- Principles and framework (ISO, 2006a); this standard provides a general framework about practices, applications and limitations of LCA ;
- ISO 14044:2006 Environmental management -- Life cycle assessment -- Requirements and guidelines (ISO, 2006b); it has been developed for the preparation, management and critical review of the life cycle and provides guidelines for the LCA assessment, the phase of results interpretation and for the assessment of the nature and quality of data collected.

Other interesting technical references or standards, prepared with the aim to support practitioners in the application and to make correct choices when apply ISO 14040 and ISO 14044 for an LCA study are:

- ISO/TR 14047:2012 Environmental management -- Life cycle assessment -- Illustrative examples on how to apply ISO 14044 to impact assessment situations (ISO, 2012b);
- 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, 2012c).

Following ISO standards (ISO, 2006a,b) the procedure for an LCA study consists on four different phases interconnected with each other (Fig. 10):

I. Goal definition and scoping;
II. Inventory analysis;
III. Impact assessment;
IV. Interpretation.

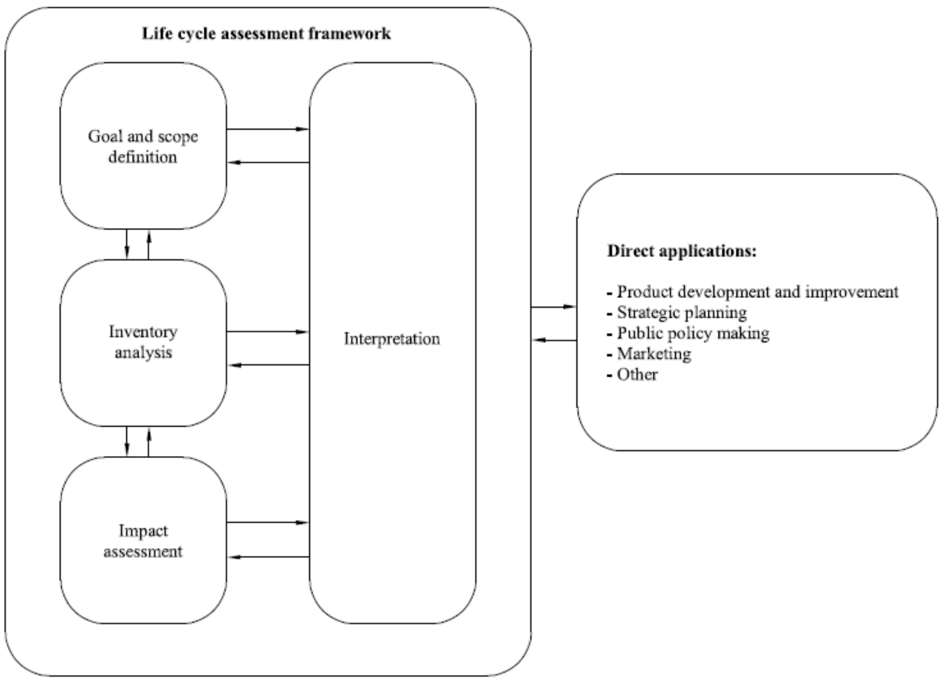


Figure 10 Life Cycle Assessment phases (ISO, 2006a)

In the <u>"Goal and Scope definition"</u> phase must be clearly defined goals and scope of the study that must be consistent with the intended application. This phase is therefore a very important step for the whole process in order to obtain the most significant results that are possible. Any decision taken in this phase will have implications both on how the study will be conducted and on the goodness of the final results. In defining the scope of the LCA must be taken into account and clearly describes the following topics (ISO, 2006a):

- *Product system*: is the set of unit processes that have one or more defined functions, and which represents the life cycle of a product. The process units are linked together by intermediate flows, with other systems of product by product flow, and with the environment by elementary flows;

- *Product system functions*: they are the characteristic functions of the product system;
- *Functional unit*: is the unit of reference for all the inflows and outflows respect to the system and for the potential environmental effects. When comparing between them different products or procedures, it is of particular importance for the system to study the validity of the functional equivalence criterion, i.e. the properties and functions of the products must be similar to be able to compare;
- *System boundaries*: represent the whole of unit processes, and the level of detail to be included in the study. Must be determined all temporal, spatial and functional aspects related to the study, and in accordance with the goals of the LCA. In order to reduce the extent and complexity of the investigation within reasonable limits, can be considered exclusion criteria (cut-off rules), based on the contributions of mass, energy and / or environmental relevance;
- *Allocation procedure*: consists in the method of distribution of the processes shared among multiple product systems;
- *LCA methodology and types of impacts*;
- *The interpretation* to be used;
- *The requirements of the data* (types and sources of data): various types of data can be collected from various types of sources; They can come directly from the production sites associated with the processes included within the system boundaries (primary data), refer to literature data (secondary data), estimates or other sources (tertiary data);
- The *requirements of data quality*: include factors related to time, geographical and technological data, their accuracy, completeness, representativeness, consistency, reproducibility of the methods, uncertainty and data sources;
- The *assumptions* made;
- The *limitations* of the study;
- The interpretation to be used;
- *Type and format of the report* required for the study;
- The *choices of values and optional items*: any subjective decision or in any case not based on scientific considerations must be reported;
- The *type of critical review* (if necessary): it is made by a committee of experts and is mandatory for comparative studies open to the public.

The definition of the objective and the scope of a study provide the general background to conduct the LCA inventory lifecycle (ISO, 2006a). Subsequently, the “Inventory analysis” includes the quantitative description of the data and calculation procedures that allow quantifying the input and output material end energy flows from and to a product system, in relation to the boundaries of the system. The inventory analysis should include the following elements (ISO, 2006b):

- Process flowchart where are graphically represented all unit processes connected by flows of materials included in the model;
- Description of each unitary process and of the factors that influence the elements in the input and output;
- The list of streams and associated data relevant to the operational conditions associated with each process unit;
- A list indicating the unit of measurement used;
- The description of the techniques of data collection and calculation techniques for each category;
- Providing instructions to document particular cases, irregularities or other aspects associated with the data collected.

In many LCA case studies, arise the need to partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems; when it happens these material or energy must be allocated to the different products according to clearly defined procedures in ISO standard (ISO, 2006b) which suggests the following procedure:

1. Where possible you should avoid allocation by dividing the unit process to be allocated into sub-processes or expanding the system boundaries system to include additional functions related to the co-products;

2. In cases where the allocation is not avoidable, it must be used clear and defined physical relationships (depending on the mass, volume, etc.); if physical relationships cannot be used, other relationships (for example, the economic value of co-products) could be taken into account.

The phase of "<u>Life Cycle Impact Assessment</u>" consists in the calculation of potential impact (mid-point level) or damage (end-point level) indicators, starting from Life Cycle Inventory phase results. The results of the inventory assessment are converted into well-defined category indicators. The steps of a Life Cycle Impact Assessment are the following and are divided in mandatory (the first two steps) and optional:

a) *Classification*: the results of the inventory are divided among the various impact categories; these can be grouped into three, so called, major areas of protection (damage categories): resource depletion, human health and environmental quality. Within each impact category will be contained all the data that can potentially contribute to that environmental problem. It is important to remember that a flow of material can be differently classified and assigned to more than one environmental impacts;

b) *Characterization*: in this stage the results of the inventory analysis are converted in environmental measurable impact indicators using scientific models and equivalence factors calculated on a scientific basis and internationally recognized (characterization factors). After completing the classification of the different impacts caused by the process, methods of characterization allow to determine in homogeneous and in a quantitative way the contribution of individual impact. In literature many assessment methods are published, and this particular argument are deepened in the next paragraph (§1.3.2)

c) *Normalization* (optional): this procedure normalized the indicator results dividing them by a selected reference value to express impact indicator data in a way that can be compared among the different impact categories;

d) *Grouping* (optional): sorting and possibly ranking of the impact categories in homogenous groups;

e) *Weighting* (optional): each impact categories is multiplied for a weight or relative value, based on subjective choice of the values, and then summed to obtain an overall result;

Other analysis could be implemented to give consistence to the assessment results and in particular (ISO, 2006b):

- *Gravity analysis* to identify those data having the greatest contribution to the indicator result. These items may then be investigated with increased priority to ensure that effective decisions are made.
- *Uncertainty analysis* is a procedure to determine how uncertainties in data and assumptions progress in the calculations and how they affect the reliability of the results of the LCIA.
- *Sensitivity analysis* that has the aim to determine how changes in data and methodological choices affect the results of the LCIA.

Finally, Life Cycle Interpretation step should be conducted with the objective to analyze the results of the previous phases, make adequate conclusions and to provide an easily understandable, complete and consistent presentation of the results of the LCA study in a transparent manner and in accordance with the goal and scope of the study (ISO, 2006b). The interpretation phase also allows to identify areas where improvements could be implemented. The conclusions that emerge from this phase can generate a process of review and revision of the scope in accordance with the iterative nature of the method (ISO, 2006b).

In the next paragraph the focus the attention is focused on the impact assessment phase, and in particular on three common assessment method used for impact an damage calculation.

1.3.2 LCIA Methods analysis: Eco-indicator 99, Impact 2002+ and Recipe2008

In this section are analyzed three impact assessment methods commonly used for the classification and the characterization procedure that allows to calculate impact and damage indicators. The choice to make a punctual analysis of the methods comes from general considerations previously seen in the past paragraphs, and in particular taking in consideration that:

- Life cycle assessment phase in LCA is maybe the most critical phase in LCA and commonly under study and development, in terms of methods updating;
- Many suggestions from literature have underlined that in the definition and calculation of indicators could be include also social and economic evaluations in an optical of measuring sustainability performances of a product or service;
- In the existing assessment method for environmental LCA "social aspects" are in some way already partially taken into account, in particular in the definition of "Human Health" damage category expressed in terms of DALY.

The methods that are analyzed are: Ecoinidcator99 (Goedkoop and Spriensma, 2001), Impact2002+ (Jolliet at al., 2003) and Recipe 2008 (Goedkoop et al., 2013): in particular this last one, the most recent method published, will be analyzed in line with the objective of the research and with the research methods implemented in this study.

Each of the cited methods will be analyzed considering the impact and damage category that it allows to calculate and with a specific deepening about pathways to definition and calculation of Human Health damage indicator.

Eco-indicator 99

This method comes from the updating and development of Eco-indicator 9 (Goedkoop M., 1995) and consider three different perspective: egalitarian perspective (medium-term perspective), individualist (short-term perspective) perspective and hierarchist perspective (long-term perspective). This method allows considering three different damage categories: Damage to mineral and fossil resources (unit: MJ surplus energy, that represent the need of adding energy in consideration to the minor availability of mineral resources in the future), Damage to ecosystem quality (unit: PDF*m^2yr where PDF represent the Potentially Disappeared Fraction of plant species) and Damage to Human Health (unit: DALY: Disability Adjuste Life Years). Classifications (in some way represent by the arrows in the next figure) and characterization phase, starting from data inventory, allows to quantify these three indicator, as show in figure 11.

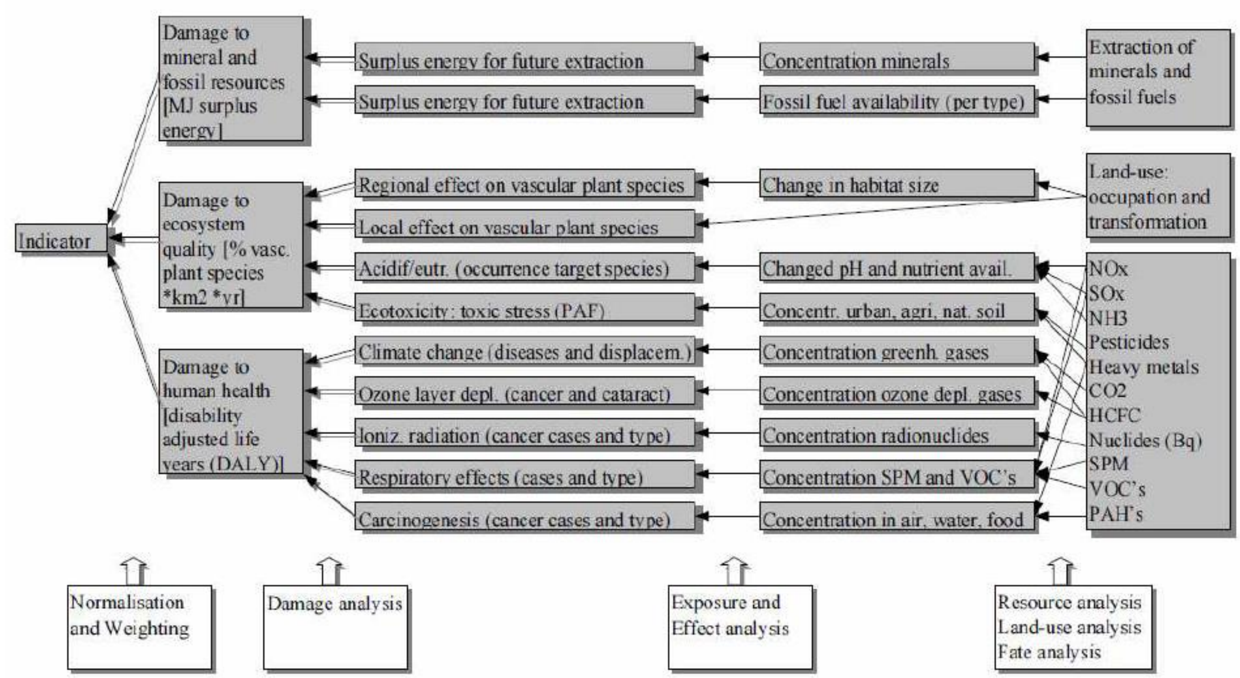


Figure 11 Eco-Indicator 99 method: inventory data and damage categories (Goedkoop e Spriensma, 2001)

The Eco-indicator model is based on the specific EUSES model: the purpose of the EUSES calculations for Eco-indicator 99 is to calculate the fate analysis of relevant substances in the environment in Europe. A steady-state concentration of a substance in different compartments is calculated taking into account standard flows. The compartments considered are: air, waste water, surface water, industrial soil and agricultural soil.

Considering the particular damage category "*Human Health*", five specific causes are considered in the definition and calculation of this indicator:

- Damage to Human Health caused by carcinogens substances;
- Damage to Human Health caused by respiratory effects;
- Damage to Human Health caused by climate change;
- Damage to Human Health caused by ionizing radiations;
- Damage to Human Health caused by ozone layer depletion.

All these contributions are evaluated through the application of a damage model (§ 1.3.3), in particular from the Hofstetter (1998) proposal, that suggest three separate steps: fate analysis (from emission to concentration in the specific compartment), effect analysis (from concentration to specific damage), damage analysis (considering possible different receptors, from specific damage to calculation of DALY).

Considering the damage to human health caused by *respiratory effects* the model used the same method proposed from Hofstetter (1998) and evaluates primary pollutants emitted into the air, the second

ary pollutants, that are formed in the environment from the primary pollutants, the fate factor, the contribution to any of the three perspectives and, finally, the resulting DALYs per kilograms emission to the air in Europe. Table 7 report an example of data used for this characterization phase through Eco-indicator 99 model.

Table 7 Damage to Human Health caused by respiratory problems from inorganic substances (Goedkoop e Spriensma, 2001)

Emissions to air							
Primary Pollutant	Secondary Pollutant	fate factor m2a/m3	Cultural perspective	Egalitarian Dalys/kg	Hierarchist Dalys/kg	Individualist Dalys/kg	standard deviation σ_g^2
CO	CO	1.00E-04	E	7.31E-07			64
TSP	PM10	4.40E-06	E,H,I	1.10E-04	1.10E-04	8.03E-05	19
PM10	PM10	1.50E-05	E,H,I	3.75E-04	3.75E-04	2.74E-04	19
PM2.5	PM2.5	1.70E-05	E,H,I	7.00E-04	7.00E-04	5.10E-04	19

The damage to human health caused by climate change is calculate considering six effects and two different time frame (short term from 2000 to 2100 and long term from 2000 to 2200). In the newt table (tab. 8) is show an example of calculated factors (DALY).

Table 8 Results for Damage to Human Health caused by climate change (Goedkoop e Spriensma, 2001)

		Malaria	Schistosomiasis	Dengue fever	Cardiovascular disorders	Respiratory disorders	People displaced (sea level)	Total death
		death	death	death	death	death	number	death
CO2 up to 2100	per tC	1.4E-05	0	3.3E-07	1.6E-05	2.3E-06	7.8E-07	3.3E-05
CO2 up to 2200	per tC	1.4E-05	0	3.3E-07	2.5E-05	3.0E-06	1.0E-06	4.2E-05
CH4 up to 2100	per tCH4	8.3E-05	0	2.7E-06	7.1E-05	1.7E-05	4.4E-06	1.7E-04
CH4 up to 2200	per tCH4	8.3E-05	0	2.7E-06	8.1E-05	1.9E-05	5.0E-06	1.9E-04
N2O up to 2100	per tN2O	1.3E-03	0	3.0E-05	1.4E-03	2.0E-04	7.4E-05	2.9E-03
N2O up to 2200	per tN2O	1.3E-03	0	3.0E-05	2.5E-03	2.7E-04	1.0E-04	4.1E-03

As it is possible to see from table these following effects have been considered for the estimate:

- Malaria, where that numbers take into account that mostly children are victims of malaria but some non-immune individuals will be affected as well;
- Dengue fever;
- Schistosomiasis;
- Acute mortality due to *respiratory effects*. For this point it is not clear because this effects is been considered in relationship with climate change. In fact Hofstetter (1998) in its publications

has considered in the damage model for the evaluation of human health effects by respiratory problems specific data that are representative of well specified environmental conditions. In this sense, linking respiratory effect to climate change means assuming fixed conditions;

- Disabilities related to the sea-level rise as infertility (heavy stressed people are often infertile), stress incontinence, unipolar major depression, post-traumatic stress disorders and panic disorders.

Impact 2002+

In the life cycle impact assessment contest, life cycle inventory results are connected to the corresponding environmental impact where LCI results are classified into impact categories each with a category indicator. These categories indicators could be put in any point between inventory results and category endpoints in the cause-effect chain (Jolliet et al., 2003). In this framework two type of methods have been developed: classical impact assessment method which limit quantification to early stages ion the cause-effect chain, as CML method (Guineé et al., 2002); damage oriented method that model the cause-effect chain until the endpoint categories, as the already seen Eco-indicator 99 method. Starting from the awareness of the development of these different approach, at the beginning of this century, the SETAC/UNEP Life Cycle Initiative suggested the use both these approaches, integrating them by grouping midpoint category with similar effects into a defined set of damage categories. In line with this suggestion the IMPACT 2002+ LCIA methodology proposed an implementation of combined midpoint-endpoint approach, linking inventory results with 14 midpoint categories, finally linked to other 4 damage category, providing characterization factors for almost 1500 LCI results. Figure 12 shows the structure of the IMPACT 2001+ methods, where the cause-effect chain is represented by the flows that linked inventory results, midpoint categories end endpoint categories. To better understand difference between indicator levels, it is opportune to know that midpoint indicator aim to characterize elementary flows, that represent any types of inventory data that contributes to the same type of impact (e.g. Human toxicity, Respiratory effects, Ionizing radiation, Ozone layer depletion, Photochemical oxidation, Aquatic ecotoxicity, Terrestrial ecotoxicity, Aquatic acidification, Aquatic eutrophication, Terrestrial acidification/nitrification, Land occupation, Water turbined, Global warming, Non-renewable energy, Mineral extraction, Water withdrawal, Water consumption). With “midpoint” is intended that this point is situated between LCI results and damage or endpoint categories (e.g. Human Health, Ecosystem quality, Climate Change and Resources). Midpoint indicators may be allocated to one or more damage categories, the latter representing quality changes of the environment. A damage indicator result is the quantified representation of this quality change and calculated by multiplying the damage factor with the inventory data (Humbert et al., 2012).

Considering IMPACT 2002+, new concepts and methods have been developed, especially for the comparative assessment of human toxicity and ecotoxicity as well as inclusion of impacts from turbined water and assessment of water withdrawal and consumption (Humbert et al., 2012)

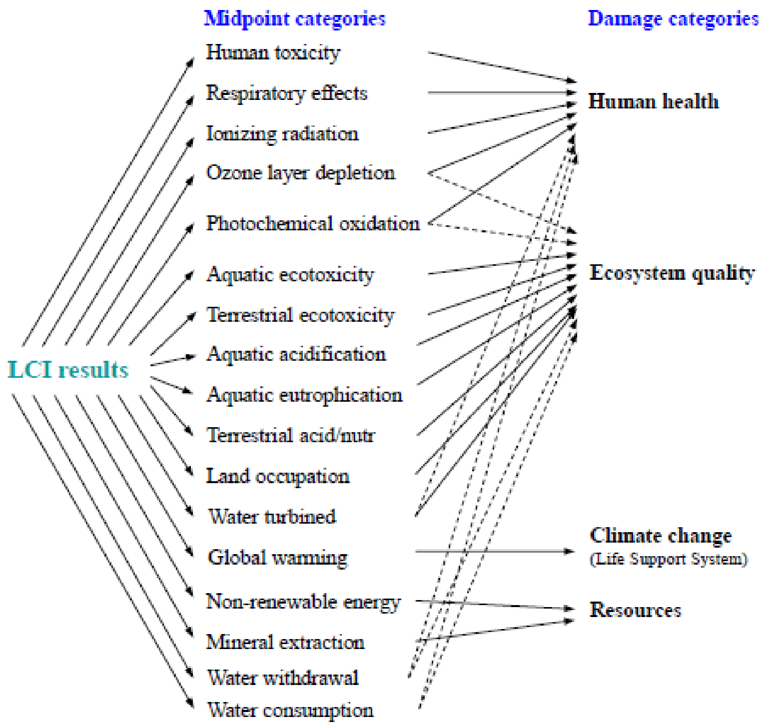


Figure 12 Scheme of the IMPACT 2002+ LCIA method (Humbert et al., 2012)

The next tables summarizes, respectively, the list of midpoint categories and the reference substance, used a reference to the others data (Tab. 9) and the various characterization damage factors of these substances (Tab. 10).

Table 9 Midpoint categories and reference substance used in IMPACT 2002+ method (Jolliet et al., 2003**)**

Midpoint category	Midpoint reference substance	Damage category
Human toxicity (carcinogens + non-carcinogens)	kg_{eq} chloroethylene into air	Human health
Respiratory (inorganics)	kg_{eq} PM2.5 into air	Human health
Ionizing radiations	Bq_{eq} carbon-14 into air	Human health
Ozone layer depletion	kg_{eq} CFC-11 into air	Human health
Photochemical oxidation [= Respiratory (organics) for human health]	Kg_{eq} ethylene into air	Human health
		Ecosystem quality
Aquatic ecotoxicity	kg_{eq} triethylene glycol into water	Ecosystem quality
Terrestrial ecotoxicity	kg_{eq} triethylene glycol into water	Ecosystem quality
Terrestrial acidification/nutrification	kg_{eq} SO_2 into air	Ecosystem quality
Aquatic acidification	kg_{eq} SO_2 into air	Ecosystem quality
Aquatic eutrophication	kg_{eq} PO_4^{3-} into water	Ecosystem quality
Land occupation	m^2_{eq} organic arable land·year	Ecosystem quality
Global warming	kg_{eq} CO_2 into air	Climate change (life support system)
Non-renewable energy	MJ Total primary non-renewable or kg_{eq} crude oil (860 kg/m^3)	Resources
Mineral extraction	MJ additional energy or kg_{eq} iron (in ore)	Resources

Table 10 Characterization damage factors used in IMPACT 2002+ (Jolliet et al., 2003)

Midpoint categories	Damage factors	Units
Carcinogens	1.45E-06	DALY/kg chloroethylene
Non-carcinogens	1.45E-06	DALY/kg chloroethylene
Respiratory inorganics	7.00E-04	DALY/kg PM2.5
Ozone layer	1.05E-03	DALY/kg CFC-11
Radiation	2.10E-10	DALY/Bq carbon-14
Respiratory organics	2.13E-06	DALY/kg ethylene
Aquatic ecotoxicity	8.86E-05	PDF·m^2·yr/kg·triethylene glycol
Terrestrial ecotoxicity	8.86E-05	PDF·m^2·yr/kg·triethylene glycol
Terrestrial acidification/nutr.	1.04	PDF·m^2·yr/kg SO_2
Land occupation	1.09	PDF·m^2·yr/m^2·organic arable land·yr
Global Warming	1	kg CO_2/kg CO_2
Mineral extraction	5.10E-02	MJ/kg iron
Non-renewable energy	45.6	MJ/kg crude oil

Looking to specific impact or damage category established in this method, some interesting observations arise. *Respiratory effects* midpoint category refers to problems caused by inorganic substances. Characterization factors and taken directly from Eco-indicator 99 (Goedkoop and Spriensma 2000) that are based on the work of Hofstetter (1998) using epidemiological studies to evaluate effect factors. The *Human Health* damage category is the sum of the midpoint categories "human toxicity", "respiratory effects", "ionizing radiation", "ozone layer depletion" and "photochemical oxidation". This category is dominated by respiratory effects caused by inorganic substances emitted into air. The characterization factors is calculate similarly to Eco-indicator99 considering, as modifications, that impacts on human health caused by climate change are not taken into account and human toxicity is calculate as sum of carcinogenic and non-carginogenic effects. The damage category *Climate change* is the same category as the midpoint category *Global warming* and is expressed in terms of “kg CO2-eq”. From authors (Jolliet et al., 2003) the effect of climate change on ecosystem quality and human health is not accurate enough to calculate reliable characterization factors. For this reason it is considered alone as specific damage category.

ReCiPe 2008

Recipe impact assessment methods has the last one published thanks to the works of, mainly, CML (Centrum Milieukunde Leiden), RIVM, Radboud University and PRé. The publication in 1992 of the CML LCA-guide marked a breakthrough in the scientific foundation of LCA methodology. A further Dutch innovation was the development of Eco-indicator 95 and its later version, Eco-indicator 99 (see below). The CML-guide and the Eco-indicator guide are currently widely accepted methodologies. However, they are based on different basic points: the CML uses the midpoint approach that has been proposed as the baseline method for characterization in the Handbook on LCA (EC, 2010) while the Eco-indicator 99 focuses on the interpretation of results and uses the endpoint approach. In ReCiPe 2008 methods have been developed both midpoint than endpoint categories comprising so two set of impact categories with associated characterization factors. The follow 18 impact categories have been addressed at midpoint level (Goedkoop et al., 2013):

1. climate change (CC)
2. ozone depletion (OD)
3. terrestrial acidification (TA)
4. freshwater eutrophication (FE)
5. marine eutrophication (ME)
6. human toxicity (HT)
7. photochemical oxidant formation (POF)
8. particulate matter formation (PMF)
9. terrestrial ecotoxicity (TET)
10. freshwater ecotoxicity (FET)
11. marine ecotoxicity (MET)
12. ionising radiation (IR)
13. agricultural land occupation (ALO)
14. urban land occupation (ULO)

15. natural land transformation (NLT)
16. water depletion (WD)
17. mineral resource depletion
18. fossil fuel depletion (FD)

while at endpoint level these three different damage categories have been identified taking into account further conversions and aggregations of some impact categories:

I. damage to human health (HH)
II. damage to ecosystem diversity (ED)
III. damage to resource availability (RA)

In a similar way to the Eco-indicator 99 method also for ReCiPe 2008 three different versions have been developed considering three different perspectives: individualist (I), hierarchist (H) and egalitarian (E).

These perspectives have not the aim to represent archetypes of human behavior, but they are merely used to group similar types of assumptions and choices. Perspective I is based on the short-term interest, impact types that are undisputed, technological optimism as regards human adaptation; Perspective H is based on the most common policy principles with regards to time-frame and other issues; Perspective E is the most precautionary perspective, taking into account the longest time-frame, impact types that are not yet fully established but for which some indication is available. In the next figure (Fig. 13) is represented the entire cause–effect chain that make in relationship data inventory, midpoint indicator and endpoint indicator, while Table 11 and Table 12 show the details of the environmental mechanism specific choices and assumptions that differ across the three perspectives for environmental mechanism that allows to define, respectively, midpoint and endpoint categories.

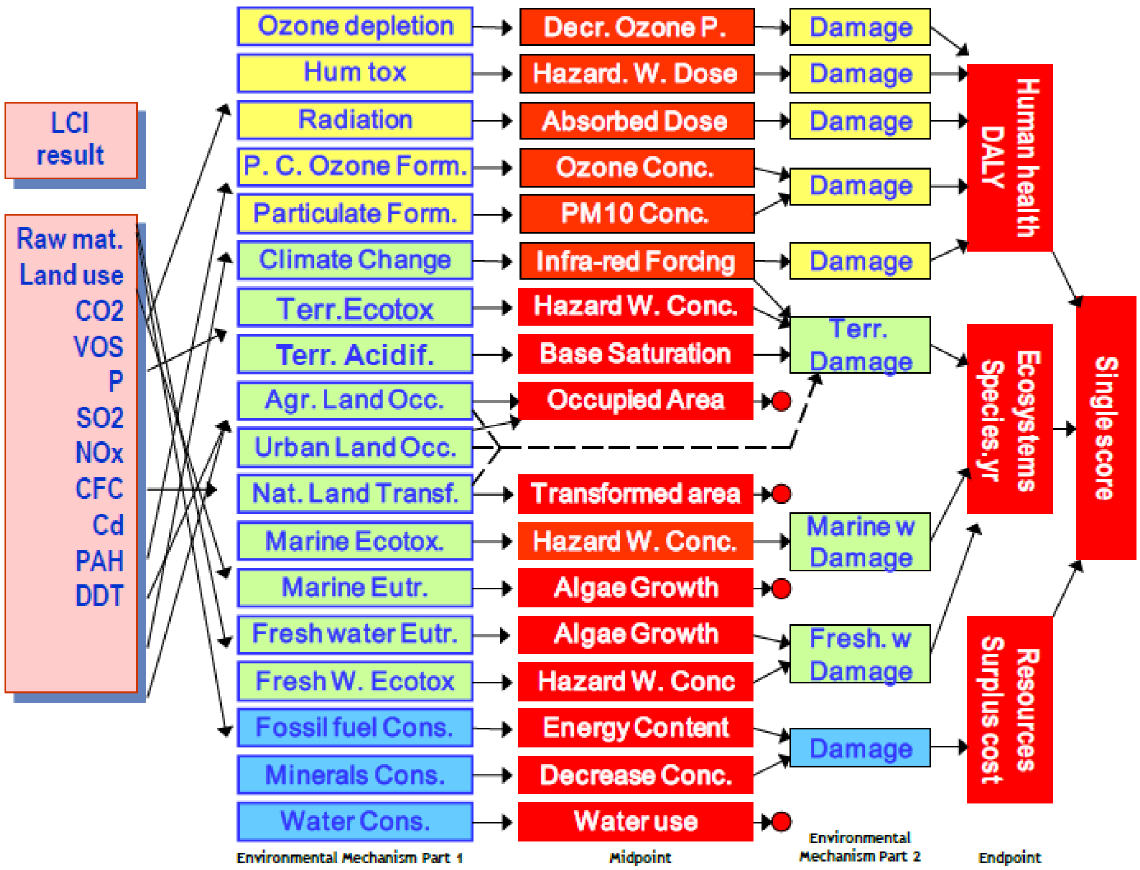


Figure 13 Relationships considered in the ReCiPe 2008 model (Goedkoop et al., 2013)

Table 11 Impact Categories: choices for the three different perspectives (Goedkoop et al., 2013)

To midpoint impact category:	Perspectives I	H	E
climate change	20-yr time horizon	100 yr	500 yr
ozone depletion	–	–	–
terrestrial acidification	20-yr time horizon	100 yr	500 yr
freshwater eutrophication	–	–	–
marine eutrophication	–	–	–
human toxicity	100-yr time horizon organics: all exposure routes metals: drinking water and air only only carcinogenic chemicals with TD_{50} classified as 1, 2A, 2B by IARC	infinite all exposure routes for all chemicals all carcinogenic chemicals with reported TD_{50}	infinite all exposure routes for all chemicals all carcinogenic chemicals with reported TD_{50}
photochemical oxidant formation	–	–	–
particulate matter formation	–	–	–
terrestrial ecotoxicity	100-yr time horizon	infinite	infinite
freshwater ecotoxicity	100-yr time horizon	infinite	infinite
marine ecotoxicity	100-yr time horizon sea + ocean for organics and non-essential metals. for essential metals the sea compartment is included only, excluding the oceanic compartments	infinite sea + ocean for all chemicals	infinite sea + ocean for all chemicals
ionising radiation	100-yr time horizon	100,000 yr	100,000 yr
agricultural land occupation	–	–	–
urban land occupation	–	–	–
natural land transformation	–	–	–
water depletion	–	–	–
mineral resource depletion	–	–	–
fossil fuel depletion	–	–	–

Table 12 From midpoint to endpoint level: choices for the three different perspectives (Goedkoop et al., 2013)

From midpoint impact category:	Perspective I	H	E
climate change	full adaptation: no cardiovascular risks no malnutrition low-range RR for natural disasters	mean adaptation: mean relative risk for all mechanisms no Diarrhoea: if GDP >6000 $/yr	no adaptation: high cardiovascular risks high risk for disasters high risk for malnutrition
climate change	dispersal of species assumed	dispersal	no dispersal
ozone depletion	–	–	–
terrestrial acidification	20-yr time horizon	100 yr	500 yr
freshwater eutrophication	NA	NA	NA
human toxicity			
photochemical oxidant formation	–	–	–
particulate matter formation	–	–	–
terrestrial ecotoxicity			
freshwater ecotoxicity			
marine ecotoxicity			
ionising radiation	–	–	–
land occupation	Positive effects of land expansion are considered	Fragmentation problem considered	No positive effects of land expansion considered
land transformation	Maximum restoration time is 100 yr	Mean restoration times	Maximum restoration times
water depletion	NA	NA	NA
mineral resource depletion	–	–	–
fossil fuel depletion	time horizon – 2030	For coal: time horizon – 2030 For all other fossils: 2030-2080	For coal: time horizon – 2030 For all other fossils: 2030-2080

Analyzing the *Human Health* damage category, as it is possible to see from Figure 13, it is determined from six different midpoint categories (ozone depletion, human toxicity, particular matter formation, photochemical ozone formation, ionizing radiation and climate change). An example of environmental mechanism to determine contributions on human health and ecosystem categories starting from climate change impact is represented in the next figure (Fig. 14).

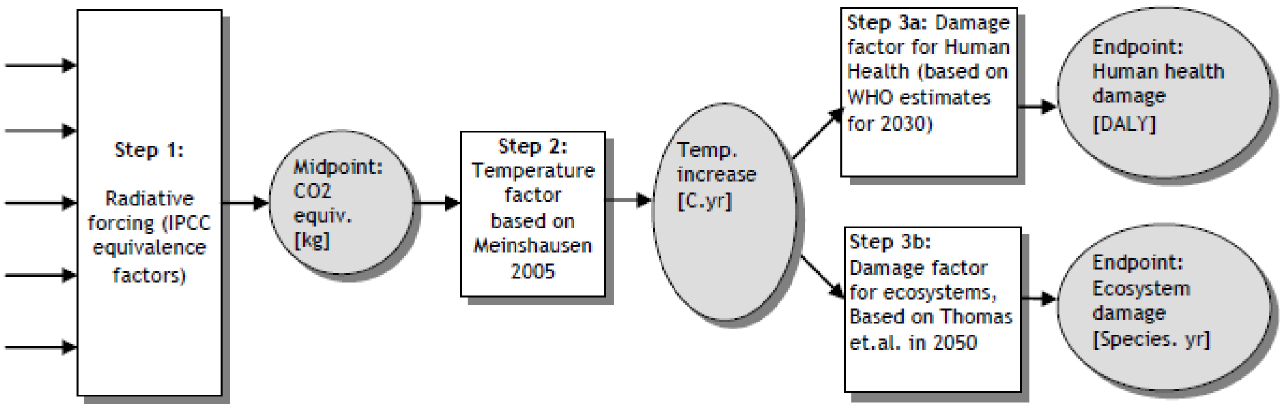


Figure 14 Harmonized midpoint-endpoint model for climate change (Goedkoop et al., 2013)

To calculate *Human Health* damage indicator ReCiPe 2008 applies the concept of DALY that include the years of life lost and life of years disable (without age weighting and discounting). As already discussed, the DALY concept was introduced in LCA by Hofstetter (1998). The DALY of a disease derived from human health and medical statistics and has been reported for a wide range of diseases (e.g. various type of cancer, vector-borne diseases and others diseases). In general, if equal weightings are applied giving the same importance of 1 year of life lost for all ages and if any discount for future damages is disregarded, DALY is the sum of years of life lost (YLL) and years of life disabled (YLD) defined as DALY = YLL + YLD, calculating YLD as products of "w" x "D" where "w" is a severity factor between 0 (complete health) and 1 (dead), and "D" is the duration of the disease. Moreover Goedkoop et al. (2013) underline the importance of a definition of space and time dimensions: DALYs refer to a specified region and time frame so applying world average DALY estimates in the calculation of characterization factors implies acceptance of the assumption that damage to human health due to life cycle emissions can be represented by world averages. For LCA case studies focusing on region-specific human health impacts it is necessary have great attention about DALY because if the study is focused on specific region boundaries in the world the DALY calculation may cause a change in the results. This note may be particularly important for emissions occurring now but having their impact in the future, such as emissions of carcinogenic or other impactful substances. Putting attention on *Human Health damage due to particulate matter and* *ozone,* the model evaluate the effects in terms of respiratory problems considering the substances emitted in the air. Different Fine Particulate Matters were considered: $PM_{2.5}$, $PM_{2.5\text{-}10}$ and PM_{10} coming from both anthropogenic and natural sources. ReCiPe 2008 focused in particular on effects of PM from anthropogenic sources, since only this fraction may be influenced by human activity. Fine Particulate Matter with a diameter of less than 10 µm (PM_{10}) represents a complex mixture of organic and inorganic substances and causes health problems as it reaches the upper part of the airways and lungs when inhaled. Secondary PM_{10} aerosols are formed in air from emissions of sulfur dioxide (SO_2), ammonia (NH_3), and nitrogen oxides (NO_x) among others (WHO, 2003). Inhalation of different particulate sizes can cause different health problems. From recent WHO studies, the effects of chronic PM exposure on mortality (life expectancy) seem to be attributable to $PM_{2.5}$ rather than to coarser particles. Particles with a diameter of 2.5–10 µm ($PM_{2.5–10}$) may have more visible impacts on respiratory morbidity (WHO, 2006). Considering Ozone, this is not is not directly emitted into the atmosphere, but it is formed as a result of photochemical reactions of NO_x and Non Methane Volatile Organic Compounds (NMVOCs). Ozone is a health hazard to humans because it can inflame airways and damage lungs. Ozone concentrations lead to an increased frequency and severity of humans with respiratory distress, such as asthma and Chronic Obstructive Pulmonary Diseases (Goedkoop et al., 2013). Starting from these substances to calculate damage in terms of DALY in relationship to their emissions in the air ReCiPe 2008 implement a damage model (§1.3.3) that includes fate, effect and damage analysis.

Moreover, studying as in the ReCiPe 2008 model has been developed the environmental mechanisms linked to *Climate Change*, as illustrate in Figure 14, four steps have been applied (De Schryver et al., 2009): 1) determination of radiative forcing, with the calculation of the GWP (global warming potential) characterization factor, that take into account the time-dependent abundance of an emitted substance (a generic greenhouse gas – GHG) in the air and its radiative coefficient (i.e. $W/m^{-2}*kg^{-1}$) related to the carbon dioxide relative values (CO_2 has been chosen as reference by the scientific community). 2) Determination of a temperature factor that related the emission flow of a GHG and the effect on the temperature. 3) Estimation of damage to human health in terms of DALYs and 4) estimation of damage to ecosystem diversity with a prediction model for the extinction of species on a global scale.

As mentioned before different perspective could be considered in the impact pathway calculation, and for climate change impact it is possible to use the following choices: the Hierarchist perspective seeks consensus, and the 100 year timeframe is the most frequently used (for instance it is referenced to in the ISO standards on LCA (ISO, 2006a,b); the Egalitarian world view takes a long term perspective, assuming the 500 year timeframe; the Individualist perspective assumes a short time frame, and thus it is possible to use the 20 year time frame.

Effects of climate change is considered in the calculation of human health damage, but could be interesting to know what kind of health effects linked to climate change are considered in the model. The ReCiPe 2008 Report (Goedkoop et al., 2013) helps us to find an answer to this question: in the next table (Tab. 13) are listed health effects linked to climate change. As it is possible to see the method does not consider many aspects as for example cardiovascular diseases, respiratory problems and natural disaster caused from climate change.

Table 13 ReCiPe 2008: health effects linked to climate change (Goedkoop et al., 2013)

Health effects	Analyzed in this report	Not considered
Malnutrition	1.	
Diarrhoea	2.	
Cardiovascular diseases	3.	
Respiratory problems		x
Natural disasters		x
Cyclones		x
Coastal and inland flooding	4.	
Droughts		x
Vector borne diseases		
Malaria	5.	
Dengue		x
Yellow fever		x
Rodent borne diseases		
Leptospirosis		X
Encephalitis		X
Lime		X

In this optic and from this idea, a deepened study and analysis of the ReCiPe 2008 model has been done during the research period with the aim to individuate model limitations regarding Human Health damage calculation. All six environmental mechanisms (ozone depletion, human toxicity, particular matter formation, photochemical ozone formation, ionizing radiation and climate change) have been analyzed and results are summarized in the next table (Tab.14).

Table 14 ReCiPe 2008 - Analysis of the Human Health damage model

Environmental mechanism	Specifications	Completeness of the model	Possible improvements
Climate Change	Cause: Greenhouse Gases emission in air. The model is based on air temperature, precipitations and animals and plants distribution but not considers respectively these effects: a) variation of atmospheric air circulation, pollens and pollutants distribution that give respiratory problems; b) drought, cyclones and flooding that generate natural disasters; c) vector and rodent borne diseases	NO	Some health effects could be integrated

Environmental mechanism	Specifications	Completeness of the model	Possible improvements
Ozone Depletion	The method takes into account all ozone depletion substances suggested from EPA (US Environmental Protection Agency): CFC, HCFC, Halon, HBFC, CCl_4, CH_3CCl_3, CH_3Br)	YES	-
Human Toxicity	Diffusion compartments (freshwater, sea, ocean, soil) identified with limitation to the European scale	NO	Consideration of a greater geographical scale
Particulate matter formation	European environmental system considered as a semi-open system: taking into account only outcome emissions but not considering income emissions (e.g. powders from Sahara zone through air currents)	NO	Contribution of emissions coming from external part side in comparison with the studied system
Ozone depletion	The model takes into account NO_x and NMVOC as absorbed ozone fractions	YES	-
Ionizing radiations	The model takes into account hereditary disease and cancer in terms of DALY but not consider cardiovascular pathologies	NO	Some health effects could be integrated

Obtained results underlined as also in this most modern assessment method, improvements could be done, especially considering the human health damage category that is representative of a social dimension inside a model born to evaluate environmental problems. To conclude the overview on the ReCiPe method must be cited the updating that has been made in 2016 (Huijbregts et al., 2016) that provided characterization factors that are representative for the global scale instead of the European scale. The number of environmental interventions has been expanded and have been added impacts of water use on human health, impacts of water use and climate change on freshwater ecosystem and impacts of water use and tropospheric ozone formation on terrestrial ecosystem as new damage pathways. The next figure (Fig. 15) is representative to the new update model.

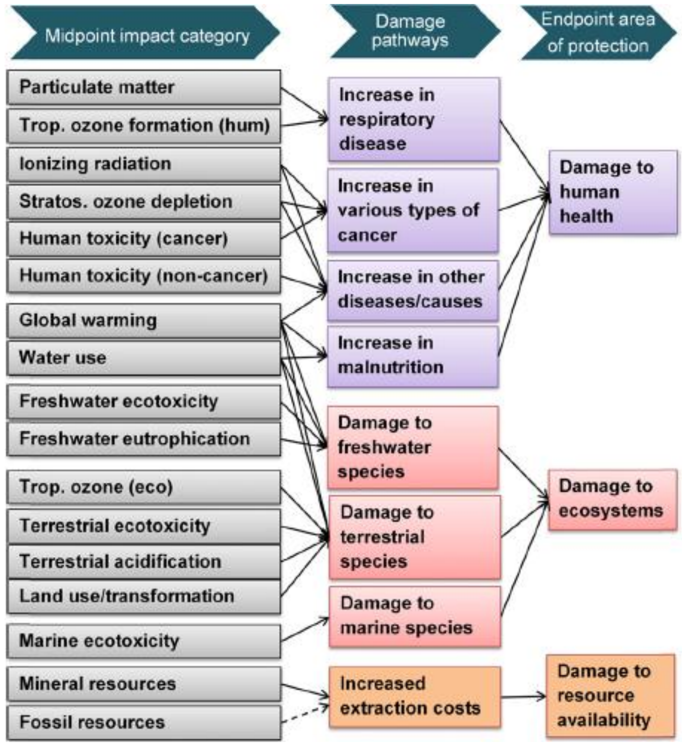


Figure 15 Impact and damage categories in ReCiPe 2016 method (Huijbregts et al., 2016)

Despite the development of the method other future improvement should be done especially in the way on which impact pathways are modelled; examples of missing pathways are: human exposure pathways related to indoor emissions to chemicals and fine particulate matter and direct application of pesticides to food items, change in incidence of infectious diseases due to climate change, fossil resource scarcity. Possible future improvements might be additional impact categories as marine eutrophication, invasive species and plastic debris, noise and impacts from nanoparticles.

1.3.3 Damage model: estimation of human health damage from respiratory disease

The common model for the evaluation of human health from respiratory problem, used as reference in the most used LCIA methods as see in the last section, is that proposed from Hofstetter (1998). It is in fact applied by frequently used methods Eco-inidcator 99 (Goedkoop and Spriensma, 2001), Impact 2002+ (Jolliet at al., 2003) and ReCiPe 2008 (Goedkoop et al., 2013): in this model, particulate matter (responsible for respiratory diseases) is dispersed considering mainly the dilution height and the residence time for particles, calculating damage in terms of Disability Adjusted Life Years (Notter, 2015). The model proposed by Hofstetter is based on the general idea of cause-effect pathways, where, in the field of LCIA, the use of cause-damage-analysis requires the development of damage functions which link the environmental interventions from the inventory data with the damage to the different safeguard subjects (Hofstetter, 1998). The definition of safeguard subjects is a prerequisite for the damage assessment, in line with the aim of the LCA analysis, and could be for example human health, ecosystem, buildings, agricultural yields, aesthetic values, and biodiversity. The safeguard subject "human health" includes in terms of LCIA both pressures on and damages to human health, both of which are due to changes in environmental conditions. For the definition and to built model Hofstetter underlined the necessary dichotomy between a top-down and a bottom-up analysis: these two procedures must to be combined in order to use all the available and accurate information to describe as many causal relationships as possible and to use the descriptive models as a reliability check to improve the quality of the prescriptive techniques. The next figure (Fig. 16) illustrates the analytical path that leads from observed human health damages to its causes (top-down approach).

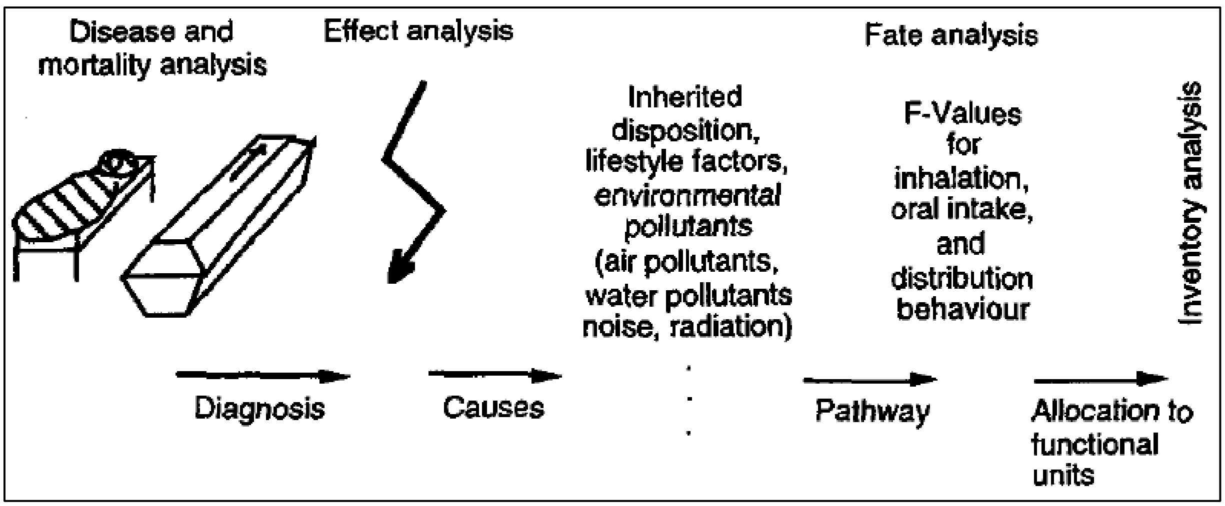


Figure 16 The top down procedure for Human Health damage (Hofstetter, 1998)

In this case for the definition of the model were implemented the following steps:

- The starting point was a normative determination of what the safeguard subject is and which damages represent an impairment of the safeguard subject (disease and mortality of humans can be conceptualized as damages to the safeguard subject of human health).
- Observation of patterns of diseases and of cases of mortality. Medical studies and diagnosis helped to identify the effects which caused disease and mortality, through the identification of the internal organ that is damaged and the mechanism causing the harm.
- Identification of the causes for these harms, using epidemiological studies.
- Identification of the causal risk factor basing on a reliable exposure assessment.
- Identification of the amount of emissions causing the exposure scenario.
- Attribution of the emissions to functional units.

It is easy to understand how this description of the damage-cause analysis implies the integration of different descriptive part and data that comes from difference disciplines as medicine, toxicology, environmental chemistry, and engineering.

If top-down approach helped especially to build the model, on the other sense a bottom-up approach allows considering emission to finally calculate the associate damage in relationship to the safeguard subjects defined for the analysis. Figure 17 illustrate a general set up of the impact pathway analysis within the ecosphere where the upper arrows for each level of analysis give examples for the cause oriented modelling and the lower arrows specify the descriptive modelling.

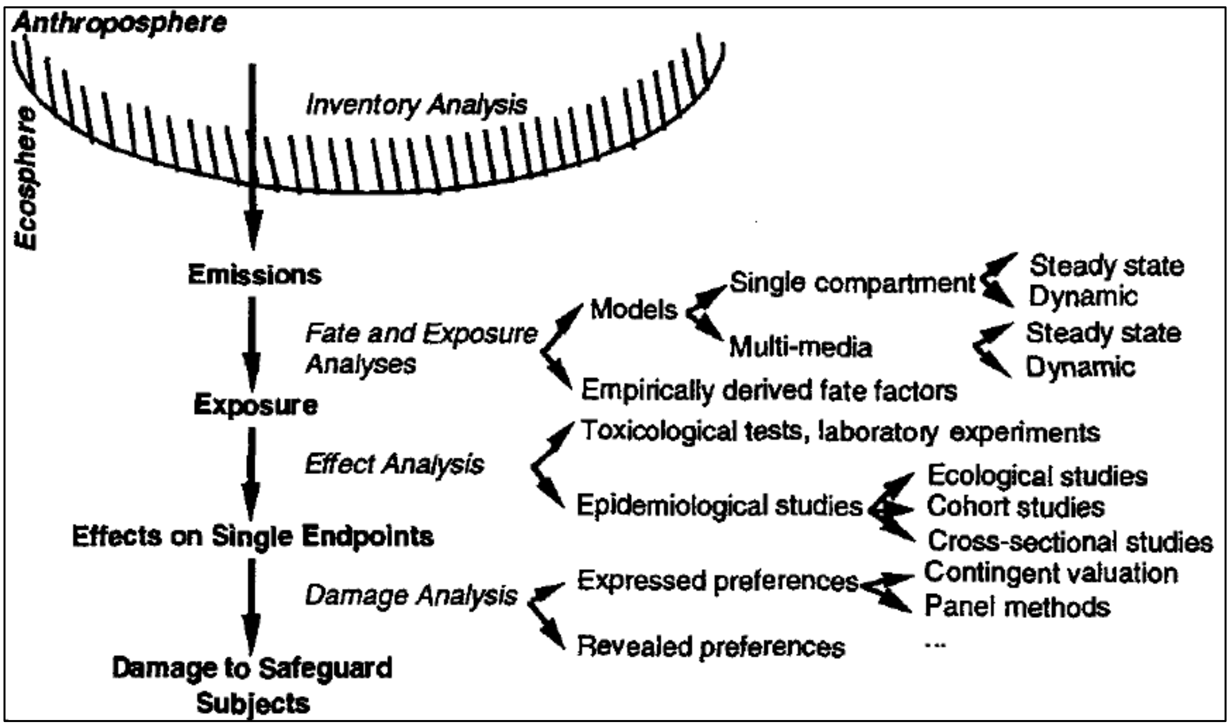


Figure 17 General set-up (bottom up approach) which is applicable to most impact pathways (Hofstetter, 1998)

The *fate analysis* model the relationship between emissions to air, surface water or soil and the exposure of humans, animals or plants to a contamination due to "inhaled" air, dermal absorbed air or water, water and food.

Exposure analysis could be done through two ways, depending on the effect analysis: it could use the concentration of pollutants in the compartments mentioned in the fate analysis (e.g., if epidemiological studies are used) or considering the part of pollutants which enter into the organism Secondary).

The *effect analysis* uses dose-response relationships to quantify the effects that can be expected due to the exposure. The endpoints affected are elements of the safeguard subject (e.g. cough or lung

cancer). LCA includes the effects that occur all over the world without limitations to time or place. The different sensibilities of receptors are reflected in the use of an average pattern.
The *damage analysis* links the effects on single endpoints to an index for the damage considers in the analysis. Focusing the attention on human health damage category, the next figure (Fig. 18) and the next discussion help to better understand the reasoning and choices made to define the model; this model is nowadays implemented in the most common LCIA method.

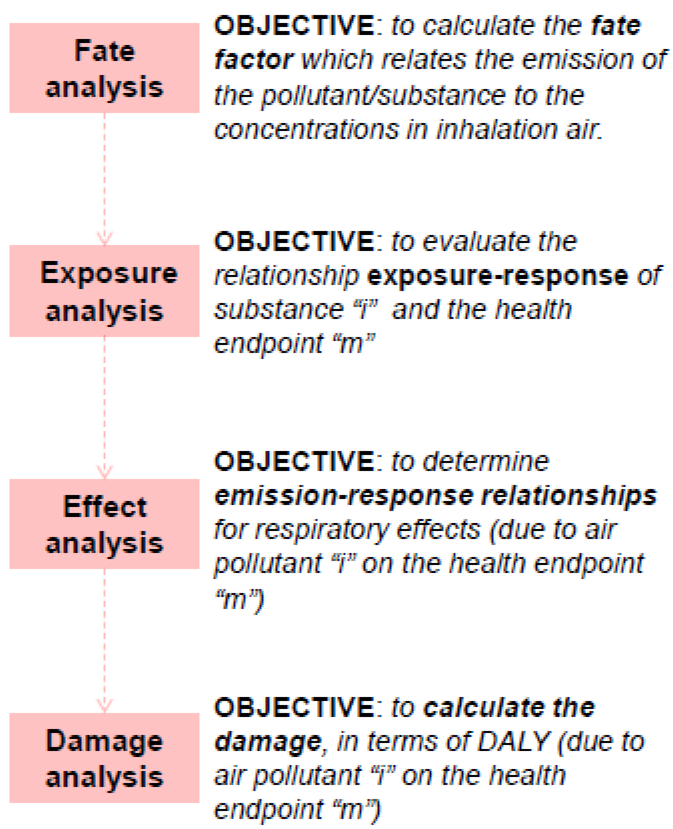


Figure 18 Damage assessment model for Human Health category

The aim of the fate analysis is to calculate accurate fate factors which relate the primary emission of substances to the concentrations in inhalation air for those substances that have been identified to cause respiratory diseases. The inhaled substances are the ones which have been shown in epidemiological studies to be related to morbidity or mortality assigned to the respiratory tract and are: Particulate matter PM_{10} and $PM_{2.5}$, nitrate and sulphate, $S0_2$, O_3, CO and probably NO_x. The model considers the residence time of these substances and the height of the mixing layer for particles in the atmosphere. In reference with measured or calculated concentrations for some areas due to known emissions the model allows to calculate the fate factors (in terms of m^2*year/m^3): this term comes from the calculation of average concentration of the pollutant in the air, the emission flow of this substance and the surface over which the emission occurs. The exposure analysis has the objective to evaluate the relationship exposure-response of substance in relationship with all possible targets. Fate and exposure analysis together contribute to the determination of the so called “intake fraction” (Humbert at al., 2011): the intake fraction is the fraction of the emission that are inhaled and is dependent from source, location and population density areas. In this area regionalizing intake fractions and therefore associated characterization factors by considering variability in population density patterns is an important step toward the reduction of overall variability and uncertainty in evaluating human health damage when LCIA is used (Humbert at al., 2011). Figure 19 represents an example of $PM_{2.5}$ intake fraction values from many publications, categorized for different emission location typologies.

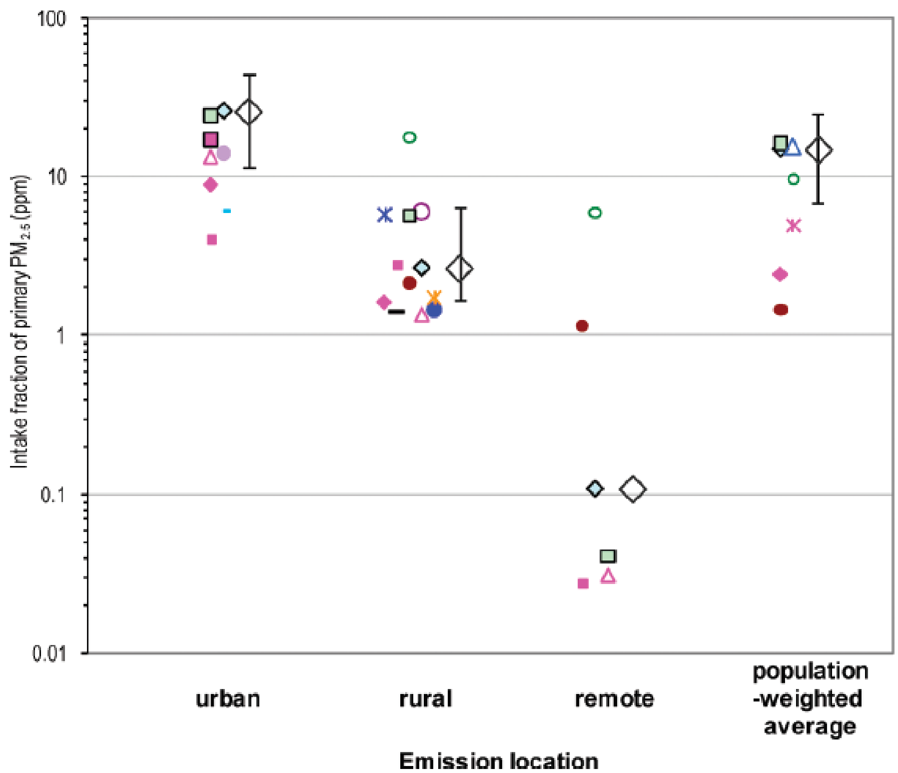


Figure 19 Intake fraction for primary $PM_{2.5}$ (Humbert at al., 2011)

The effect analysis aims to determine the effect factors which relate observed health effects due to exposure to substances considered. This provides the basis together with the fate factors for the calculation of the respiratory effects per kg emission of pollutants. Effect analysis was based on basically assumption from epidemiological studies and on the estimation of the dose-response relationships for all investigated substances as particles, ozone, sulphur dioxide, carbon monoxide and nitrogen dioxide (Hofstetter, 1998). The criteria that were considered for the use of epidemiological studies to estimate dose-response relationships are the follow:

- The exposure as an assumed risk factor has to occur before effects are observed.
- The biological plausibility should be given. This criterion depends on the state of knowledge. There are some cases in which epidemiological results stimulated toxicological research that then lend support to the plausibility of the identified relationship.
- The consistency of the results from a large set of studies with similar objectives but different approaches and study areas supports the interpretation of the results.
- Results should be coherent, i.e., if a risk factor increases the occurrence of cough one should also observe an increase in the demand for medicine to cure cough.

Starting from these considerations epidemiological researches were analyzes for the definition of the effect factor for any substance considered in the damage model, considering also these four assumptions:

- personal exposure can be approximated calculate considering the measurement of ambient concentrations;
- people breath outdoor air during 24 hours although it is known that they spend more than 22 hours indoors. Several studies shown that indoors the concentration of PM_{10} is lower than outdoors and that personal samplers show inhalation concentrations that are closer to indoor than to outdoor concentrations. Other researches demonstrated that both the use of gas stoves and smoking increase the PM_{10} concentration indoors above the values outdoors;
- variations over time in the pollutant concentration can be taken care of by an integration over time (relevant only for long-term studies);
- people outside of the study region were not considered and the concentration within defined gridcells (established to analyze well defined region) were considered homogenous (this assumption reflects the low density of monitoring stations and the fact that personal samplers are almost never used).

Basing on these criteria and assuming these consideration dose-response relationships for different respiratory effects caused by difference substances were determined. In the next table (Tab. 15) are reported some values calculates for exposure-response relationship for human health impacts from air pollution on the respiratory system. Complete set of data could be found in the publication of (Pilkington et al., 1997) that reports a total overview of assessment and Exposure-Response functions.

Table 15 The exposure-response (E-R) slope for Human Health impacts from air pollution in Western Europe

Pollutant	Endpoint	Affected population group	E-R slope [cases/(year*person*$\mu g/m^3$)]
PM_{10}	Bronchodilator usage	Adult asthmatics Asthm children	0.163 0.078
PM_{10}	Cough	Adult asthmatics Asthm children	0.166 0.133
$PM_{2.5}$ Sulphates	Bronchodilator usage	Adult asthmatics Asthm children	0.272 0.129
$PM_{2.5}$ Sulphates	Cough	Adult asthmatics Asthm children	0.280 0.233
NItrates	Lower respiratory symptoms (wheeze)	Adult asthmatics Asthm children	0.061 0.103
NItrates	Chronic bronchitis	Children Adults	1.61 E-3 4.9 E-5
Ozone	Asthma attacks	All	4.29 E-3
SO_2	Respiratory hospital admissions	All	2.04 E-3
NO_2	Respiratory hospital admissions	All	1.4 E-3

Several studies underline the assumption of a linear relationship, in the model definition, between dose and response. Non-linearities contained in the dose-response curve were exclude (not taking into account the possibility of synergistic or antagonistic effects due to toxicity mixes). Non-linear responses require more locally specified information than can be delivered by current LCA method (Heijungs and Ligthart, 2004).

Epidemiological studies are an excellent methodology to reveal associations between ambient air pollution and adverse health effects but in LCA the interest is focus on the determination of causal relationships and not in epidemiological associations. So, after effect analysis the last step is to determine the consequences from these respiratory effects for human health and well-being in terms of Years Lived Disabled (YLD) and Years Life Lost (YLL), and so, calculating the DALY indicator. Also these data come from epidemiological and medical studies and from health and safety datasets and statistics as that published by World Health Organization (WHO).

Putting the attention on the Particulate Matter as pollutant, the next figure (Fig. 20) show al the model steps to estimate damage to human health from respiratory problem caused from PM. In the figure are included unit for all sub-indicator calculate in the pathway to estimate the final damage.

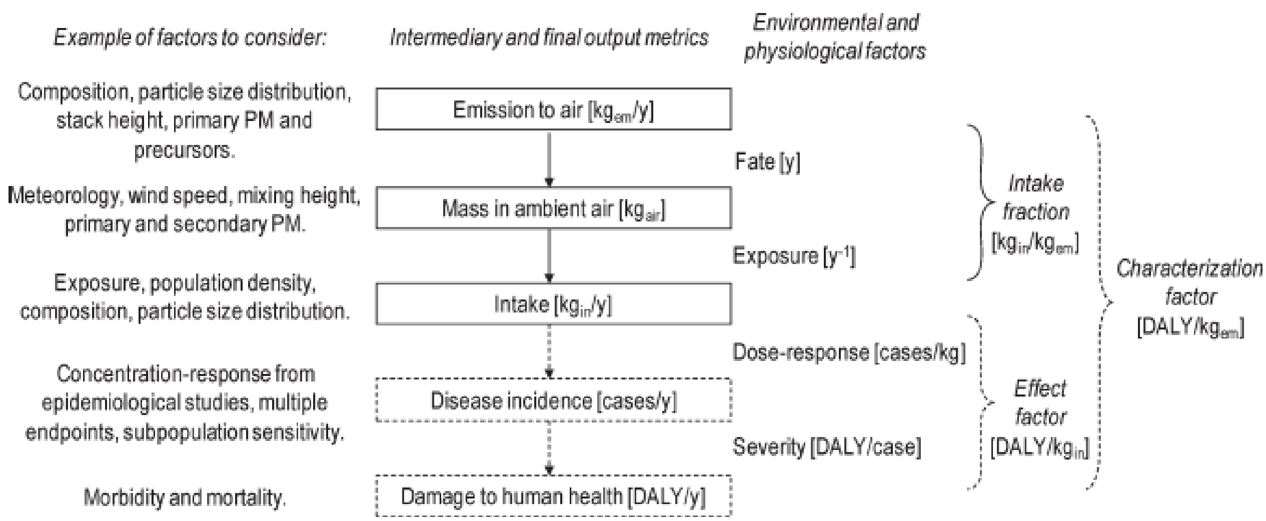


Figure 20 Human Health damage model for particulate matter (Humbert at al., 2011)

To conclude this section, considering again the human health damage due to respiratory problems caused by inhaled substances, it is useful to underline the last developments in this research field. The reason to put attention on these effects caused from specific substances is in line with the objectives of the research, as will be explained in the next sections (§ 1.5 and 1.6).

As already seen PM are considered inside the LCIA methods but these one are unable to differentiate particulate matter as $PM_{2.5}$ and PM_{10} despite that it is well known that there are many important particle properties (e.g. size, water solubility, chemical composition) that significantly influence human health (Kelly and Fussell, 2012). Recently new research substantially developed impact assessment model for PM based on physico-chemical particle properties (Notter, 2015). For example for the PM fate analysis sophisticated models for atmospheric transport and removal processes, such as dry and wet depositions, have been included and fate and exposure analysis have been merged and newly defined as intake fraction, as previously cited. Following the main characteristics of this new approach are briefly summarized for each of the step that contribute to the definition of the damage:

- *Fate model*. Dispersion and dilution of particles are included considering particle lifetime, distance traveled height of the mixing layer and height of the emission release above ground. Removal process are also considered: they are strictly linked to deposition (the fraction of particles removed by gravitational sedimentation, which is a function of particle diameter), to wet deposition (depends on the fraction of time when it is raining, residence time of the particles in the atmosphere and precipitation-scavenging coefficient) and coagulation (the process where two particles combine to form one new particle).
- *Exposure model*. This model is divided in three steps: intake (depends on the exposure concentration, the breathing volume, the residence time of the particles in the ambient air and

the fraction of time a person spends outdoors), uptake (determining the amount of particles retained in the lung by applying a lung deposition model) and population uptake (multiplying the uptake for a single person by the population density, considering three different population densities: city center, high and low population density, that represent typical European demographic conditions).

- *Effect model*, that takes into account the effect of size particles, the effect of solubility and the effect of chemical composition.
- *Damage model,* to distribute the DALY for cardiopulmonary diseases (lung cancer) over the effect factors for cardiopulmonary diseases (lung cancer) according to the "weight" derived with respect to the effect model (chemical composition, solubility and size), exposure model (population density) and fate model (stack height, emission site).

All these assumptions have been the base for the determination of new characterization factors in the new impact assessment model. The characterization factors for $PM_{2.5}$ and PM_{10} with unspecified chemistry were implemented in the existing methods, Eco-Indicator 99 (Goedkoop and Spriensma, 2001), ReCiPe 2008 (Goedkop et al., 2009) and Impact 2002+ (Jolliet et al., 2003). In figure 21 are reported different values of characterization factors derived from new impact assessment for $PM_{2.5}$ and PM_{10} compared with data from Eco-Indicator 99, ReCiPe 2008 and Impact 2002+ LCIA methods.

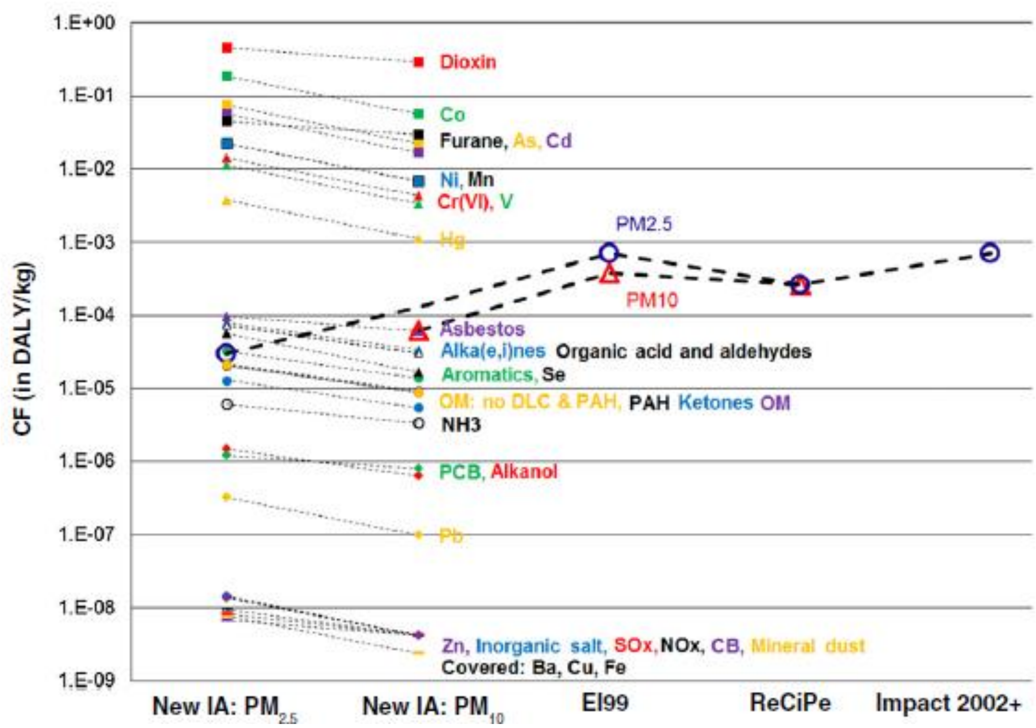


Figure 21 Different characterization factors from new and existing methods (Notter, 2015)

The difference between the values from the new impact assessment and Eco-Indicator 99, ReCiPe 2008 and Impact 2002 methods is less than one order of magnitude for PM_{10} and less than two orders of magnitude for $PM_{2.5}$.

1.4 Human Health, Climate Change and Particulate Matters

The purpose of this section is to underline how the problem of human health preservation, climate change with all associated effects on human species and air quality (linked especially with the particulate matters concentration in the air) are become in the last recent year very important topics in the Global, European and National Health, Safety and Environmental policies. This, obviously, have and will have relevant repercussions on the company activities and so have and will become strategic issues to consider in the development policy of companies.

1.4.1 The topic of Human Health

The preservation and the improvement of the life quality level of people are become in the last decade key points in the worldwide development policies. Many efforts have been made by Governments and Public Institutions, as World Health Organization (WHO), to study, analyze and find possible solutions for to guarantee acceptable human health conditions. Human health is a very general topic that is linked to more specific problematics (e.g. work conditions, air quality, food quality and availability, etc.) and have to be considered together with other development policies (e.g. Sustainability, Safety, Air Quality, Energy policies, etc.). So, Health has become a more central concern in development, both as a contributor to, and an indicator of, sustainable development. Health is a value and also a key to productivity and for these reasons the World Economic Forum (WEF) and the Organization for Economic Cooperation and Development (OECD) have explicitly addressed health issues that require attention as development or security issues. The health sector itself is changing: some health systems are more oriented to the needs of poor people, give greater attention to promoting health throughout the lifespan, redress inequities in health status, show heightened concern for quality, measure performance and are attempting to close the gap in research capacity between developed and developing countries. Many of the key determinants of health and disease, as well as the solutions, lie outside the direct control of the health sector, in sectors concerned with environment, water and sanitation agriculture, education, employment, urban and rural livelihoods, trade, tourism, energy and housing. Addressing the underlying determinants of health is the key to ensure sustainable development and sustained health improvements in the long term. Much progress has been made in forging closer links between health and other sectors, particularly through local and national inter-sectoral health and development plans and through increased use of planning tools such as health impact assessment procedures, integrated monitoring and surveillance systems and improved health information systems and indicators. Focusing on the relationship between human health and environmental conditions, global environmental threats to health include climate change, depletion of the ozone layer, reduction of biodiversity, degradation of ecosystems and the spread of persistent organic pollutants. The long-term health consequences of human induced climate change are likely to be profound and include threats to the food supply, natural disasters, infectious diseases, sea-level rise, changes in precipitation patterns and increased frequencies of extreme climate events, which may impinge particularly upon some of the least developed countries. Planning for the protection of human health from the potential impacts of global environmental threats requires a much improved understanding of the disease inducing mechanisms involved and of the vulnerability of populations. To better understand the last developments in human health science very interesting are data and statistics published by WHO. This Organization was established in 1948 as the specialized agency of the United Nations serving as the directing and coordinating authority for international health matters and public health; one of WHO's constitutional functions is to provide objective and reliable information and advice in the field of human health. For example WHO analyzed the principal causes of deaths in European Region in the period 1990 – 2009 (WHO, 2013a) and underlined that one of the six principal causes is linked to the respiratory problems (fig. 22)

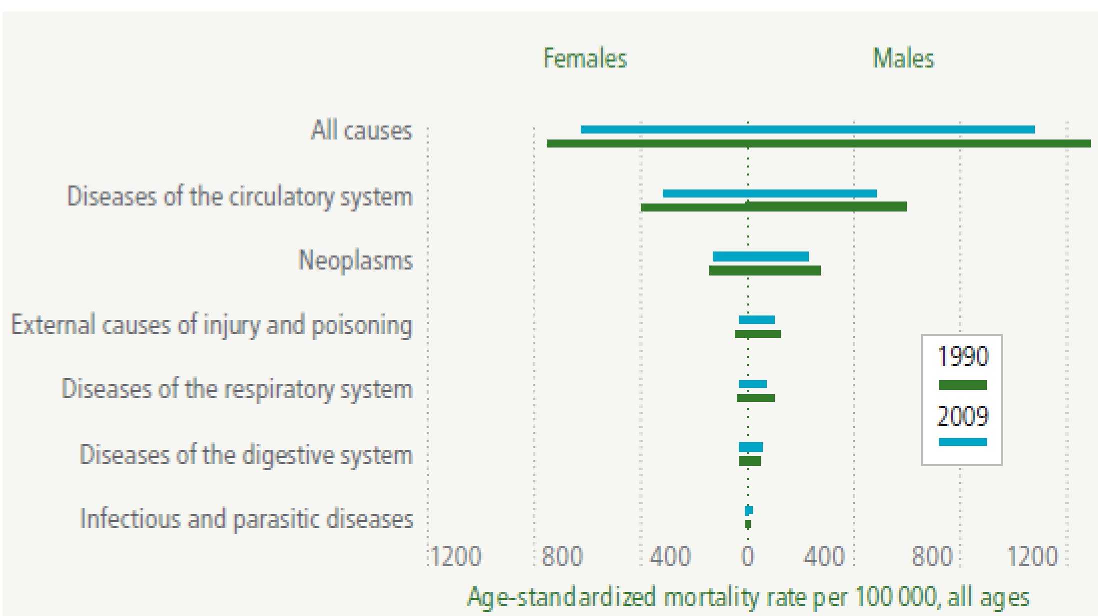


Figure 22 Causes of death by main broad group in the European Region (WHO, 2013a)

Respiratory diseases and external causes account for nearly 60% of all deaths among infants.

Analyzing also the data in terms of DALY, WHO published past and present calculated data and has given a perspective scenario based on the 2030 time horizon (Fig.23).

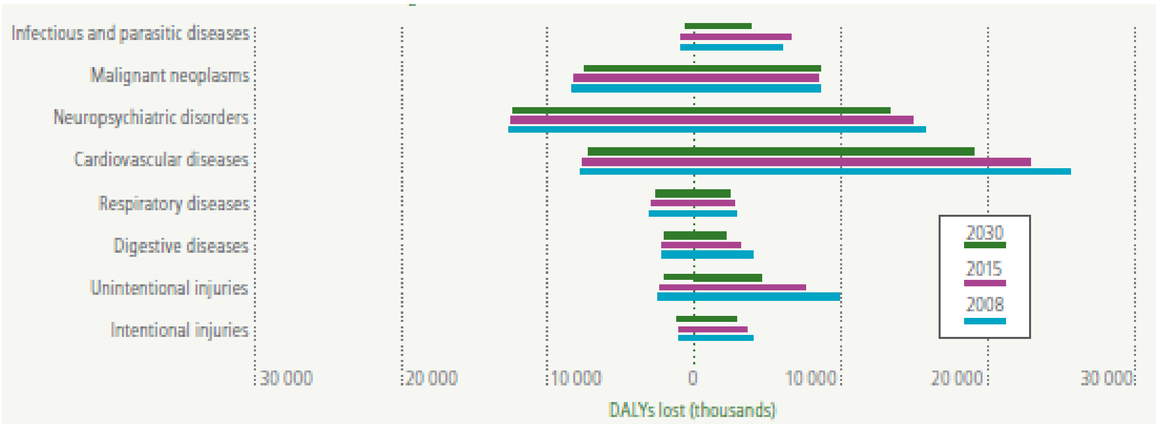


Figure 23 Projected DALYs lost, 2008, 2015 and 2030 in countries in the European Region (WHO, 2013a)

As it is possible to see from the figure, respiratory diseases will be one of the more relevant problem in next future considering its effects on the health of population. Moreover, in consideration to the influence of environmental conditions on health, environmental factors over the course of people's lives is known to determine the occurrence of major health problems, and these factors contribute directly or indirectly to shaping the health profile and disease burden of a population for good or ill (e.g. clean water, poor air quality, extreme climate conditions, etc.). Expert WHO groups also endorsed target for Human Health conditions improvement (targets for the so called Health 2020 plan): for example to reduce premature mortality in Europe by 2020 one of the key target area has the 1.5% relative annual reduction in overall mortality from diseases of the circulatory system, neoplasms, diabetes, and chronic respiratory disease by 2020 (WHO, 2013a). Policy-makers, public health practitioners and people in communities across Europe agree that well-being includes health as an essential part, if not a prerequisite. Health should not be taken to mean that health is the same as well-being, but that health – including its physical, mental and social aspects – matters for well-being.

At European Level, in 2013, Member States approved a framework with targets and indicators to monitor the implementation and impact of Health 2020, and agreed that 2010 would be the baseline for evaluating progress towards achieving its six targets (WHO, 2015):

1. Reduce premature mortality in Europe.
2. Increase life expectancy in Europe.
3. Reduce inequities in health in Europe.
4. Enhance the well-being of the European population.
5. Move towards universal health coverage.

6. Establish national targets set by Member States.

WHO Regional Office for Europe established also the European Health Information Initiative (EHII), a country-driven, multi-partner network committed to enhancing the health of people in the Region by improving the information that underpins policy. Very interesting are the key areas of work of EHII as show in figure 24.

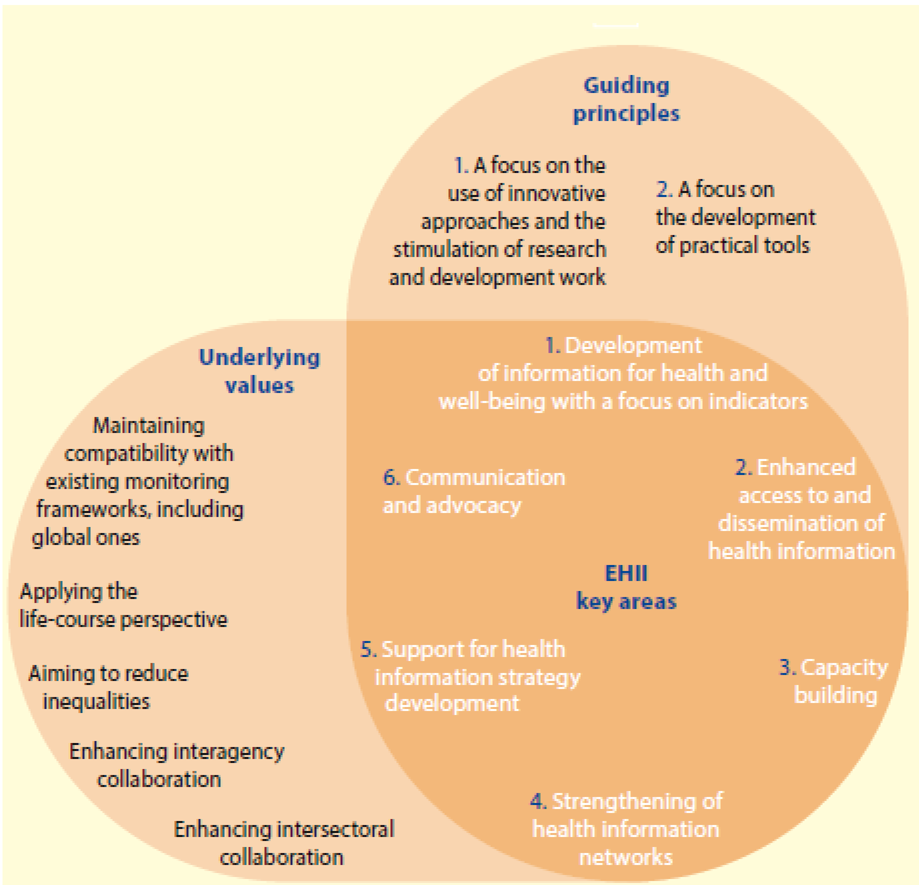


Figure 24 Key areas of work of EHII (WHO, 2015)

From this figure some useful considerations should be done:

- Guideline principles: the use of innovative approaches is suggested, and one of them could be the SLCA methodology for example, or other impact assessment method that allows to measure some human health damages in terms of DALY. In these sense they could be taken in consideration as practical tools to be used.
- Underlying Values: “applying the life-course perspective” is strictly in line with the life cycle perspective analysis on which environmental, economic and social assessment methodology

are based. Interagency and inter-sectoral collaborations perspectives could "open the door" to the life cycle methodology through the human health policies word.

The importance that Human Health have assumed in a sustainable development optic is demonstrate also from its consideration inside the legislation. Coming back about a decade, in 2007 was published by European Commission the White Paper "Together for Health: A Strategic Approach for the EU 2008-2013" (EC, 2007), that could be consider one of the first real and concrete document that underlines the principles for European actions on health. This document confirmed that Health is central in people's lives and needs to be supported by effective policies and actions in Member States, at EC level and at global level. In this White Book have been fixed fundamental principles and strategic objectives that could be summarized as follow:

- Fundamental principles: a) A strategy based on shared health values; b) "Health is the greatest wealth"; c) Health in all policies; d) Strengthening the EU's voice in global health;
- Strategic objectives: a) Fostering good health in an ageing Europe; b) Protecting citizens from health threats. In this objective are included actions that are also needed on emerging health threats such as those linked to climate change, to address its potential impact on public health and healthcare systems; c) Supporting dynamic health systems and new technologies.

Starting from these assumptions some general actions have been proposed as for example:

- System of European Community Health Indicators with common mechanisms for collection of comparable health data at all levels, including a Communication on an exchange of health-related information;
- Development of a programme of analytical studies of the economic relationships between health status, health investment and economic growth and development;
- Strengthening integration of health concerns into all policies at Community, Member State and regional levels, including use of Impact Assessment and evaluation tools;
- Development and delivery of actions on tobacco, nutrition, alcohol, mental health and other broader environmental and socioeconomic factors affecting health;
- Health aspects on adaptation to climate change.

In the Article 6 of the Treaty on the functioning of the European Union (EU, 2012) has reported as "*The Union shall have competence to carry out actions to support, coordinate or supplement the actions of the Member States. The areas of such action shall, at European level, be: (a) protection and improvement of human health […]*". Human Health is so a main topic in the European Policy.

Always at European level in the 2014 the European Parliament has prepared a regulation for the establishment of a third Programme for the Union's action in the field of health (2014-2020) (EU, 2014). The general objectives of the Programme shall be to complement, support and add value to the policies of the Member States to improve the health of Union citizens and reduce health inequalities by promoting health, encouraging innovation in health, increasing the sustainability of health systems and protecting Union citizens from serious cross- border health threats. In this program objective and actions have been fixed, but also funds and financial provisions (the financial envelope for the implementation of the Programme for the period from 1 January 2014 to 31 December 2020 shall be EUR 449 394 000 in current prices), methods to implement the actions and ways to monitoring them. Interesting are the thematic priorities reported in the Annex (EU, 2014), between them we can find actions to:

- Promote health, prevent diseases and foster supportive environments for healthy lifestyles taking into account the 'health in all policies' principle;
- Protect Union citizens from serious cross-border health threats. Actions required by, or contributing to, the implementation of Union legislation in the fields of communicable diseases and other health threats, including those caused by biological and chemical incidents, environment and climate change. Such action may include activities aimed at facilitating the implementation, application, monitoring and review of that legislation;
- Contribute to innovative, efficient and sustainable health systems;
- Facilitate access to better and safer healthcare for Union citizens.

At national level, in Italy has been published by the Ministry of Health the National Plan for Prevention 2014 – 2018 (Ministero della Salute, 2013). This plan takes into account directive from WHO and from European Commission and aim to identify primary action area to improve health conditions of Italian people. It is interesting to note that, between others, one of the strategies delineated by the plan is the implementation of s activities to support environmental policies and improvements policies of air, water, soil basing on the concept of “Health in all development policies”. Very interesting (in the contest of this research work) is also one of the ten macro-objectives of the National plan: the macro-objective 2.8 “Reduction of environmental exposures that are potentially damaging to health” (Ministero della Salute, 2013). It has been estimated that urban atmospheric pollution, in terms of $PM_{2.5}$, is the cause of the 3% of deaths from cardiovascular diseases, of 5% of deaths caused from lung cancer and 1% mortality due to acute respiratory infections in children. WHO estimations for the Italian scenario associate to the environmental pollution an index of 3-4%, in terms of DALY. One of the critical point underlined is the absence of adequate instruments to support Administrations in the assessment and management of health impacts caused by environmental problematics.

To conclude this section it seems appropriates a brief discussion about the relationship between human health and environment in the global context. At the beginning of the new century the Organization for Economic Co-operation and Development (OECD), an international organization for economic studies with the aim to promote policies that will improve the economic and social well-being of people around the world, confirmed that the loss of health due to environmental degradation is substantial and calls for interventions (OECD, 2001). The cost-benefit ratio for any given policy intervention will depend on the state of the environment and the pattern of disease of the affected population and certain priority issues for intervention common to almost all OECD countries can be identified; these ones is summarized in the next Table 16.

Table 16 Priority environment-related diseases, issues and sectors in OECD countries (OECD, 2001)

	High-income OECD countries	Middle-income OECD countries
Diseases	Cardiopulmonary diseases Cancer Depression	Communicable diseases Cardiopulmonary diseases Cancer
Issues	Air pollution Chemicals Noise/liveability	Sanitation/food/housing Air pollution Chemicals
Sectors	Transport Industry/agriculture Housing	Public hygiene Transport/energy Industry/agriculture

As it is possible to see respiratory problems due also to air pollution quality mainly influenced from transport, industry and agriculture are considered between the priority environment-related diseases. Moreover, OLCD underlined as environmental degradation can have a significant impact on human health. Estimates of the share of environment related human health loss are as high as 5% for high-income OECD countries, 8% for middle-income OECD countries and 13% for non-OECD countries. It has been estimate that the health-related cost of environmental degradation is equal to 134 DALYs/ 1000 capita. Air pollution and exposure to hazardous chemicals are important causes of the environment-related burden of disease in OECD countries. The transport and energy sectors are major contributors to air pollution, while important sources of chemical pollution are agriculture, industry, and waste disposal and incineration. Opportunities for reducing environment-related health risks are considerable. The benefits of many environmental policies in terms of reduced health care costs and increased productivity significantly exceed the costs of implementing these policies.

Marmot et al. (2012) said that investment in early child development, active labour-market policies, social protection, housing, and mitigation of climate change will help protect populations from the adverse effects of the economic crisis and lay the foundation for a healthier future. Once again, actions on environmental issues linked to health population have seen strategic action for future. Moreover, was suggested the adoption of strategies to improve air quality and reduce health risks from air pollutants for all groups across the entire society. In general environment and sustainability are also linked to social equity: where environmental harm occurs it is often linked to the unequal distribution of environmental hazards. Factors determining health and social justice are interdependent with factors determining environmental and economic sustain ability. For example, over-consumption of animal fats is associated with increased risk of prevent able diet-related diseases, including several cancers and cardiovascular disease, while production of animal-based food to supply demand is associated with environmental costs, including water use and greenhouse gas emissions.

To consolidate the strong link between Human Health and Environment, citing again the Treaty on the functioning of the European Union (EU, 2012), at Title XXX, Article 191, we can read: "*Union policy on the environment shall contribute to pursuit of the following objectives:*

- *preserving, protecting and improving the quality of the environment,*
- *protecting human health,*
- *prudent and rational utilization of natural resources,*
- *promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combating climate change.".*

From this Article it is clear the existing relationships between environment and effects on human health.

Taking into account health and environment, WHO published a road map to give an enhanced global response to the adverse health effects of air pollution (WHO, 2016a). The proposed road map (2016-2019) identifies and harnesses opportunities for synergies and efficiencies linked to those policies that focus on reducing climate change and monitoring progress with the relevant Sustainable Development Goals. For example, the links with the sustainable development goals provide a rationale and framework for the health sector to effectively contribute to achieving some of the "non-health" sustainable development goals, and can also offer a focus for early action on air pollution prevention. This sort of guideline suggest as one of the beneficial impacts of climate change mitigation is that the funding associated with it can be used to improve air quality. Further, the increase in public awareness stimulates the demand for policies that reduce air pollution, prevent diseases and improve health and well-being. So efforts to achieve environmental improvements could give social (in terms of human health quality level) improvements, too. To obtain such efficiency gains, it is crucial to identify co-benefits from different measures, to health and air pollution, and to climate change and sustainable development.

1.4.2 The problem of Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science related to climate change. It was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessment of the scientific basis of climate change, its impact and future risks, and options for adaptation and mitigation. IPCC defined Climate Change as "*a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use*". Human activities are one of the main responsible for climate change considering that recent anthropogenic emissions of greenhouse gases (GHG) are the highest in history. As consequences recent climate changes have had widespread impacts on human and natural systems. Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere. The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880 to 2012 (IPCC, 2014). The next figure (Fig. 25) represents the trends of greenhouse gas (in particular carbon dioxide, methane and dinitrogen monoxide), the main responsible agents of climate change, in atmosphere.

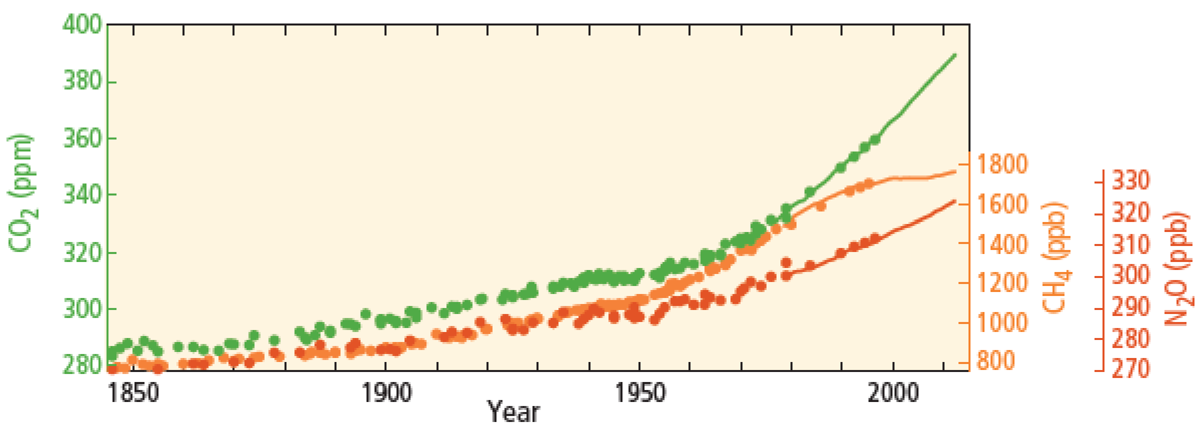


Figure 25 Globally averaged greenhouse gas concentrations (IPCC, 2014)

As anticipated above, the causes of climate change are mainly the anthropogenic greenhouse gas emissions. These have increased in a significant way since the pre-industrial era driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. Changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate (IPCC, 2014). Many studies have been made trying to predict future scenarios and are basically for actual development policies. Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socio-economic development and climate policy. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Figure 26 illustrates provisional data of CO_2 concentrations in atmosphere, considering the different hypothesized scenarios.

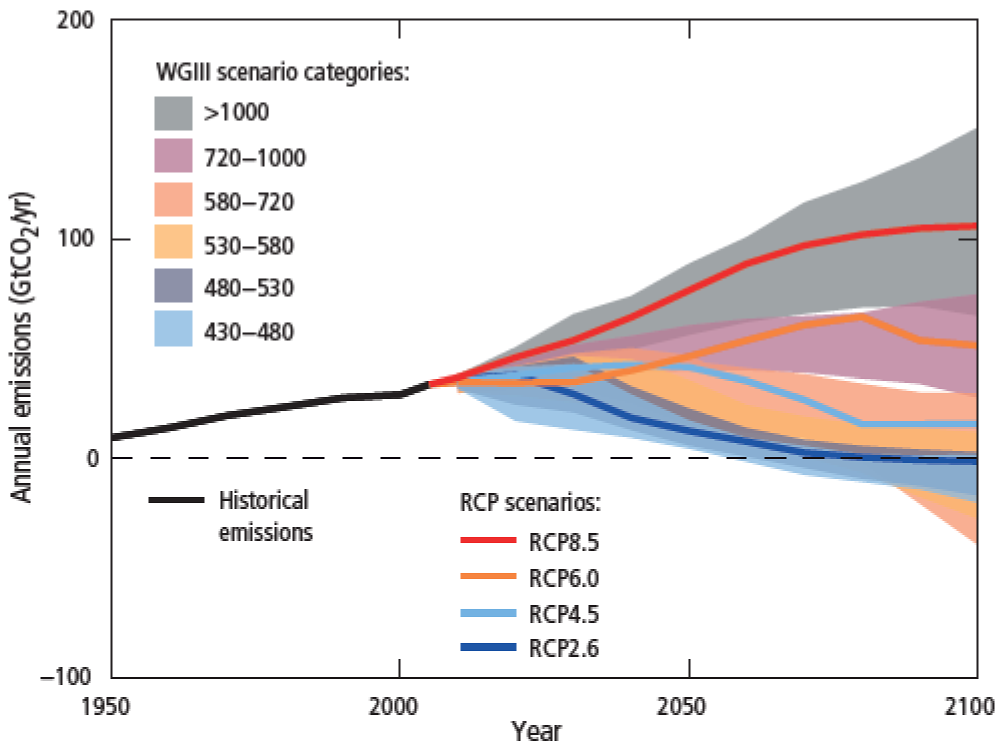


Figure 26 Annual anthropogenic CO2 emissions (IPCC, 2014)

As consequences of GHG emissions change in the climate system have been predicted. In terms of temperature changes (other changes could be about sea level rise, precipitations, etc.). The global average surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will likely be in the range 0.3°C to 0.7°C. This assumes that there will be no major volcanic eruptions or changes in some natural sources (e.g., CH4 and N2O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario. The increase of global average surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is likely to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5 (see Fig. 27).

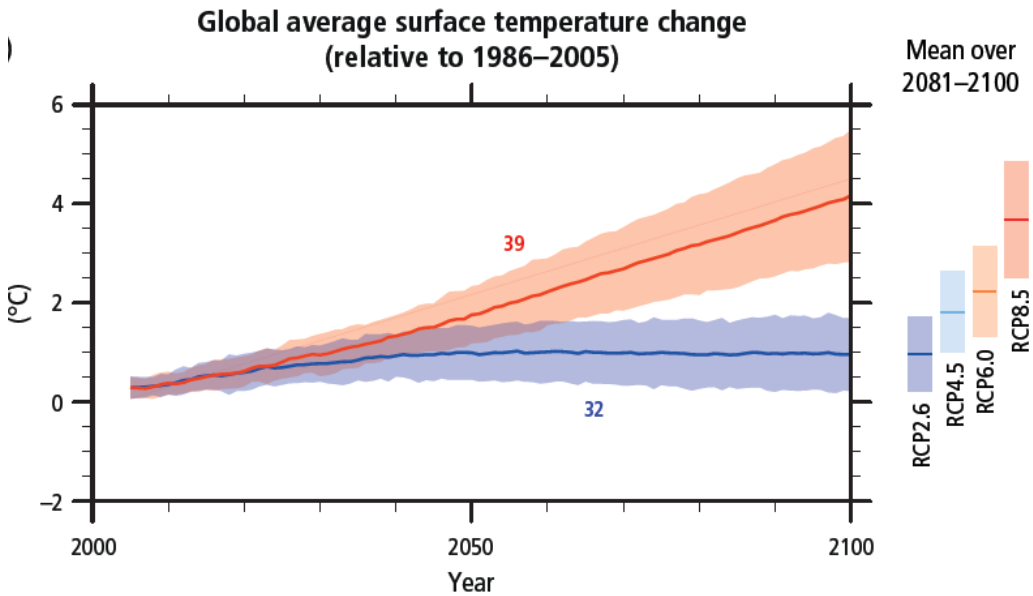


Figure 27 Global average temperature change scenarios (IPCC, 2014)

The drivers of climate change are both natural and anthropogenic substances, but the second ones are the main responsible for the actual temperature rise and other issues coming from GHG emissions to the atmosphere. Figure 28 clearly shows this trend.

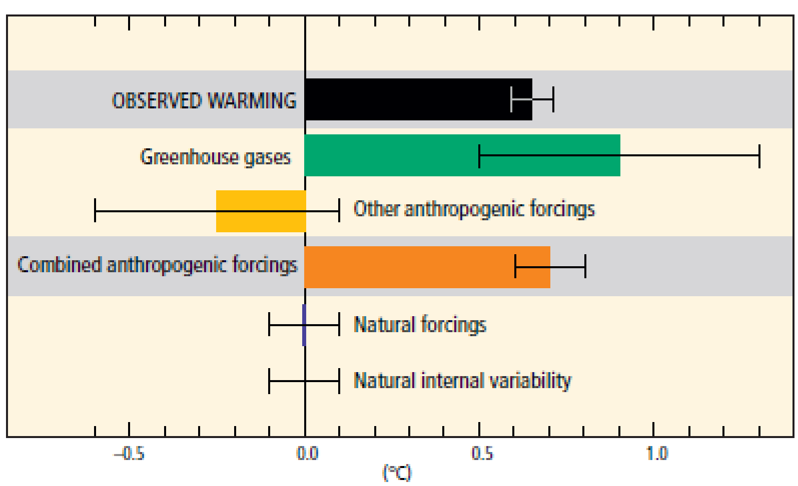


Figure 28 Contributions to observed surface temperature change over the period 1951–2010 (IPCC, 2014)

As it is possible to see, natural forcings give a very little contribution to the observed global warming in comparison with anthropogenic ones.

The main economic sectors responsible for GHG emissions are globally the Electricity and Heat production, the Agriculture and forestry sector (named AFOLU – agriculture, forestry and other land use), the industry and transport sectors. Figure 29 illustrates the incidence of these main GHG emitted sectors, in reference with the 2010 emissions.

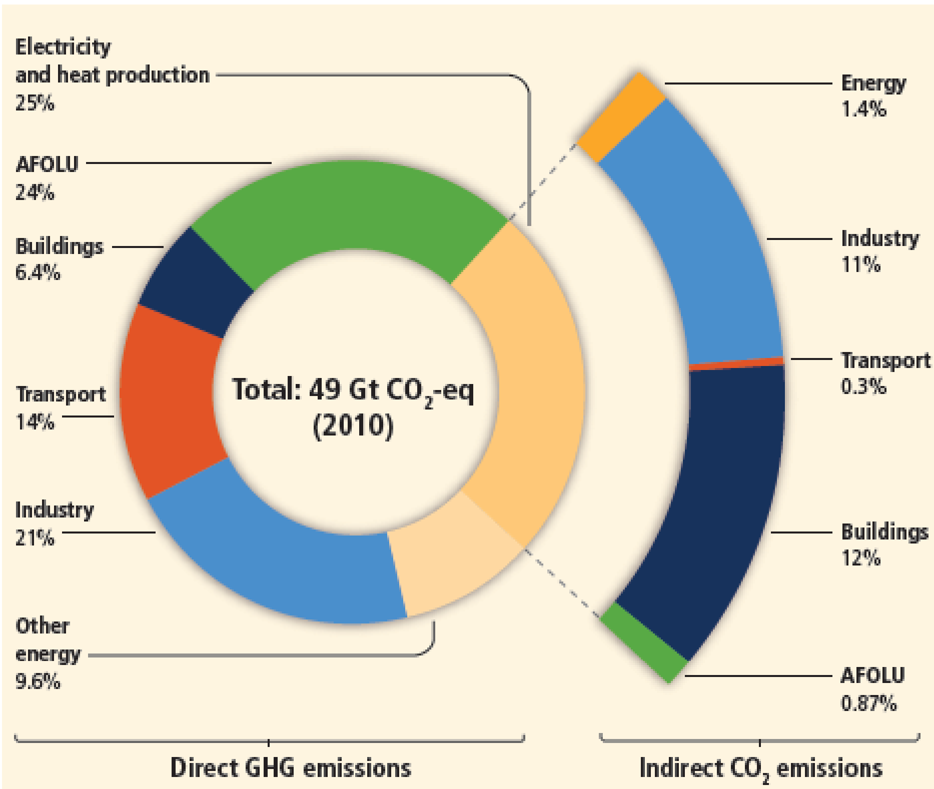


Figure 29 Greenhouse gas emissions by economic sectors (IPCC, 2014)

The problem of climate change ant its effects is became an issue and consequently a strategic topic, not only for Governmental and worldwide Organizations but also for Enterprises. Climate change and all related topics affect legislations, reference standard, human behavior and also market.

Very interesting is the publication of the World Economic Forum (WEF, 2016) that summarized the major global risks for the globe in the present years. Different types of risk categories have been taken into account and general results are reported in the next figure (Fig. 30), where economic (blue), environmental (green), geopolitical (orange), societal (red) and technological (violet) main global risks are reported. Risk has been evaluated considering together impact (effect) and its likelihood (cause).

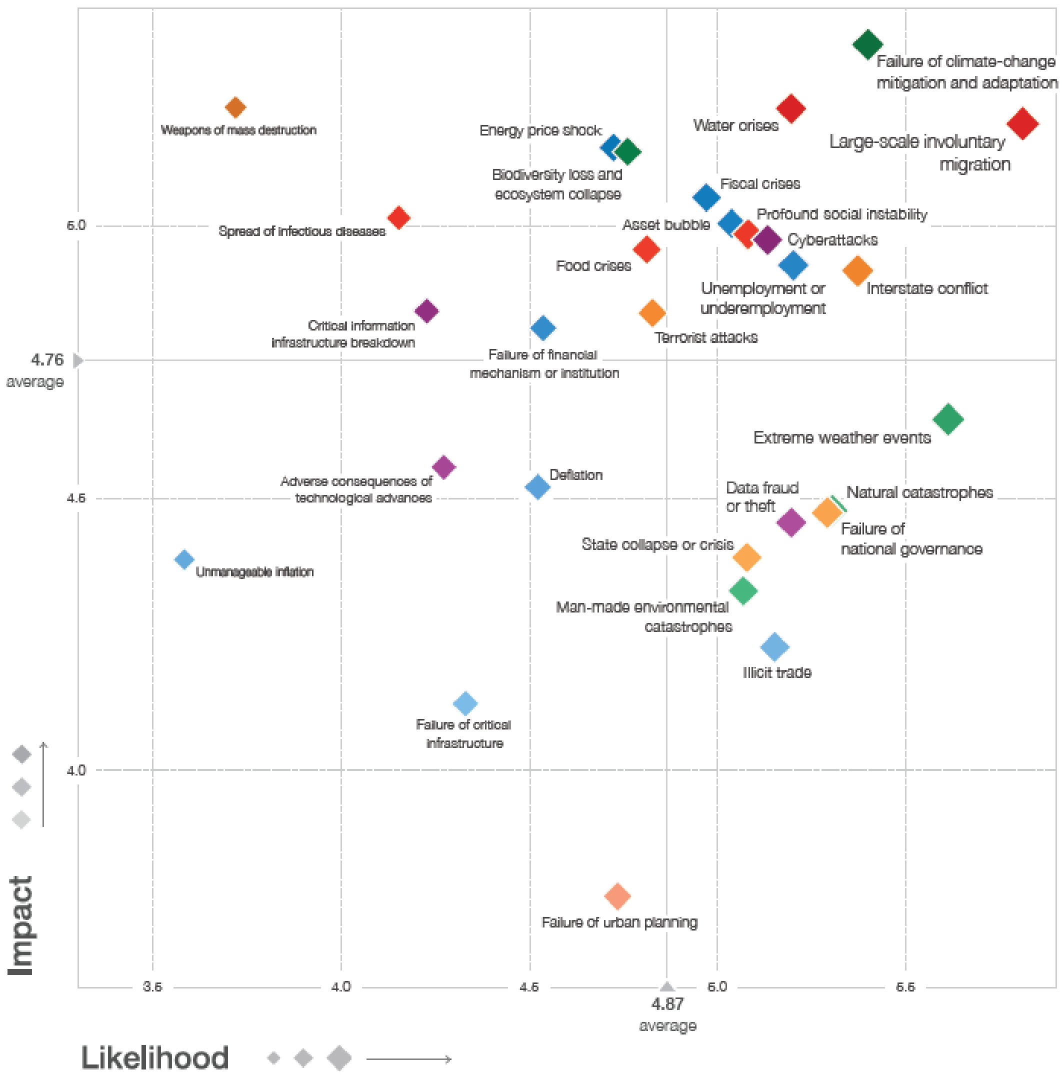


Figure 30 The main worldwide global risks (WEF, 2016)

One of the major actual risks underlined by WEF is the failure of climate change mitigation and adaptation policies: in the last years (2016) this topic has been considered the third Global Risk in Terms of Likelihood and the first Global Risk in Terms of Impact (WEF, 2016). WEF underlined also as the environmental problem of climate change could have strong influence on other sectors as economic and social sectors: it influences for example agriculture and food availability, security and production and also distribution and transport infrastructures.

Also the World Bank, with the publications of the “Little Green Data Book” (WB, 2016) shows the relationship between environmental and health issues with the economic development. The World Bank, in this publication, underlined as the Sustainable Development Goals (SDGs) came into force at the beginning of 2016. Millennium Development Goals (MDGs) have been built and a new global development agenda has been articulated to eradicate poverty and shift the world into a sustainable development path by 2030. The SDGs are comprehensive, including goals on poverty reduction, education, health, environment, and peaceful and inclusive societies. In this contest the World Bank has provided about 50 indicators for more than 200 countries to monitor, between them, agriculture, biodiversity, emissions, water, environmental and health trends.

The problem of Climate change and its magnitude, as soon as seen, is relevant at global world but it has obviously consequences on local dimension and single enterprises, that are increasingly called to respect environmental and sustainability targets required by laws, but also are driven from non-mandatory aspects (first of all consumers expectations and global market) in the definitions of their green and sustainability development policy.

1.4.3 Air quality, particulate matters and influence on Human Health (respiratory problems)

The previous sections (§ 1.4.1 and 1.4.2) have the aim to focus the attention on topics of Human Health and of Climate Change underlying the increasing attention that all stakeholders (from Governmental authorities and scientific community to enterprise and consumers) are putting on these issues. With any doubts, a link between these two actual and very important global themes is constitute from the topics of "air quality" that, obviously, strongly influences the human health quality level and, at the same time is influenced from effect of climate change. In line with the development of this thesis work, the presence of particulate matters and its effect on respiratory problems are considers as main drivers of air quality levels, considering their effects on the human health.

Air pollution is defined by the United States Environmental Protection Agency (EPA) as "The presence of contaminants or pollutant substances in the air that interfere with human health or welfare, or produce other harmful environmental effects" (Vallero, 2008). Over the past few decades the central feature of air pollution has been its association with harm, especially harm to humans in terms of diseases, such as respiratory diseases associated with air pollutants. Harm implies a value, a measurable society values is lost or diminished (Vallero, 2008). In this sense the DALY indicator, as seen in the previous sections, could be a useful reference to these estimations. In the United States to address these harms has been established the so called National Ambient Air Quality Standards to address six "criteria air pollutants":

a) particulate matter (PM),
b) ozone (O3),
c) carbon monoxide (CO),
d) sulfur dioxide (SO2),
e) nitrogen dioxide (NO2),
f) lead (Pb).

Particulate matter and Ozone, as it is possible to see, have been considered from many decades, as some of the main responsible pollutants that give respiratory diseases.
Also the World Health Organization is studying the problem of air pollution and its effects on population; it estimates that Air pollution is responsible for almost 6.5 million deaths annually, or one in nine premature deaths every year (WHO, 2016b). This makes it the world's largest environmental health risk, and among the largest global health risks, in line with previously seen about the World Economic Forum projections. Black Carbon (a climate pollutant) is a major component of health-harmful $PM_{2.5}$ air pollution, and comes particularly from diesel vehicles, diesel engines, coal and biomass stoves and waste incineration. Ground-level Ozone is also "climate pollutant", formed by a mix of air pollutants typically emitted over cities or nearby rural areas, including methane from urban sewage, waste, and agriculture, as well as oxides of nitrogen from vehicles (WHO, 2016b).
Focusing on the Particulate Matter (PM), it is widespread air pollutant, consisting of a mixture of solid and liquid particles suspended in the air (WHO, 2013b). Commonly used indicators describing PM that are relevant to health refer to the mass concentration of particles with a diameter of less than 10 μm (PM_{10}) and of particles with a diameter of less than 2.5 μm ($PM_{2.5}$). $PM_{2.5}$, often called fine PM, also comprises ultrafine particles having a diameter of less than 0.1 μm. Others PM classifications takes into account their source ore their formation process: particles can either have natural or anthropogenic sources and are either emitted as primary particles (i.e. they are directly emitted into the atmosphere) or formed by secondary processes (i.e. by transformation of emitted precursor gases) (Fuzzi et al.,2015). Anthropogenic sources include combustion engines (both diesel and petrol), solid-fuel (coal, lignite, heavy oil and biomass) combustion for energy production in households and industry, other industrial activities (building, mining, manufacture of cement, ceramic and bricks, and smelting), and erosion of the pavement by road traffic and abrasion of brakes and tires. Agriculture is the main source of ammonium. Secondary particles are formed in the air through chemical reactions of gaseous pollutants. They are products of atmospheric transformation of nitrogen oxides (mainly emitted by traffic and some industrial processes) and sulfur dioxide resulting from the combustion of sulfur-containing fuels. Secondary particles are mostly found in fine PM (WHO, 2013b). The health effects of inhalable PM are well documented in literature and are due to exposure over both the short term (hours, days) and long term (months, years) and include:

- respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms and an increase in hospital admissions;
- mortality from cardiovascular and respiratory diseases and from lung cancer.

There is good evidence of the effects of short-term exposure to PM_{10} on respiratory health, but for mortality, and especially as a consequence of long-term exposure, $PM_{2.5}$ is a stronger risk factor than the coarse part of PM_{10}. Very interesting is the estimation gives from WHO (2013b): all-cause daily mortality is estimated to increase by 0.2–0.6% per 10 μg/m^3 of PM_{10}. Long-term exposure to $PM_{2.5}$ is associated with an increase in the long-term risk of cardiopulmonary mortality by 6–13% per 10 μg/m^3 of $PM_{2.5.}$ From these data it is clear the relevant relationship between damage and PM concentrations in the inhalable air. In the last figures are reported the average concentration measured in 2010 in the European regions (Fig. 31) and the number of deaths caused from environmental pollutions in 2013, in some European countries (Fig. 32).

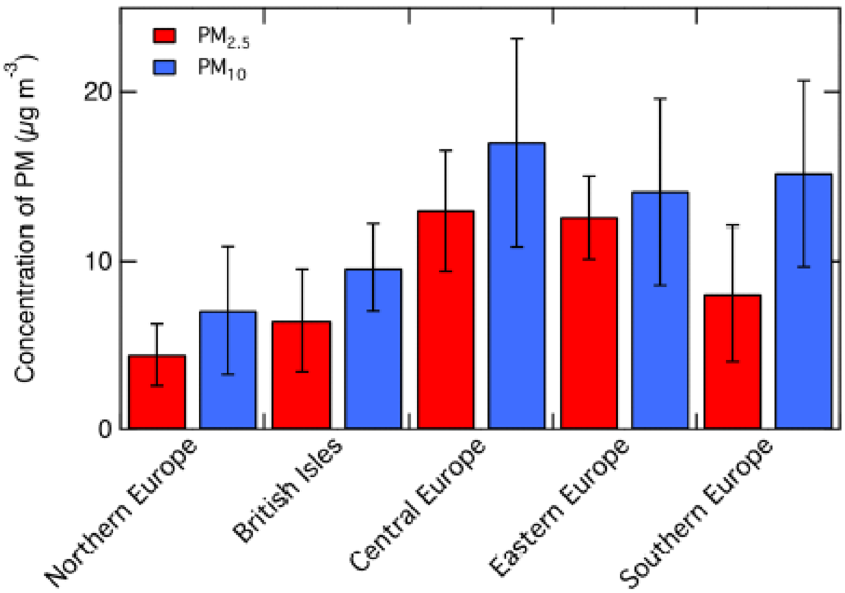


Figure 31 Average PM10 and PM2:5 concentrations in Europe in 2010 (Fuzzi et al., 2015)

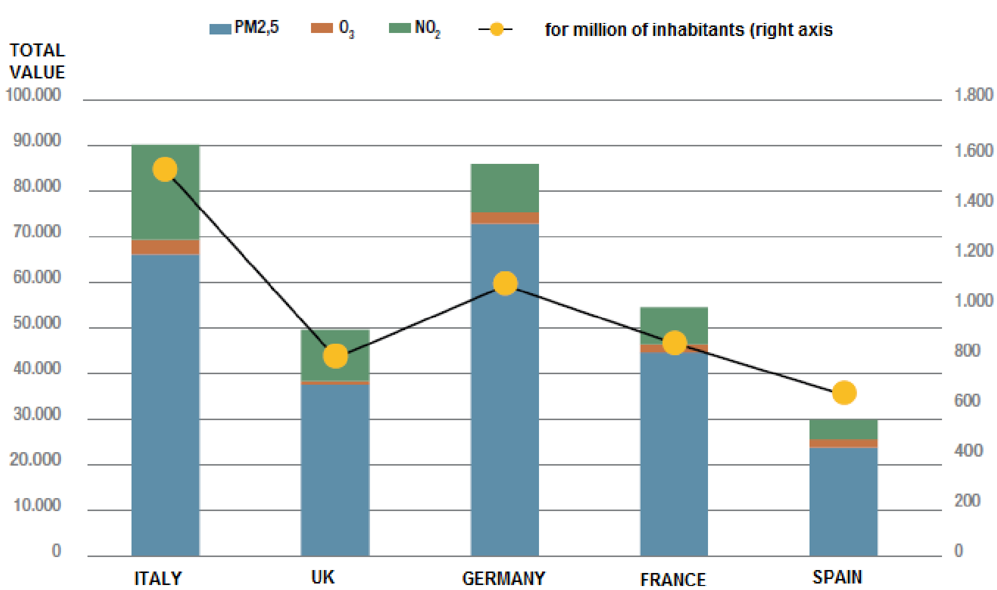


Figure 32 Deaths caused from air pollution, in Europe (Fuzzi et al., 2015)

A factor that could contribute to modify the PM concentration parameter is also the climate change. The relationship between climate change and air quality is complex. If we consider the effects of air quality impacts on climate change, the dominant factor is the emissions of pollutants that have fairly well-understood direct effects on aerosols and trace gases (climate forcers). Instead, in the other sense, the impact of climate change on air quality is difficult to assess (Fuzzi et al., 2015). Changes in air pollutants in response to climate change depend upon how the multiple complex interactions among the chemical species, the land surface and other factors respond to changes in climate (temperature, rainfall, humidity, etc). For example, temperature affects the chemical rates that are temperature and moisture dependent (Fuzzi et al., 2015). Despite that some studies and model tried to simulate this relationship: for example Jacop and Winner (2009) estimated that in the 21st-century the climate change could influence the PM concentrations in the order of 0.1-1.0 μg/m^3 for North America and Europe.

To conclude this section, following is reported a figure that shows the sectors that are the principal source of emissions in Italy.

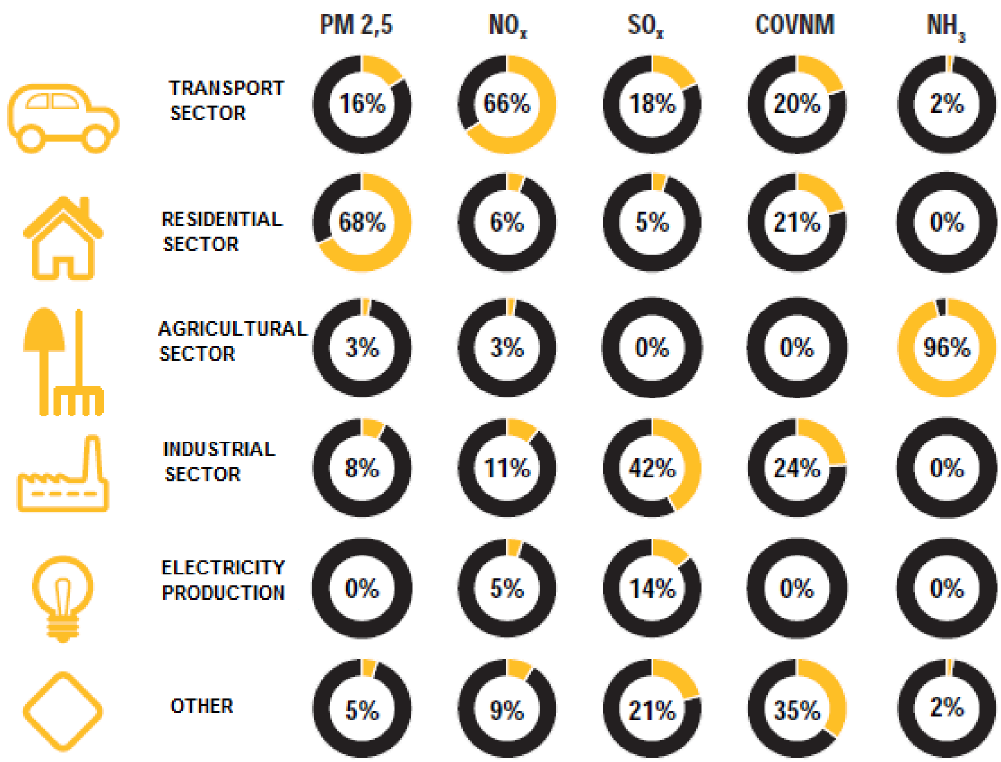


Figure 33 Overview of the sources of emissions for sectorial activities in Italy (Aneris et al., 2017)

In Italy the five main contributions to the emissions in the air that have influence on the air quality are: transport, residential, agricultural, industrial sectors and the sector of energy production.

1.5 Research questions

In this globalized word the concept of sustainability is one of the most discussed in an optic of worldwide future scenarios and development. According to the introduction and the literature review presented in the previous paragraphs many inherent topics are still under debate inside the scientific community. First of all, a consolidated sustainability assessment methodology that takes into account environmental, economic and social performances has not yet shared; on the other hand, existing assessment method to calculate damage to human health, that is considered one of the main areas of protection in the social science, could be improved integrating actual relevant aspects that gives effects on the well-being of people.

Some observations and results from the previous introduction and literature analysis must be taken in mind to contextualize the research:

- Human health and well-being preservation and improvement are one of the main aspects considered in the international, European and national policies and development strategies;
- Existing LCIA methods allow to calculate the Human Health damage, in terms of DALY;
- Human Health indicator takes into account consequences of environmental impacts on a social dimension, and so could be seen a coherent product performance indicator in a sustainability assessment optic;
- Climate change is one of the most relevant problem actually worldwide considered, for its risks and effects on the social and economic sphere;
- One of the effects of the climate change is the global temperature rise;
- Air quality is one of the principal themes developed in all environmental policies;
- Particulate matters are one of the main responsible substance for the air quality degradation;
- Temperature level affects the particulate concentrations in the inhaled air;
- Health effects linked to climate change, in terms of respiratory problems, are not considered in the actual LCIA methods.

In consideration to this background and to specific areas of investigations that have been analyzed, the research questions raised are relative to:

- The possibility to integrate the effects of emissions into inhaled air (in particular particulate matter and ozone) due to temperature rise associated to climate change in a Life Cycle Impact Assessments method.
- The possibility to improving the actual Human Health damage category assessment model (that includes both particulate matter formation and climate change impacts) to make available

for LCA and sustainability practitioners a method to integrate particular matter formation in climate change impact assessment, for a life cycle analysis of products or services.

1.6 Research objectives

According to the observations reported in the previous paragraph that consider a wide range of theoretical and operative assumptions, studies and experiences, the need of a method that take into account health effects linked to climate change clearly emerges, in particular effect on respiratory problems due to concentrations of Particular Matter and other substances in the air (in particular Ozone). Starting from the existing LCIA model and in particular the last published, most recent and update ReCiPe impact assessment model, improvements are needed and possible considering especially the fate analysis. Focusing the analysis in this first step of a complete damage analysis it is possible to integrate effects of climate change, in terms of temperature rise, on respiratory problems through the estimation of the variation of particulate matter and other substances concentrations in the air.

In line with the limits and the research needs emerged from literature review, the present research had the following objectives:

- Basing on the future scenarios that are consequence of climate change, to find formulas to estimate the relationship between temperature rise and pollutant concentration in the air, in the European or national contest;
- Improvement of the ReCiPe life cycle assessment method for the Human Health damage category assessment, considering the changes of pollutant concentration in the air (that gives respiratory problems) due to temperature rise associated to climate change;
- The verification of the applicability of the improved model in real case studies testing their effectiveness in measuring the effects of climate change and particles concentrations on human health damage category.

2 Materials and Methods

2.1 Research structure

According to the formulated objectives, the research method is based on empirical data, statistics and assumptions to add a new contribute to the assessment model and on a multiple case studies analysis. The research is based on:

- published data and on a consolidate approach for the improving of the damage model (in particular the fate analysis)
- Primary data directly collected from companies or secondary data coming from database recognized by LCA community for the life cycle analysis of the specific products and services.

The case studies for the implementation of the update method have been chose considering the main sectors responsible for climate change, temperature rise and emissions of particles in the air responsible for the air quality degradation. Applicability of the model has been tested in four different system products: transport service (two different typologies), agricultural product and food product.

2.2 Model to consider climate effect on human health assessment

2.2.1 Conceptual Model

In line with it has been exposed in the previous paragraphs (in particular §1.3.3) the general structure of a damage model for the calculation of the Human Health damage indicator is composed by at least four steps: fate, exposure, effect and damage analysis. This research is focused on the first one (fate analysis) through the study of the relationships between emissions of pollutants and the concentrations in the inhalation air.

In general the conceptual model developed is summarized in the next representations and formulas:

$$\Delta T \rightarrow \Delta c_{pol} \rightarrow \Delta HH$$

$$\Delta c_{pol,i} = f(\Delta T) \qquad [1]$$

$$\Delta HH = f(\Delta c_{pol,i}) \qquad [2]$$

with:

ΔT: average temperature rise due to climate change

$\Delta c_{pol,i}$: variation of concentration in inhaled air of pollutant “i”

ΔHH : variation of Human Health damage indicator

So, the approach followed to improve the existing model has been developed through these steps: a) individuation of different Temperature rise scenarios (Climate Change); b) evaluation of the relationship between average temperature variation and substances concentration ($PM_{2.5}$, PM_{10}, Ozone) in inhaled air; c) evaluation of the effects of changing concentrations on Human Health damage indicator.

For the first point relative to the estimation of temperature rise, the theorem of the "marginality of impacts" (Heijungs et al., 1992; Heijungs, 1995) has been applied: although effects of each life cycle product on climate change are in some way measurable in LCA (in term of equivalent-CO_2 emitted), the contribution to the global effect (temperature rise) of each single product is not possible to estimate, because just "marginal".

Moreover, as underlined by some published studies (Heijungs et al., 2004; Humbert et al., 2011), the damage model is represented by linear relationship (cause-effect or dose response linear relationship) and this law has been taken into account in this research for the modifications made in the considered fate analysis.

The aspect of "regionalization" has also been taken into account (Humbert et al., 2011), considering the regional differences in fate and exposure: European scenario has been considered.

In the next section (§ 2.2.2) are singularly explained each single step.

2.2.2 Methodological proposal

Temperature scenarios (ΔT_x)

According with the IPCC scenarios (§ 1.4.2 and fig.27), considering a time horizon of 100 years in line with the average Hierarchist perspective adopted in LCA and considering the theorem of the "marginality of impacts", a temperature increase value of ΔT_x = 2°C (ΔT_2) has been considered in the research. Furthermore, a sensitivity analysis has been implemented considering other different temperature increase scenarios (with ΔT_1= 1°C; ΔT_3=3°C; ΔT_4=4°C and ΔT_5=5°C).

Temperature-concentration law ($\Delta c_{pol} = f(\Delta T_x)$)

Primary data were not available, so these relationships have been found analyzing literature. The geographical boundaries established for this research that are relevant for the determination of the relationship, have been European ones. Some studies confirmed the relationship between climate change, air quality, particulate matter formation and respiratory diseases but a unique and shared function do not exist for each of the pollutants considered in this analysis. Different formulas for the relationship between $\Delta c_{pol,i}$ (variation of concentrations of substance "i", with i: $PM_{2.5}$, PM_{10} and Ozone) and ΔT come from environmental publications; the principal results are summarized in table 17.

Table 17 Relationship $\Delta c_{pol,i}/\Delta T$ in the European scenarios

Substance «i»	**Reference**	**Relationship $\Delta c_{pol,i}/\Delta T$** ($\mu g/m^3K$)
$PM_{2.5}$	Tai, 2012	(+/-)4
	Megaritis et al.,2014	(+/-)4
PM_{10}	Dias et al., 2012	1.4
	Carvalho,2010	(1-4)
Ozone	Doherty et al., 2012	(4.4-6.4)
	Carvalho,2010	(1-3)
	Jacob., 2009	(4-20)

The values in Table 17 have been founded as directly reported in publications or come from data and graphs interpolations. Some values given in "ppm" have been converted in "$\mu g/m^3$". As it is possible to see in many cases the results are a scenario represented by a range of values (both negative and positive) and not a punctual number, because the various assumptions that have been made in the different environmental studies. In this research for each pollutants "i" the highest and lower values founded for the relationships has been considered, as representative of "worst" and "best" scenarios. Baseline scenario considered $\Delta T_x = 0°C$ (ΔT_0, Base case). Furthermore, only data for $PM_{2.5}$, PM_{10} and Ozone have been considered, in line with the main substances responsible for respiratory problems and because the lack in literature of others data.

Variation of pollutant concentrations – Variation of Human Health damage indicator ($\Delta HH = f(\Delta c_{pol,i})$)

The last step has been the correction of the existing model before the implementation of four different case studies to verify the effectiveness of this one and evaluate the differences in terms of damage to human health.

In this phase so called "variation indexes" for each "i" substances (V-index$_i$) have been calculated, in the following way:

- Definition of $c_{i,AVERAGE\ VALUE}$ for each substance "i". These values, published from European Environmental Agency, are the actual average concentrations of $PM_{2.5}$, PM_{10} and O_3 in air in Europe (EEA, 2015). In the next table (Tab. 18) are reported the average concentrations considered.

Table 18 European average concentrations in air considered in the study

Substance «i»	**$C_{i,AVERAGE}$ values** ($\mu g/m^3$)
$PM_{2.5}$	25
PM_{10}	40

Substance «i»	$C_{i,AVERAGE}$ values ($\mu g/m^3$)
Ozone (O_3)	120

- Calculation of V-index$_i$. These indexes have been calculated as follow, with the aim to quantify the absolute variation in air of pollutants linked to the variation of concentration ($\Delta c_{pol,i}$) due to ΔT_x.

$$V\text{-index}_i = \{[c_{i,AVERAGE\ VALUE} + (\Delta c_{pol,i} / \Delta T)^* \Delta T_x] / c_{i,AVERAGE\ VALUE}\} - 1 \qquad [3]$$

- Starting from the assumption that actual $C_{i,AVERAGE}$ values are due to the actual global emissions (including so the emissions coming from product inventories calculated from existing database considered in actual LCIA model), these indexes have been used to modified data inventories in LCA case study (inventory emissions of pollutants "i") to calculate the variation in terms of mass of pollutant "i" that should be added to mass values from database to do new concentration levels ($c_{i,AVERAGE\ VALUE}+\Delta c_{pol,I}$) caused from temperature modifications (ΔT_x).
  These pollutants mass variation (Δm_i) represent, for each substance "i", the absolute variation (in terms of emission in the air) that is responsible of the variation of concentration in air of the substance "i", caused by a temperature change. Mass variation is calculated as follow:

$$\Delta m_i = V\text{-index}_i * m_i\ , \qquad [4]$$

  where "m_i" is the value obtain from original (base case) life cycle inventory analysis of LCA study for each substance "i".
  So fate analysis has been indirectly modifies and Δm_i values are added to the inventory data to evaluate differences in terms of human health damage, implementing the LCIA method.

In this way it is possible to modify and update the actual LCIA model (for the purpose of this research), with any modifications to the LCIA model algorithm (that is not free accessible) but through indirect modifications, working on inventory data. This is possible for fate analysis modifications.
Following this procedure and applying these formulas it is possible to evaluate differences in Human Health damage indicator (ΔHH) considering results from update model and base case model (where procedure and formulas are not applied).

To verify applicability and effectiveness of the model, this one has been implemented in four case studies where three different scenarios have been studied:

- "Base case" scenario. LCA study has been implemented considering $\Delta T_x = 0°C$ (ΔT_0). In this way no modifications have been taken into account. In fact considering [3] and [4] ΔHH it is equal to zero
- "Best Case" scenario. LCA study has been implemented considering an average $\Delta T_x = 2°C$ (ΔT_2). Lowest values of Table 17 have been considered and consequently V-index$_i$ values have been calculated. Values considered for this scenario are reported in the next table (Tab. 19).

Table 19 "Best case" scenario: reference data considered in the update model

Substance «i»	**Relationship** ($\mu g/m^3K$)	**V-index$_i$ value**
$PM_{2.5}$	-4	-0.32
PM_{10}	1	0.050
Ozone (O_3)	1	0.017

- "Worst Case" scenario. LCA study has been implemented considering an average $\Delta T_x = 2°C$ (ΔT_2). Highest values of Table 17 have been considered and consequently V-index$_i$ values have been calculated. Values considered for this scenario are reported in the next table (Tab. 20).

Table 20 "Worst case" scenario: reference data considered in the update model

Substance «i»	**Relationship** ($\mu g/m^3K$)	**V-index$_i$ value**
$PM_{2.5}$	4	0.32
PM_{10}	4	0.20
Ozone (O_3)	20	0.33

The evaluation of the "best" and the "worst" cases allow to delineate a range of results that include all other intermediate values.

Considering that the key determinants of GHG emissions and also particles emissions are energy production, consumption and efficiency, transport, agriculture and food production, and waste management (Ayres et al., 2009; Haines et al., 2007) case studies have been individuate in these sectors. In particular LCA has been implemented for transport, agriculture and food products/services.

3 Results: applicability and effectiveness

LCA Model modifications

For the the LCA case studies SimaPro v.8.3.0 software (Pré, 2016) has been used, implementing ReCiPe 2008 LCIA method for the impact and damage assessment.

In the next figures (Fig. 34 and 35) are shown how LCA “base case” model has been modified to considered the temperature variation and the variation of pollutant “i” (that take into account the variation of concentration).

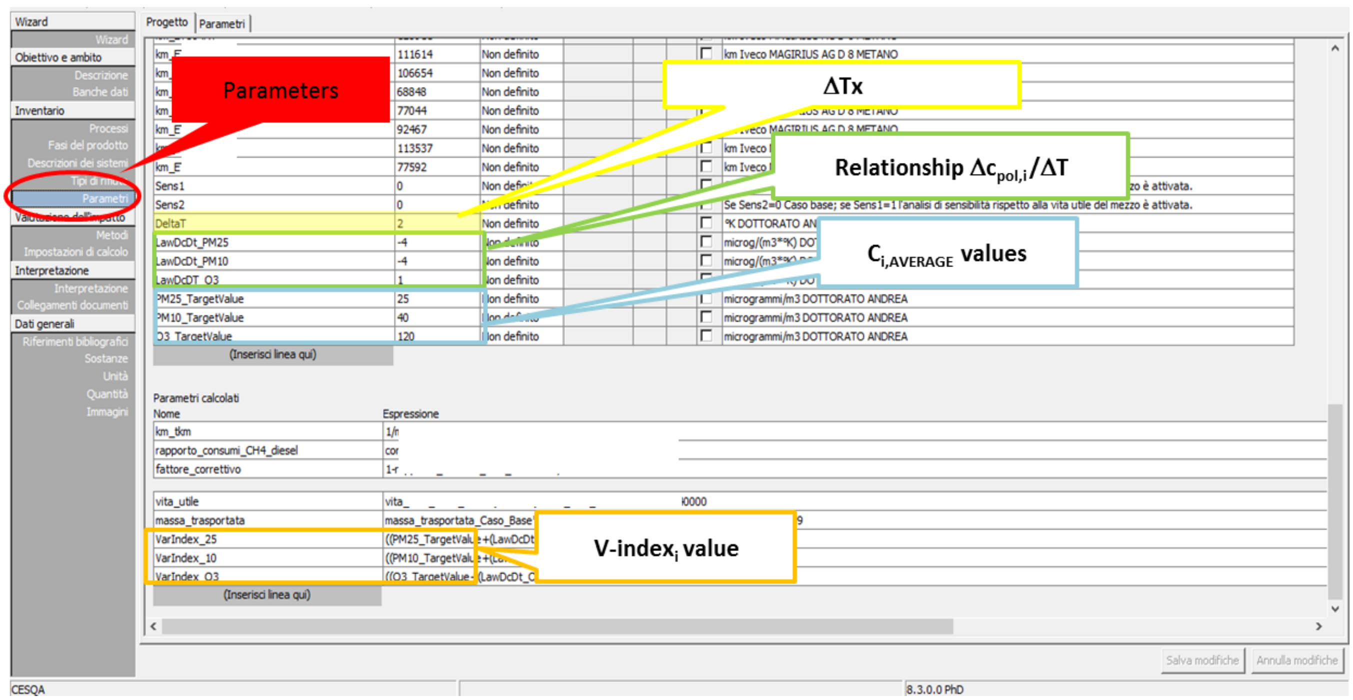


Figure 34 Model updating in the SimaPro software – parameters data

The values calculated and described in § 2.2.2 have been put in the section “Parameters” of SimpaPro software. In this way become easy to modify ΔT_x values (for example for implemented the base case with ΔT_0=0 and for sensitivity analysis) and the relationship $\Delta c_{pol,i}$ /ΔT_x (for “best” and “worst” case studies). The V-index$_i$ values are then calculated applying formula [3] in the section “Calculated Parameters” of the SimaPro sheet. These values have been so used to calculate Δm_i; these calculations have been put in one of the processes of the system product analyzed as inventory data, as show in the next figure (Fig. 35). In this way the system product analyzed “take into account” the surplus of pollutant emitted that are linked to the pollutant air concentration due to temperature rise.

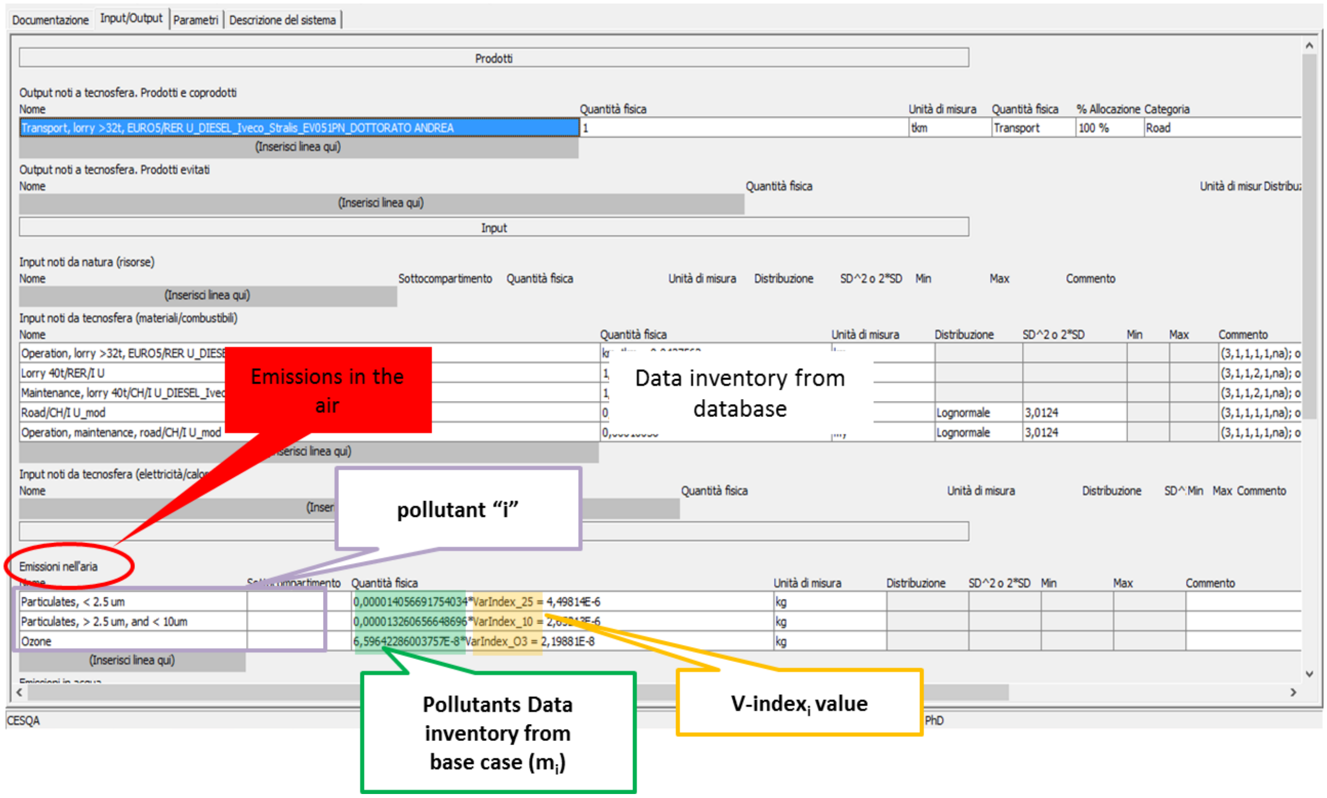


Figure 35 Model updating in the SimaPro software – inventory data

How it is possible to see in figure 35, m_i values are put in the "Emissions into the air" section. In this way the ReCiPe LCIA model takes into account these inventory data in the classification and characterization analysis to evaluate them in terms of human health damage (through exposure, effect and damage analysis included in the model algorithm).

3.1 Case study 1: Service transport by a diesel lorry

3.1.1 Goal and scope definition

The product system analyzed is a service transport by a diesel lorry; the function of the product system is defined as "the transport of good in national and European places". The functional unit (FU) considered for the LCA study is the transport of 1 ton of goods for 1 kilometer of distance, expressed as 1 tkm. As reference value is considered a diesel lorry with an average consumption of 0.28 liters/km, considering an average load of 22.9 tons transported (Fedele e al., 2015b). The processes included in the system boundaries (Fig. 36) are:

- Vehicle manufacturing
- Transport of goods (including diesel production, consumption and emissions)
- Vehicle maintenance (lubricating oil, filters, tires consumption)

- Lorry disposal (considering 540.000 km the average total distance covered for lorry useful life)

Other auxiliary processes, but also very important to considered (Ecoinvent, 2016) are:

- Road construction
- Road maintenance
- Road disposal

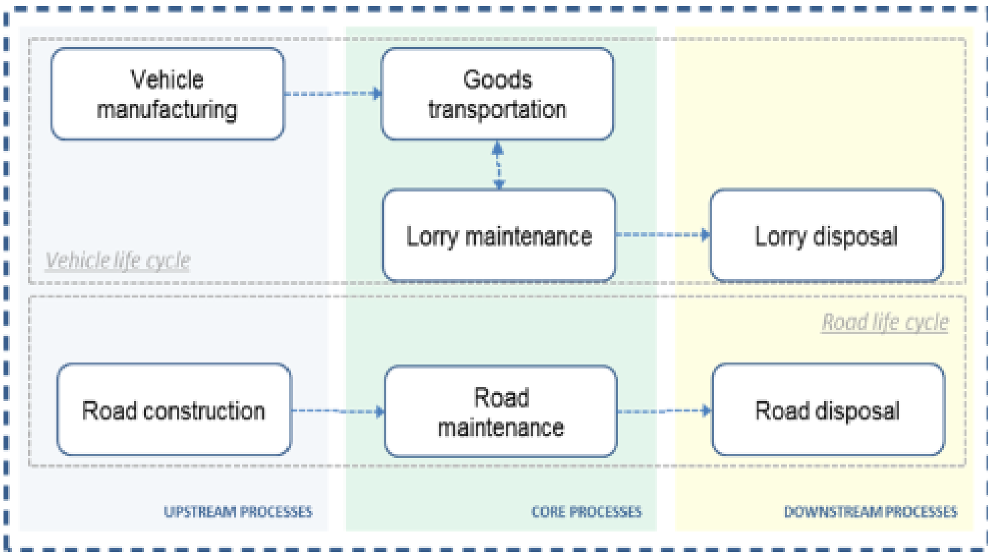


Figure 36 Service Transport by a diesel lorry: system boundaries

The LCIA method is ReCiPe Endpoint (H).

Human Health damage category, measured in DALY, is calculated and analyzed both for midpoint than endopoint indicator levels.

3.1.2 Base case

Base case LCA study do not considered the effect of temperature (ΔT_0 = 0°C) on results. This analysis is useful to compared final results and to calculate Δm_i for "best" and worst" scenario (§ 3.1.3 and 3.1.4)

Inventory data

For the aim of the research only inventory data relative to the emissions of pollutants in the air are interesting. In the next table (Tab. 21) are reported inventory data of considered "i" pollutants basing on the FU. The complete inventory data list (in reference to the air emissions) is reported in Annex A.

Table 21 Data inventory results (case study 1)

Substance «i»	**m_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	1.41 E-05
Particulate matter (PM_{10})	1.33 E-05
Ozone (O_3)	6.60 E-08

Results

The result calculated for Human Health damage indicator, basing on the chosen FU, is 1.137 E-07 DALY.

Results considering each midpoint impact category and for each single life cycle process are expressed in Table 22.

Table 22 Case study 1 - Base case Results

				Life Cycle Processes						
IMPACT CATEGORY	**UNIT**	**TOTAL**	**%**	Transport process	Manufacturing, Lorry	Maintenance, lorry	Construction, Road	Maintenance, road	Disposal, lorry	Disposal, road
Climate change	DALY	8,222E-08	72,31	5,438E-08	4,257E-09	2,437E-09	1,664E-08	4,131E-09	1,939E-10	1,811E-10
Ozone depletion	DALY	2,185E-11	0,02	1,272E-11	5,890E-13	7,984E-13	7,009E-12	6,869E-13	4,777E-15	5,139E-14
Human toxicity	DALY	6,230E-09	5,48	9,073E-10	2,387E-09	3,892E-10	2,076E-09	3,991E-10	6,275E-11	8,556E-12
Photochemical oxidant formation	DALY	1,247E-11	0,01	5,879E-12	4,311E-13	2,126E-13	5,560E-12	3,230E-13	4,782E-15	5,646E-14
Particulate matter formation	DALY	2,515E-08	22,12	1,197E-08	2,116E-09	6,252E-10	9,353E-09	9,751E-10	8,350E-12	1,018E-10
Ionising radiation	DALY	6,879E-11	0,06	1,199E-11	1,047E-11	4,855E-12	3,219E-11	9,091E-12	3,737E-14	1,496E-13
TOTAL	DALY	1,137E-07	100,00	6,729E-08	8,772E-09	3,457E-09	2,811E-08	5,515E-09	2,651E-10	2,917E-10

3.1.3 Best Case

Considering ΔT_2=2°C, and data from Tables 18, 19 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 23.

Table 23 Δm_i results (case study 1 – best case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	- 4.50E-06
Particulate matter (PM_{10})	6.63E-07
Ozone (O_3)	1.12E-09

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator (ΔHH): -1.859E-9 DALY. This difference is entirely accounted in the "particulate matter formation" midpoint indicator. Table 24 shows the results for the best case scenario.

Table 24 Case study 1 - Best case Results

IMPACT CATEGORY	**UNIT**	**TOTAL**	**%**
Climate change	DALY	8.222E-08	73.51
Ozone depletion	DALY	2.185E-11	0.02
Human toxicity	DALY	6.230E-09	5.57
Photochemical oxidant formation	DALY	1.247E-11	0.01
Particulate matter formation	DALY	2.329E-08	20.82
Ionising radiation	DALY	6.879E-11	0.06
TOTAL	DALY	1.118E-07	100.00

3.1.4 Worst case

Considering ΔT_2=2°C, and data from Tables 18, 20 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated. Results are reported in Table 25.

Table 25 Δm_i results (case study 1 – worst case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	4.50E-06
Particulate matter (PM_{10})	2.65E-06
Ozone (O_3)	2.18E-08

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator: +1.859E-9 DALY. This difference is entirely accounted in the "particulate matter formation" midpoint indicator. Table 26 shows the results for the worst case scenario.

Table 26 Case study 1 - Worst case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8.222E-08	71.15
Ozone depletion	DALY	2.185E-11	0.02
Human toxicity	DALY	6.230E-09	5.39
Photochemical oxidant formation	DALY	1.247E-11	0.01
Particulate matter formation	DALY	2.701E-08	23.37
Ionising radiation	DALY	6.879E-11	0.06
TOTAL	DALY	1.156E-07	100.00

3.2 Case study 2: Service transport by a methane lorry

3.2.1 Goal and scope definition

The product system analyzed is a service transport by a methane lorry; the function of the product system is defined as "the transport of good in national and European places", similarly to the previous case study. The functional unit (FU) considered for the LCA study is the transport of 1 ton of goods for

1 kilometer of distance, expressed as 1 tkm. As reference value is considered a methane lorry with an average consumption of 0.25 kg/km, considering an average load of 22.9 tons transported. The processes included in the system boundaries are the same of case study 1 (Fig. 36):

- Vehicle manufacturing
- Transport of goods (including diesel production, consumption and emissions)
- Vehicle maintenance (lubricating oil, filters, tires consumption)
- Lorry disposal (considering 540.000 km the average total distance covered for lorry useful life)

Other auxiliary processes, but also very important to considered (Ecoinvent, 2016) are:

- Road construction
- Road maintenance
- Road disposal

The LCIA method is ReCiPe Endpoint (H).

Human Health damage category, measured in DALY, is calculated and analyzed both for midpoint than endopoint indicator levels.

3.2.2 Base case

Base case LCA study do not considered the effect of temperature (ΔT_0 = 0°C) on results. This analysis is useful to compared final results and to calculate Δm_i for “best” and worst” scenario (§ 3.2.3 and 3.2.4)

Inventory data

For the aim of the research only inventory data relative to the emissions of pollutants in the air are interesting. In the next table (Tab. 27) are reported inventory data of considered “i” pollutants basing on the FU. The complete inventory data list (in reference to the air emissions) is reported in Annex B.

Table 27 Data inventory results (case study 1)

Substance «i»	**m_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	1.26 E-05
Particulate matter (PM_{10})	1.31 E-05
Ozone (O_3)	7.19 E-08

Results

The result calculated for Human Health damage indicator, basing on the FU chose, is 1.116 E-07 DALY.

Results considering each midpoint impact category and for each single life cycle process are expressed in Table 28.

Table 28 Case study 1 - Base case Results

IMPACT CATEGORY	UNIT	TOTAL	%	Life Cycle Processes: Transport process	Manufacturing, Lorry	Maintenance, lorry	Construction, Road	Maintenance, road	Disposal, lorry	Disposal, road
Climate change	DALY	8,282E-08	74,23	5,497E-08	4,257E-09	2,448E-09	1,664E-08	4,131E-09	1,939E-10	1,811E-10
Ozone depletion	DALY	2,175E-11	0,02	1,259E-11	5,890E-13	8,111E-13	7,009E-12	6,869E-13	4,777E-15	5,139E-14
Human toxicity	DALY	5,806E-09	5,20	4,809E-10	2,387E-09	3,912E-10	2,076E-09	3,991E-10	6,275E-11	8,556E-12
Photochemical oxidant formation	DALY	1,198E-11	0,01	5,388E-12	4,311E-13	2,171E-13	5,560E-12	3,230E-13	4,782E-15	5,646E-14
Particulate matter formation	DALY	2,285E-08	20,48	9,665E-09	2,116E-09	6,298E-10	9,353E-09	9,751E-10	8,350E-12	1,018E-10
Ionising radiation	DALY	6,254E-11	0,06	5,715E-12	1,047E-11	4,886E-12	3,219E-11	9,091E-12	3,737E-14	1,496E-13
TOTAL	DALY	1,116E-07	100,00	6,514E-08	8,772E-09	3,475E-09	2,811E-08	5,515E-09	2,651E-10	2,917E-10

3.2.3 Best Case

Considering ΔT_2=2°C, and data from Tables 18, 19 and 27 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 27, Δm_i are calculated through formula [4]. Results are reported in Table 29.

Table 29 Δm_i results (case study 2 – best case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	- 4.50E-06
Particulate matter (PM_{10})	6.63E-07
Ozone (O_3)	1.12E-09

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator (ΔHH): -1.731E-9 DALY. This difference is entirely accounted in the “particulate matter formation” midpoint indicator. Table 30 shows the results for the best case scenario.

Table 30 Case study 2 - Best case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8.282E-08	75.40
Ozone depletion	DALY	2.175E-11	0.02
Human toxicity	DALY	5.806E-09	5.29
Photochemical oxidant formation	DALY	1.198E-11	0.01
Particulate matter formation	DALY	2.112E-08	19.23
Ionising radiation	DALY	6.254E-11	0.06
TOTAL	DALY	1.098E-07	100.00

3.2.4 Worst case

Considering ΔT_2=2°C, and data from Tables 18, 20 and 27 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 27, Δm_i are calculated through formula [4]. Results are reported in Table 31.

Table 31 Δm_i results (case study 2 – worst case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	4.04E-06
Particulate matter (PM_{10})	2.62E-06

Substance «i»	Δm_i (kg) / FU
Ozone (O_3)	2.37E-08

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator: +1.731E-9 DALY. These differences are entirely accounted in the “particulate matter formation” midpoint indicator. Table 32 shows the results for the worst case scenario.

Table 32 Case study 2 - Worst case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8.282E-08	73.10
Ozone depletion	DALY	2.175E-11	0.02
Human toxicity	DALY	5.806E-09	5.12
Photochemical oxidant formation	DALY	1.198E-11	0.01
Particulate matter formation	DALY	2.458E-08	21.69
Ionising radiation	DALY	6.254E-11	0.06
TOTAL	DALY	1.133E-07	100.00

3.3 Case study 3: Production of conventional soybean

3.3.1 Goal and scope definition

The product system analyzed is an agricultural cultivation for the production of soybean, through techniques of conventional agriculture; a “cradle to farm gate” system is considered. The function of the product system is defined as “the production of conventional soybean in the Northern Italy”; the focus of this specific study is on the agricultural stage, and the product system includes all of the agricultural processes that are required for the production of soybeans as well as the auxiliary processes such as the transport of seeds and fertilizers and the maintenance of farm vehicles (Fedele et al., 2014). The functional unit (FU) considered for the LCA study is the production of 1 kg of conventional soybean. Primary data have been used coming from a farm located in the Polesine area in the eastern part of the Po Valley region. The processes included in the system boundaries are depicted in Figure 37:

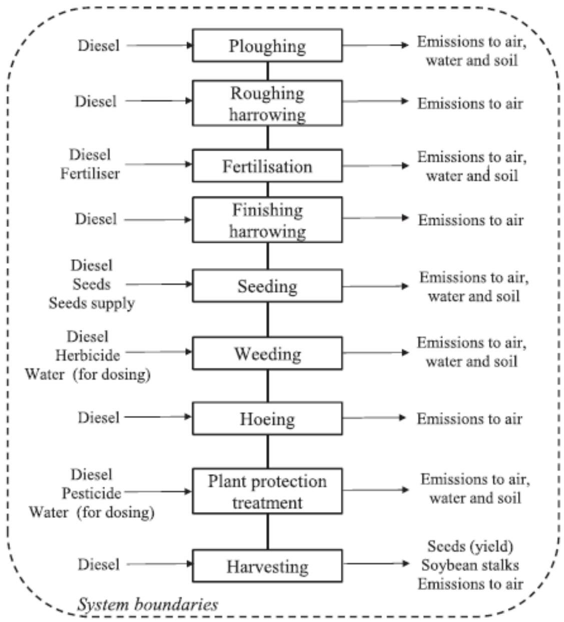


Figure 37 Production of conventional soybean: system boundaries

System boundaries include all agricultural processes from ploughing to harvesting, taking into account for each one input and output mass and energy flows: diesel consumption, fertilizer, herbicide and pesticide applied to the soil and plants, seeds and water used for the agriculture production (in input) and emissions in all various environmental compartments (in output).

The LCIA method is ReCiPe Endpoint (H).

Human Health damage category, measured in DALY, is calculated and analyzed both for midpoint than endopoint indicator levels.

3.3.2 Base case

Base case LCA study do not considered the effect of temperature (ΔT_0 = 0°C) on results. This analysis is useful to compared final results and to calculate Δm_i for "best" and worst" scenario (§ 3.3.3 and 3.3.4)

Inventory data

For the aim of the research only inventory data relative to the emissions of pollutants in the air are interesting. In the next table (Tab. 33) are reported inventory data of considered "i" pollutants basing on the FU. The complete inventory data list (in reference to the air emissions) is reported in Annex C.

Table 33 Data inventory results (case study 3)

Substance «i»	**m_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	8.99 E-05
Particulate matter (PM_{10})	1.59 E-04
Ozone (O_3)	4.50 E-07

Results

The result calculated for Human Health damage indicator, basing on the FU that has been chosen, is 1.765 E-06 DALY. Results considering each midpoint impact category and for each single life cycle process are expressed in Table 34.

Table 34 Case study 3 - Base case Results

				Life Cycle Processes									
IMPACT CATEGORY	**UNIT**	**TOTAL**	**%**	**Field Emissions**	**Ploghing**	**Roughing harrowing**	**Fertilization**	**Finishing harrowing**	**Seeding**	**Weeding**	**Hoeing**	**Plant protection treatments**	**Harvesting**
Climate change	DALY	1,410E-06	79,90	1,103E-06	3,639E-08	8,733E-09	1,762E-07	3,639E-09	5,639E-08	5,260E-09	2,911E-09	3,121E-09	1,455E-08
Ozone depletion	DALY	3,479E-11	0,00	0,000E+00	5,487E-14	1,317E-14	3,048E-11	5,487E-15	2,636E-12	1,184E-12	4,389E-15	3,876E-13	2,195E-14
Human toxicity	DALY	7,695E-08	4,36	5,438E-08	1,331E-10	3,193E-11	2,022E-08	1,331E-11	1,821E-09	2,156E-10	1,064E-11	8,047E-11	5,322E-11
Photochemical oxidant formation	DALY	9,197E-11	0,01	2,166E-11	2,024E-11	4,858E-12	2,556E-11	2,024E-12	5,408E-12	1,336E-12	1,619E-12	1,169E-12	8,096E-12
Particulate matter formation	DALY	2,768E-07	15,69	3,177E-08	3,146E-08	7,551E-09	1,675E-07	3,146E-09	1,544E-08	2,768E-09	2,517E-09	2,051E-09	1,259E-08
Ionising radiation	DALY	7,193E-10	0,04	0,000E+00	0,000E+00	0,000E+00	6,700E-10	0,000E+00	3,267E-11	1,176E-11	0,000E+00	4,818E-12	0,000E+00
TOTAL	DALY	1,765E-06	100,00	1,189E-06	6,800E-08	1,632E-08	3,646E-07	6,800E-09	7,369E-08	8,258E-09	5,440E-09	5,259E-09	2,720E-08

3.3.3 Best Case

Considering ΔT_2=2°C, and data from Tables 18, 19 and 33 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 33, Δm_i are calculated through formula [4]. Results are reported in Table 35.

Table 35 Δm_i results (case study 3 – best case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	- 2.88E-05
Particulate matter (PM_{10})	7.95E-06
Ozone (O_3)	7.65E-09

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator (ΔHH): -1.575E-8 DALY. This differences is entirely accounted in the "particulate matter formation" midpoint indicator. Table 36 shows the results for the best case scenario.

Table 36 Case study 3 - Best case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	1,410E-06	80,62
Ozone depletion	DALY	3,479E-11	0,00
Human toxicity	DALY	7,695E-08	4,40
Photochemical oxidant formation	DALY	9,197E-11	0,01
Particulate matter formation	DALY	2,610E-07	14,93
Ionising radiation	DALY	7,193E-10	0,04
TOTAL	DALY	1,749E-06	100,00

3.3.4 Worst case

Considering ΔT_2=2°C, and data from Tables 18, 20 and 33 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 33, Δm_i are calculated through formula [4]. Results are reported in Table 31.

Table 37 Δm_i results (case study 3 – worst case)

Substance «i»	**Δm_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	2.88E-05
Particulate matter (PM_{10})	3.18E-05
Ozone (O_3)	1.49E-07

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator: +1.575E-8 DALY. This difference is entirely accounted in the "particulate matter formation" midpoint indicator. Table 38 shows the results for the worst case scenario.

Table 38 Case study 3 - Worst case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	1,410E-06	79,20
Ozone depletion	DALY	3,479E-11	0,00
Human toxicity	DALY	7,695E-08	4,32
Photochemical oxidant formation	DALY	9,197E-11	0,01
Particulate matter formation	DALY	2,926E-07	16,43
Ionising radiation	DALY	7,193E-10	0,04
TOTAL	DALY	1,780E-06	100,00

3.4 Case study 4: Production of hens eggs

3.4.1 Goal and scope definition

The product system analyzed is the production of hens eggs for human consumption; a "cradle to grave" system is considered. The function of the product system is defined as "the production of hens eggs for human consumption (category A) in Italy". The objective of this study is to calculate the impacts of the entire life cycle of 1 kg of hens eggs (functional units) produced by a North Italian company considering a national scenario for the product commercialization. The study analyzed all the life cycle processes from breeding of chicks to product delivery and consumption (Fedele et al., 2016). Primary data have been used for eggs production and packaging, other secondary data come from LCA database. The processes included in the system boundaries are reported in Figure 38:

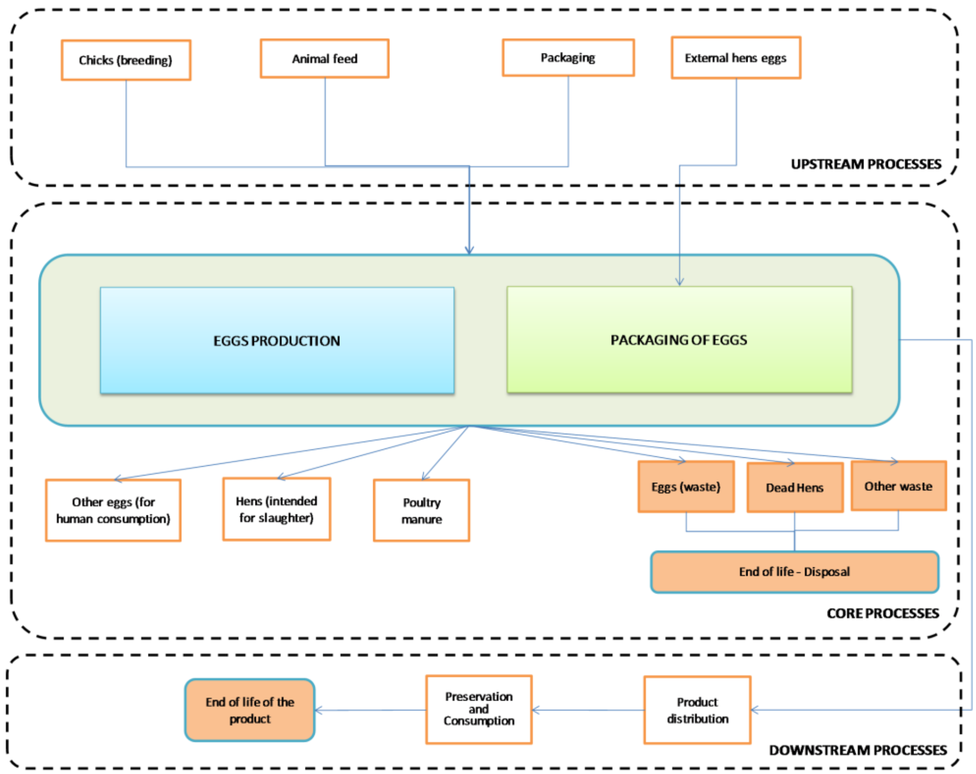


Figure 38 Production of hens eggs: system boundaries

Coproducts are considered in the LCA study: other typology of eggs, hens (for slaughter) and poultry manure. A mass based allocation is applied in line with the standard ISO 14040 requirements (ISO, 2006a).

3.4.2 Base case

Base case LCA study do not considered the effect of temperature (ΔT_0 = 0°C) on results. This analysis is useful to compared final results and to calculate Δm_i for "best" and worst" scenario (§ 3.4.3 and 3.4.4).

Inventory data

For the aim of the research only inventory data relative to the emissions of pollutants in the air are interesting. In the next table (Tab. 39) are reported inventory data of considered "i" pollutants basing on the FU. The complete inventory data list (in reference to the air emissions) is reported in Annex D.

Table 39 Data inventory results (case study 4)

Substance «i»	**m_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	1.37 E-03
Particulate matter (PM_{10})	6.76 E-04
Ozone (O_3)	1.01 E-05

Results

The result calculated for Human Health damage indicator, basing on the FU chose, is 6.876 E-06 DALY. Results considering each midpoint impact category and for each single life cycle process are expressed in Table 34.

Table 40 Case study 4 - Base case Results

				Life Cycle Processes	
IMPACT CATEGORY	**UNIT**	**TOTAL**	**%**	**All Processes from Breeding of chicks to eggs Preservation and consumption**	**End of Life**
Climate change	DALY	4,391E-06	63,87	4,259E-06	1,325E-07
Ozone depletion	DALY	1,033E-09	0,02	1,031E-09	1,933E-12
Human toxicity	DALY	5,060E-07	7,36	4,722E-07	3,377E-08
Photochemical oxidant formation	DALY	4,491E-10	0,01	4,462E-10	2,958E-12
Particulate matter formation	DALY	1,972E-06	28,68	1,969E-06	3,026E-09
Ionising radiation	DALY	4,858E-09	0,07	4,837E-09	2,126E-11
TOTAL	DALY	6,876E-06	100,00	6,706E-06	1,694E-07

3.4.3 Best Case

Considering ΔT_2=2°C, and data from Tables 18, 19 and 39 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 39, Δm_i are calculated through formula [4]. Results are reported in Table 41.

Table 41 Δm_i results (case study 4 – best case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	-4,39E-04
Particulate matter (PM_{10})	3,38E-05
Ozone (O_3)	1,71E-07

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator (ΔHH): -1.493E-7 DALY. This difference is entirely accounted in the “particulate matter formation” midpoint indicator. Table 42 shows the results for the best case scenario.

Table 42 Case study 4 - Best case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	4,391E-06	65,28
Ozone depletion	DALY	1,033E-09	0,02
Human toxicity	DALY	5,060E-07	7,52
Photochemical oxidant formation	DALY	4,491E-10	0,01
Particulate matter formation	DALY	1,823E-06	27,10
Ionising radiation	DALY	4,858E-09	0,07
TOTAL	DALY	6,726E-06	100,00

3.4.4 Worst case

Considering ΔT_2=2°C, and data from Tables 18, 20 and 39 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 39, Δm_i are calculated through formula [4]. Results are reported in Table 43.

Table 43 Δm_i results (case study 4 – worst case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	4,39E-04
Particulate matter (PM_{10})	1,35E-04
Ozone (O_3)	3,33E-06

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator: +1.493E-7 DALY. These differences are entirely accounted in the "particulate matter formation" midpoint indicator. Table 44 shows the results for the worst case scenario.

Table 44 Case study 4 - Worst case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	4,391E-06	62,51
Ozone depletion	DALY	1,033E-09	0,01
Human toxicity	DALY	5,060E-07	7,20
Photochemical oxidant formation	DALY	4,491E-10	0,01
Particulate matter formation	DALY	2,121E-06	30,20
Ionising radiation	DALY	4,858E-09	0,07
TOTAL	DALY	7,025E-06	100,00

3.5 Sensitivity analysis

Sensitivity analysis (§ 1.3.1) is a "systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study" (ISO, 2006a).

The main parameter that is considered in this study and that could affects results are "Temperature increase" (ΔT_x): this is the parameter analyzed in the sensitivity analysis. In line with the methodological choice made (§ 2.2.2) the reference temperature variation is ΔT_2 = 2°C, but effects on results of other ΔT_x should be investigated. This analysis considers so the following values of ΔT_x, in line with the future IPCC scenarios (IPCC, 2014): ΔT_1= 1°C; ΔT_3=3°C; ΔT_4=4°C and ΔT_5=5°C.

The sensitivity analysis is based on Case Study 1 "Service transport by a diesel lorry". Results for "best" and "worst" scenario are following reported for each ΔT_x considered.

3.5.1 Temperature increase ΔT_1 = 1°C

- Best Case Scenario

Considering ΔT_1=1°C, and data from Tables 18, 19 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 41.

Table 45 Δm_i results (sensitivity analysis, ΔT= 1°C - best case)

Substance «i»	**Δm_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	-2,25E-06
Particulate matter (PM_{10})	3,32E-07
Ozone (O_3)	5,50E-10

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator (ΔHH): -9.295E-10 DALY. This difference is entirely accounted in the "particulate matter formation" midpoint indicator. Table 42 shows the results for the best case scenario.

Table 46 Sensitivity analysis, ΔT= 1°C - Best case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8,222E-08	72,91
Ozone depletion	DALY	2,185E-11	0,02
Human toxicity	DALY	6,230E-09	5,52
Photochemical oxidant formation	DALY	1,247E-11	0,01
Particulate matter formation	DALY	2,422E-08	21,48
Ionising radiation	DALY	6,879E-11	0,06
TOTAL	DALY	1,128E-07	100,00

- Worst Case Scenario

Considering ΔT_1=1°C, and data from Tables 18, 20 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 47.

Table 47 Δm_i results (sensitivity analysis, ΔT= 1°C - worst case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	2,25E-06
Particulate matter (PM_{10})	1,33E-06
Ozone (O_3)	1,10E-08

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator: +9.295E-10 DALY. This difference are entirely accounted in the "particulate matter formation" midpoint indicator. Table 48 shows the results for the worst case scenario.

Table 48 Sensitivity analysis, $\Delta T = 1°C$ - Worst case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8,222E-08	71,73
Ozone depletion	DALY	2,185E-11	0,02
Human toxicity	DALY	6,230E-09	5,43
Photochemical oxidant formation	DALY	1,247E-11	0,01
Particulate matter formation	DALY	2,608E-08	22,75
Ionising radiation	DALY	6,879E-11	0,06
TOTAL	DALY	1,146E-07	100,00

3.5.2 Temperature increase $\Delta T_3 = 3°C$

- Best Case Scenario

Considering $\Delta T_3 = 3°C$, and data from Tables 18, 19 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 49.

Table 49 Δm_i results (sensitivity analysis, $\Delta T = 3°C$ - best case)

Substance «i»	**Δm_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	-6,75E-06
Particulate matter (PM_{10})	9,95E-07
Ozone (O_3)	1,65E-09

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator (ΔHH): -2.787E-9 DALY. This difference is entirely accounted in the “particulate matter formation” midpoint indicator. Table 50 shows the results for the best case scenario.

Table 50 Sensitivity analysis, $\Delta T = 3°C$ - Best case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8,222E-08	74,13
Ozone depletion	DALY	2,185E-11	0,02
Human toxicity	DALY	6,230E-09	5,62
Photochemical oxidant formation	DALY	1,247E-11	0,01
Particulate matter formation	DALY	2,236E-08	20,16
Ionising radiation	DALY	6,879E-11	0,06
TOTAL	DALY	1,109E-07	100,00

- Worst Case Scenario

Considering ΔT_3=3°C, and data from Tables 18, 20 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 51.

Table 51 Δm_i results (sensitivity analysis, $\Delta T = 3°C$ - worst case)

Substance «i»	**Δm_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	6,75E-06
Particulate matter (PM_{10})	3,98E-06
Ozone (O_3)	3,30E-08

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator: +2.787E-9 DALY. This difference are entirely accounted in the “particulate matter formation” midpoint indicator. Table 52 shows the results for the worst case scenario.

Table 52 Sensitivity analysis, ΔT= 3°C - Worst case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8,222E-08	70,58
Ozone depletion	DALY	2,185E-11	0,02
Human toxicity	DALY	6,230E-09	5,35
Photochemical oxidant formation	DALY	1,247E-11	0,01
Particulate matter formation	DALY	2,794E-08	23,98
Ionising radiation	DALY	6,879E-11	0,06
TOTAL	DALY	1,165E-07	100,00

3.5.3 Temperature increase ΔT_4 = 4°C

- Best Case Scenario

Considering ΔT_4=4°C, and data from Tables 18, 19 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 53.

Table 53 Δm_i results (sensitivity analysis, ΔT= 4°C - best case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	-9,00E-06
Particulate matter (PM_{10})	1,33E-06
Ozone (O_3)	2,20E-09

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator (ΔHH): -3.718E-9 DALY. This difference is entirely accounted in the "particulate matter formation" midpoint indicator. Table 50 shows the results for the best case scenario.

Table 54 Sensitivity analysis, ΔT= 4°C - Best case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8,222E-08	74,76
Ozone depletion	DALY	2,185E-11	0,02
Human toxicity	DALY	6,230E-09	5,66
Photochemical oxidant formation	DALY	1,247E-11	0,01
Particulate matter formation	DALY	2,143E-08	19,48
Ionising radiation	DALY	6,879E-11	0,06
TOTAL	DALY	1,100E-07	100,00

- Worst Case Scenario

Considering ΔT_4=4°C, and data from Tables 18, 20 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 55.

Table 55 Δm_i results (sensitivity analysis, ΔT= 4°C - worst case)

Substance «i»	**Δm_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	9,00E-06
Particulate matter (PM_{10})	5,30E-06
Ozone (O_3)	4,40E-08

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator: +3.718E-9 DALY. This difference is entirely accounted in the "particulate matter formation" midpoint indicator. Table 56 shows the results for the worst case scenario.

Table 56 Sensitivity analysis, ΔT= 4°C - Worst case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8,222E-08	70,02
Ozone depletion	DALY	2,185E-11	0,02
Human toxicity	DALY	6,230E-09	5,31
Photochemical oxidant formation	DALY	1,247E-11	0,01
Particulate matter formation	DALY	2,887E-08	24,58
Ionising radiation	DALY	6,879E-11	0,06
TOTAL	DALY	1,174E-07	100,00

3.5.4 Temperature increase ΔT_5 = 5°C

- Best Case Scenario

Considering ΔT_5=5°C, and data from Tables 18, 19 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 57.

Table 57 Δm_i results (sensitivity analysis, ΔT= 5°C - best case)

Substance «i»	Δm_i (kg) / FU
Particulate matter ($PM_{2.5}$)	-1,12E-05

Particulate matter (PM_{10})	1,66E-06
Ozone (O_3)	2,75E-09

Results

Differences of particles concentrations in air coming from Δm_i calculations give the follow difference on the total Human Health damage indicator (ΔHH): -4.648E-9 DALY. This difference is entirely accounted in the "particulate matter formation" midpoint indicator. Table 58 shows the results for the best case scenario.

Table 58 Sensitivity analysis, ΔT= 5°C - Best case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8,222E-08	75,39
Ozone depletion	DALY	2,185E-11	0,02
Human toxicity	DALY	6,230E-09	5,71
Photochemical oxidant formation	DALY	1,247E-11	0,01
Particulate matter formation	DALY	2,050E-08	18,80
Ionising radiation	DALY	6,879E-11	0,06
TOTAL	DALY	1,091E-07	100,00

<u>- Worst Case Scenario</u>

Considering ΔT_5=5°C, and data from Tables 18, 20 and 21 modifications to the model are applied.

Inventory data

Applying formula [3] and considering values of Table 21, Δm_i are calculated through formula [4]. Results are reported in Table 59.

Table 59 Δm_i results (sensitivity analysis, ΔT= 5°C - worst case)

Substance «i»	**Δm_i** (kg) / FU
Particulate matter ($PM_{2.5}$)	1,12E-05

Substance «i»	**Δm_i** (kg) / FU
Particulate matter (PM_{10})	6,63E-06
Ozone (O_3)	5,50E-08

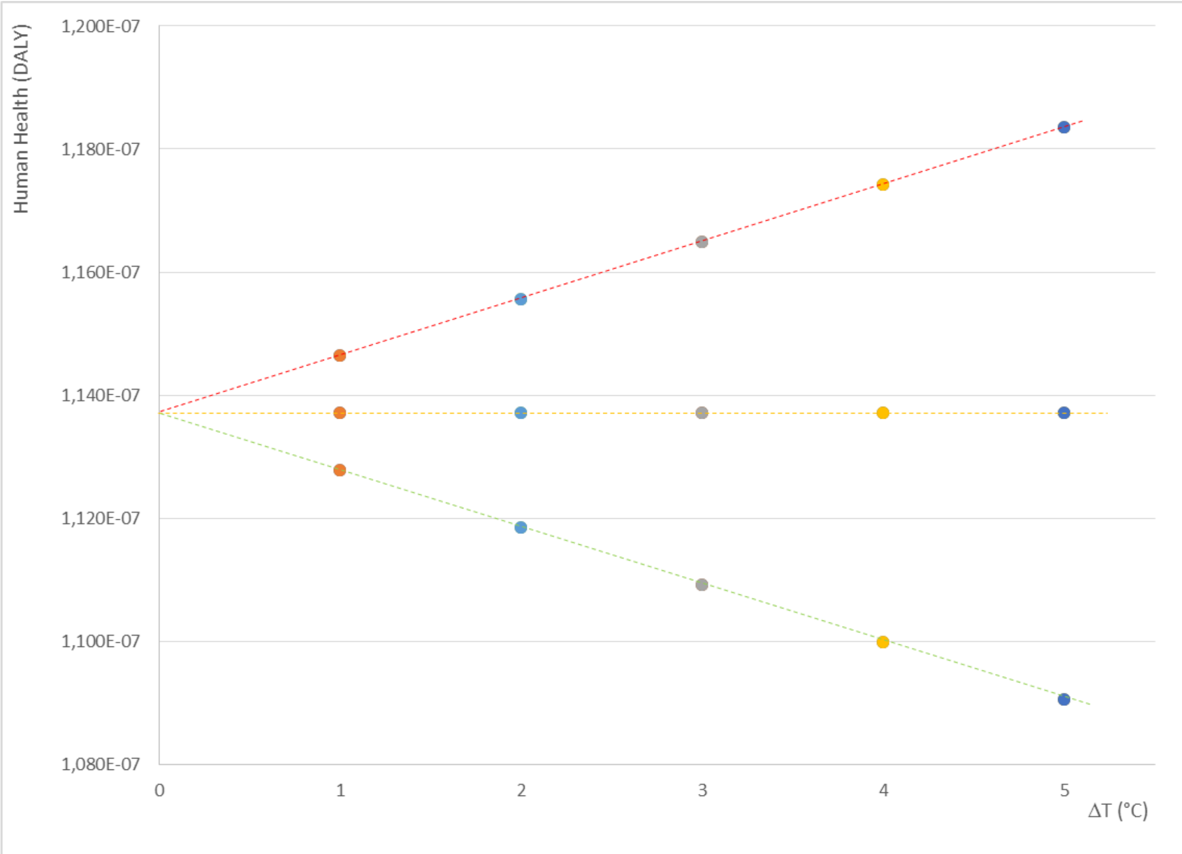
Results

Differences of particles concentrations in air coming from Δm_i calculations give the follows differences on the total Human Health damage indicator: +4.648E-9 DALY. These differences are entirely accounted in the "particulate matter formation" midpoint indicator. Table 56 shows the results for the worst case scenario.

Table 60 Sensitivity analysis, ΔT= 5°C - Worst case Results

IMPACT CATEGORY	UNIT	TOTAL	%
Climate change Human	DALY	8,222E-08	69,47
Ozone depletion	DALY	2,185E-11	0,02
Human toxicity	DALY	6,230E-09	5,26
Photochemical oxidant formation	DALY	1,247E-11	0,01
Particulate matter formation	DALY	2,980E-08	25,18
Ionising radiation	DALY	6,879E-11	0,06
TOTAL	DALY	1,183E-07	100,00

Considering all results obtained for the different temperature increase values analyzed and taking into account both "best" and "worst" scenarios, the follow figure (fig. 39) shows a graphs with all these results. The dashed "orange" line represents the base scenario, with HH damage indicator equal to 1.137E-07 DALY (§ 3.1.2).



The graph shows linear relationship between human health damage indicator and temperature increase with inverse trend between best and worst scenarios.

4 Discussions

This research is focused on the sustainability assessment and on the need of indicators that should be easy to calculate and evaluate from practitioners and enterprises. In the optics of the products improvement performances, this research takes into account the Human Health damage indicator. This indicator represents social characteristics and is influenced from environmental hotspot, and so its improvement could be seen as a step through sustainability, in line with the “LCA new” proposal, published in literature how one alternative to evaluate in a complete way the sustainability of products. The actual damage model on the basis of the Human Health damage indicator actually not consider consequences of climate change on some health effects, for example respiratory problems. These ones are nowadays even more considered in the air quality policy, for their negative relevance on the well-being of people. The improvements of the damage assessment method are development in line with these social and environmental hotpots, that doesn’t found an answer in the actual characterization method published in literature and implemented for life cycle analysis.

Improvements to the model are given not operating on the algorithm load inside the software (inaccessible), but indirectly through some formulas and steps that, starting from actual inventory data (called m_i in the study), considered hypothetical rise temperature scenario to calculate modification of particles concentrations in the air.

Considering the laws $\Delta c_i/\Delta T$ defined from the analysis and the elaboration of environmental data find in literature, it has been possible to calculate Δm_i: these variation of mass of pollutant in the air have been upload as unique value for each pollutant considered ($PM_{2.5}$, PM_{10}, O_3) in the model case studies but come from each process considered in the life cycle analysis of the product/service, in a linear proportional way in line with original inventory data (reported in the annexes). Interesting is the fact that different studies give different (opposite) trends and for this reason “best” and “worst” scenarios have been studied.

The consideration of Δm_i values in the update model allows to improve Human Health damage indicator: considering the average temperature rise scenario with $\Delta T=2°C$ in the next table (Table 61) are reported the differences between the base case and the best and worst cases analyzed, for each case study.

Table 61 Percentage differences between results (Scenario: $\Delta T=2°C$)

Case study	Scenario	Damage to Human Health Indicator (DALY)	Differences from base case result (%)
Case study 1	Base case	1.137 E-7	/

Case study	Scenario	Damage to Human Health Indicator (DALY)	Differences from base case result (%)
	Best Case	1.118 E-07	- 1.64
	Worst case	1.156 E-07	1.64
Case study 2	Base case	1.116 E-7	/
	Best Case	1.098 E-07	- 1.55
	Worst case	1.133 E-07	1.55
Case study 3	Base case	1.765 E-6	/
	Best Case	1.749 E-06	- 0.89
	Worst case	1.780 E-06	0.89
Case study 4	Base case	6.876 E-6	/
	Best Case	6.726 E-06	- 2.17
	Worst case	7.025 E-06	2.17

The differences between results calculated with classical method and the new proposal are in terms of some percentages points. The magnitude differences of total DALY values calculate in the four case studies are strictly connected with each specific product system analyzed: for example in the case study 4 (hens eggs) very impactful are the production of packaging, the breeding of chicks and the product use processes (transport, sale and conservation of product). The following figure (fig. 39) summarized results obtained for the four case studies. In line with the existing method, also the new proposed method allows a specific evaluation and interpretation of data and results, it is “system product” specific and gives the possibility to check and find the more impactful processes for the Human Health damage category.

Results obtained for the different impact categories that contribute to define Human Health indicator (for each case studies and for case-scenario) show as the most relevant categories in terms of DALY are “Climate Change” and “Particulate matter formation”: these results are in line with the contest and the focus of the research, and underline the importance to give a specific priority to these environmental-social hotspot. All Δm_i considered in the new model are accounted in the “Particulate matter formation” in the characterization of damage, but they come from climate change causes (temperature rise considered).

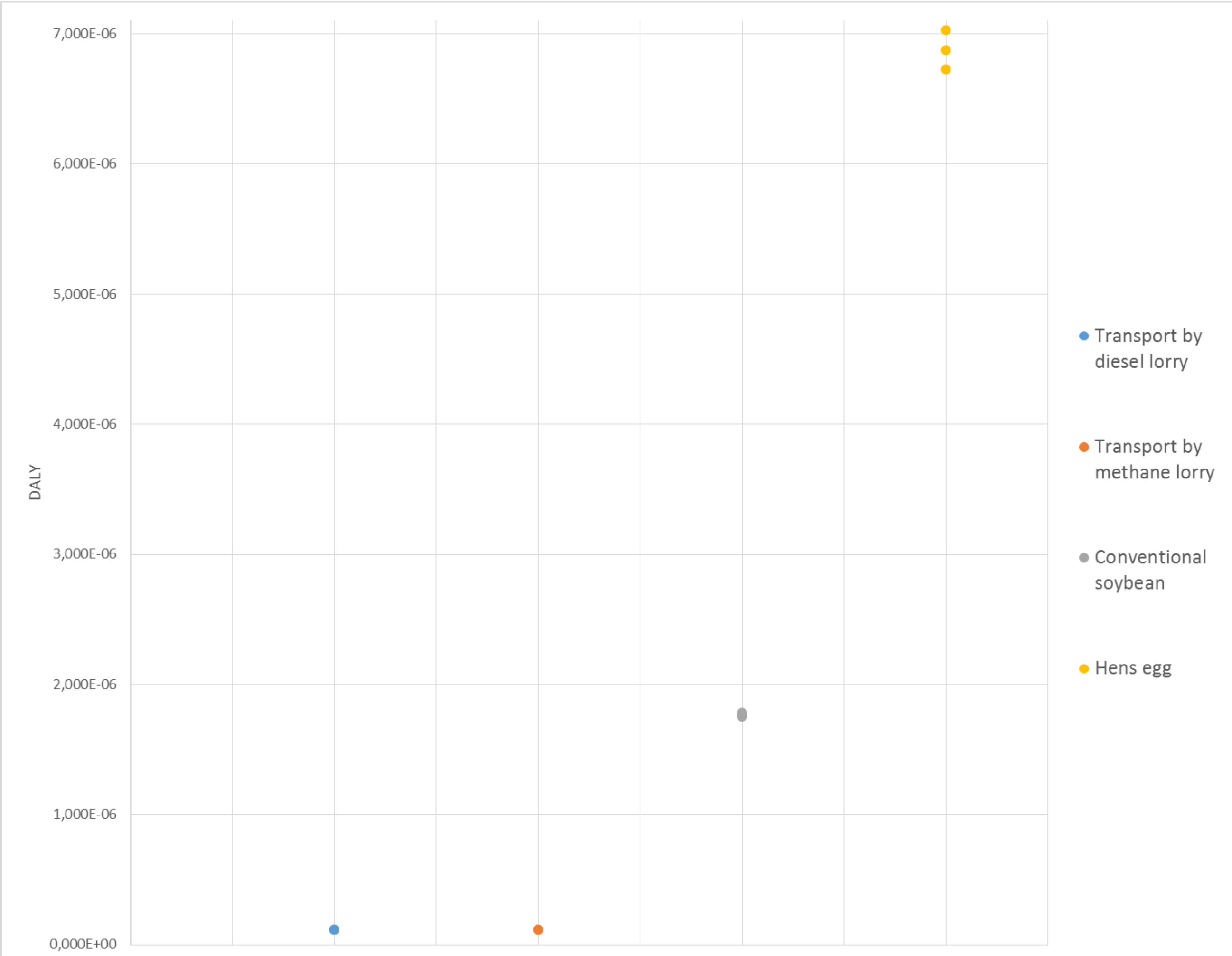


Figure 39 Human Health damage indicator results for the case studies implemented

The main substance that has influence on results is the $PM_{2.5}$. Probably this is due to the most relevant effect factors for $PM_{2.5}$ in comparison to the other substances, considering data of table 17 (the highest value is for ozone and not for $PM_{2.5}$). The same (in absolute terms) but inverse values for the $\Delta c_{PM2.5}/\Delta T$ relationship are the reason of the specular results for the "best" and "worst" scenario. The linear relations founded between ΔHH and ΔT_x in the four case studies allows in a very simply way to write function of the type HH= f (ΔT); this function could be write in a general way as: $HH_{new} = HH_0 + m * \Delta T$, where "$HH_{new}$" is the human health damage indicator values calculated with the update method, "HH_0" is the value of human health damage indicator applying classical ReCiPe 2008 characterization method, "m" is the angular coefficient (that it is possible to extrapolate from case study result) and "ΔT" is a generic temperature rise value. For example, for the case study 1 the following functions are been calculated (+/- in relative to worst or best scenario):

HH_{new} = 1.137E-07 +/- 9.295E-10 * ΔT. In a similar way function could be calculated for each case study. This relation is in line with the linear cause-response relationship for the damage models, as reported in literature

5 Conclusions and future perspectives

Sustainability has become a main topic in the international development policies and should not takes into account only environmental aspects, but also social and economic burdens linked to the life cycle of products and services developed in the global market. Despite it, sustainability assessment is a field that needs yet improvements to make available for stakeholders and companies simply and concrete instruments for an effective and useful analysis. In line with this contest and with the actual mainly international policies trends, that gives even more focus on the climate change, air quality and human health quality, the research aimed to improve existing characterization model to assess effects of climate change (in particular temperature rise) on concentrations of particles in the air (e.g. particular matter) that cause respiratory problem and have consequences in terms of Human Health damage. The model proposed from this study must be collocated as an intermediate step through a complete sustainability evaluation, taking into account specific environmental and social problems.

Starting from a deepened environmental literature research only data on particulate matters $PM_{2.5}$ and PM_{10}, and ozone are been taking into account. Other substances (e.g. nitrogen oxides) are not been taken into account for lack of data. Moreover, only these primary emissions are been considered but some studies underlined also the great relevance of secondary emissions on the respiratory problems that affect human health. Secondary particles come from chemical reactions of gaseous and are formed in the air through primary pollutants and precursor. The next figure shows a simple relationship between primary (PM, O_3 and NO_2) and other secondary substances.

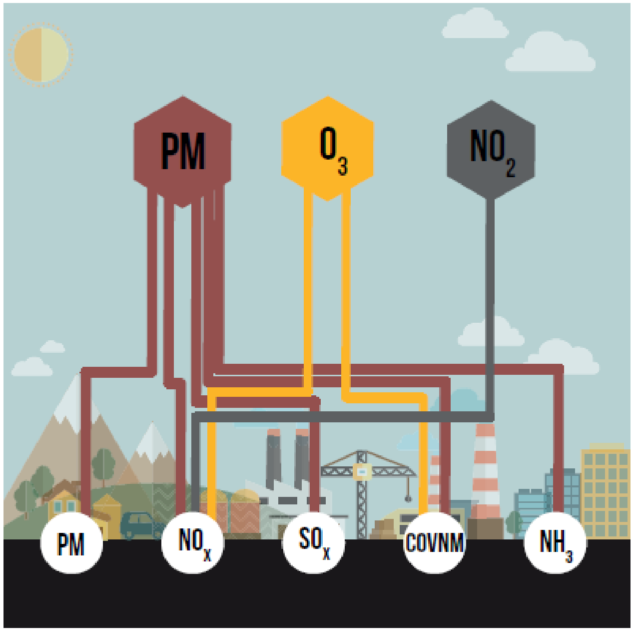


Figure 40 Primary and secondary substances in the air (Aneris et al., 2017)

About the laws “pollutant concentrations”-“temperature increase” ($\Delta c_i/\Delta T$), these are built interpolating published values and graphs inherent to European and national data. To better define these functions a greater number of studies could be useful, always considering that for the life cycle studies specific localized data are need. These values must be chosen in consideration with the geographical and also temporal boundaries of the life cycle analysis where these data will be used. In this research the data and laws utilized are valid only for European context, in which case studies have been implemented.

Another aspect that requires attention is the choice of the average concentrations of pollutant in the air. The method proposed in this research takes into account average concentrations as an assumption, basing on data published by the European Environment Agency. It is opportune to underline that the values considered are average data although is well know how particulate concentrations on the air could change during the annual seasons but also within a single day. The choice to considered average values is in consideration to the fact that the model implemented is not a dynamic model, but in line with the implementation of an LCA analysis, is based on real, preferably primary, but average data.

The updating to the existing characterization method aim of this research is concentrate in the particular step of fate analysis, the first one in the entire damage analysis model. Following developments of research could focus attention also on exposure, effect and damage analysis. Results coming from update model that consider the research proposal show a linear relationship between temperature variation and consequent Human Health damage indicator result variations. This results underline the linearity of the entire damage model (then also for exposure and effect analysis model, not only fate one), in line with the dose-response and cause-effects linearity that are assumed in the damage characterization model.

Applying this model with the aim to analyze damage to Human Health in the existing LCA software (how proposed from the research) a practitioner or a company could analyses data and make correct interpretation, basing in particular on the gravity analysis, that is a procedure that identifies those data having the greatest contribution to the indicator result (IPCC, 2006b) and so these items may then be investigated with increased priority to ensure that sound decisions are made, in an optical of product sustainability product or service development.

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Annex A – Case study 1 data inventory

			Life Cycle Processes						
SUBSTANCE	UNIT	TOTAL	Transport process	Manufacturing,Lorry	Maintenance, lorry	Construction, Road	Maintenance, road	Disposal, lorry	Disposal, road
1-Butanol	kg	4,83E-15	2,12E-16	3,31E-15	5,54E-17	2,11E-16	1,03E-15	6,09E-19	5,85E-18
1-Pentanol	kg	3,93E-15	5,09E-17	1,25E-15	1,63E-15	4,01E-16	5,90E-16	7,29E-19	5,55E-18
1-Pentene	kg	2,97E-15	3,84E-17	9,41E-16	1,24E-15	3,03E-16	4,46E-16	5,51E-19	4,19E-18
1-Propanol	kg	2,75E-13	2,64E-14	1,10E-13	2,14E-14	5,67E-14	5,97E-14	8,87E-17	4,27E-16
1,4-Butanediol	kg	3,87E-13	2,39E-15	3,63E-13	7,54E-15	7,38E-15	6,48E-15	7,39E-17	4,62E-16
2-Aminopropanol	kg	2,46E-15	1,66E-17	1,51E-15	2,33E-17	5,29E-17	8,56E-16	2,44E-19	2,77E-18
2-Butene, 2-methyl-	kg	6,58E-19	8,53E-21	2,09E-19	2,74E-19	6,72E-20	9,90E-20	1,22E-22	9,30E-22
2-Methyl-1-propanol	kg	9,91E-15	2,68E-16	4,04E-15	2,84E-15	8,55E-16	1,89E-15	1,58E-18	1,34E-17
2-Nitrobenzoic acid	kg	4,42E-15	2,98E-17	2,73E-15	2,22E-17	9,12E-17	1,54E-15	4,34E-19	4,96E-18
2-Propanol	kg	6,99E-09	1,84E-11	6,64E-09	1,38E-10	1,16E-10	6,42E-11	1,35E-12	8,30E-12
Acenaphthene	kg	2,82E-14	2,31E-15	2,10E-15	2,17E-15	5,62E-15	1,60E-14	5,84E-18	1,60E-17
Acetaldehyde	kg	2,35E-08	5,32E-10	4,14E-10	4,24E-10	1,84E-08	1,91E-09	1,37E-10	1,67E-09
Acetic acid	kg	4,51E-08	6,31E-09	5,53E-09	1,16E-08	1,20E-08	9,69E-09	1,44E-11	4,55E-11
Acetone	kg	1,24E-08	5,69E-10	8,41E-09	4,72E-10	9,96E-10	1,95E-09	2,53E-12	1,31E-11
Acetonitrile	kg	2,95E-11	7,36E-12	1,60E-11	6,96E-13	5,11E-12	3,05E-13	3,84E-15	4,71E-14
Acrolein	kg	1,16E-11	1,46E-12	4,30E-13	2,34E-13	9,21E-12	2,69E-13	2,13E-15	1,15E-14
Acrylic acid	kg	1,81E-11	4,78E-14	1,72E-11	3,56E-13	3,00E-13	1,66E-13	3,50E-15	2,15E-14
Actinides, radioactive, unspecified	Bq	2,14E-06	2,31E-07	6,41E-07	3,71E-07	7,61E-07	1,30E-07	8,64E-10	4,22E-09
Aerosols, radioactive, unspecified	Bq	2,82E-05	5,81E-06	5,17E-06	2,30E-06	1,11E-05	3,74E-06	1,59E-08	5,15E-08
Aldehydes, unspecified	kg	3,04E-10	4,74E-11	5,61E-11	9,89E-11	9,11E-11	9,61E-12	1,27E-13	4,24E-13
Aluminium	kg	9,48E-07	5,21E-08	3,43E-07	6,47E-08	3,88E-07	9,80E-08	2,29E-10	1,13E-09
Ammonia	kg	1,08E-06	2,93E-07	1,76E-07	4,74E-08	5,01E-07	5,84E-08	1,05E-09	1,56E-09
Ammonium carbonate	kg	5,93E-12	7,97E-13	1,23E-12	1,15E-12	1,51E-12	1,23E-12	1,79E-15	8,37E-15
Aniline	kg	4,20E-14	4,77E-15	2,05E-14	6,18E-15	4,75E-15	5,80E-15	5,90E-18	5,97E-17
Anthranilic acid	kg	3,22E-15	2,18E-17	1,99E-15	1,62E-17	6,65E-17	1,13E-15	3,17E-19	3,61E-18
Antimony	kg	4,66E-10	1,58E-11	3,44E-10	3,09E-11	5,64E-11	1,90E-11	1,31E-13	5,90E-13
Antimony-124	Bq	9,24E-10	2,97E-11	2,70E-11	2,41E-11	6,77E-10	1,63E-10	3,83E-13	3,14E-12
Antimony-125	Bq	9,65E-09	3,10E-10	2,82E-10	2,51E-10	7,07E-09	1,70E-09	4,00E-12	3,27E-11
Argon-41	Bq	1,11E-02	3,06E-03	2,31E-03	1,07E-03	4,29E-03	3,14E-04	7,66E-06	2,04E-05
Arsenic	kg	3,84E-09	3,94E-10	2,15E-09	2,14E-10	8,48E-10	2,28E-10	1,12E-12	5,25E-12
Arsine	kg	2,11E-16	5,57E-19	2,00E-16	4,15E-18	3,50E-18	1,94E-18	4,08E-20	2,50E-19
Barium	kg	1,43E-09	1,97E-10	2,82E-10	1,04E-10	5,53E-10	2,81E-10	8,88E-12	2,01E-12
Barium-140	Bq	6,27E-07	2,02E-08	1,84E-08	1,63E-08	4,60E-07	1,10E-07	2,60E-10	2,13E-09
Benzal chloride	kg	2,47E-18	4,19E-20	8,86E-19	1,19E-18	3,42E-19	1,34E-20	3,56E-22	3,15E-21
Benzaldehyde	kg	5,61E-12	6,95E-13	1,35E-13	6,51E-14	4,66E-12	3,94E-14	9,18E-16	5,38E-15
Benzene	kg	1,61E-07	7,45E-08	1,41E-08	8,24E-09	5,50E-08	9,04E-09	7,36E-11	4,16E-10
Benzene, 1-methyl-2-nitro-	kg	3,82E-15	2,57E-17	2,36E-15	1,92E-17	7,88E-17	1,33E-15	3,75E-19	4,28E-18
Benzene, 1,2-dichloro-	kg	8,34E-14	5,97E-16	4,94E-14	3,12E-15	2,25E-15	2,79E-14	8,74E-18	9,53E-17
Benzene, ethyl-	kg	2,43E-08	1,53E-08	2,61E-10	3,61E-10	7,95E-09	2,87E-10	3,45E-12	5,17E-11
Benzene, hexachloro-	kg	2,39E-11	8,18E-13	7,98E-12	8,27E-13	1,41E-11	7,99E-14	6,99E-14	2,84E-14
Benzene, pentachloro-	kg	2,76E-13	1,20E-14	1,84E-14	1,08E-14	6,13E-14	3,98E-15	1,69E-13	3,29E-16
Benzo(a)pyrene	kg	2,77E-10	1,91E-11	1,19E-10	1,06E-11	9,94E-11	2,77E-11	6,13E-14	6,01E-13
Beryllium	kg	2,07E-11	1,77E-12	4,69E-12	9,25E-13	1,17E-11	1,53E-12	3,22E-14	3,00E-14
Boron	kg	3,80E-08	8,51E-09	7,75E-09	3,45E-09	1,24E-08	5,84E-09	2,13E-11	5,58E-11
Boron trifluoride	kg	2,88E-18	7,62E-21	2,74E-18	5,68E-20	4,79E-20	2,65E-20	5,58E-22	3,43E-21
Bromine	kg	4,87E-09	9,42E-10	8,72E-10	4,19E-10	1,46E-09	1,15E-09	1,17E-11	6,19E-12
Butadiene	kg	2,12E-13	3,24E-15	1,96E-13	5,19E-15	5,09E-15	2,44E-15	4,08E-17	2,55E-16
Butane	kg	1,12E-06	6,78E-07	1,89E-08	2,03E-08	3,61E-07	3,48E-08	1,65E-10	2,30E-09
Butene	kg	2,42E-08	1,53E-08	2,61E-10	3,46E-10	7,92E-09	2,62E-10	3,42E-12	5,16E-11
Butyrolactone	kg	1,08E-13	3,02E-16	1,03E-13	2,13E-15	1,83E-15	9,98E-16	2,10E-17	1,28E-16
Cadmium	kg	1,91E-09	6,27E-10	7,27E-10	9,28E-11	3,93E-10	6,87E-11	6,03E-13	2,88E-12
Calcium	kg	3,41E-08	6,67E-09	5,38E-09	2,51E-09	1,42E-08	3,71E-09	1,59E-09	6,49E-11
Carbon-14	Bq	1,40E-01	2,37E-02	2,06E-02	9,72E-03	6,58E-02	1,93E-02	7,49E-05	3,05E-04
Carbon dioxide, biogenic	kg	2,11E-04	3,15E-05	3,11E-05	2,20E-05	9,04E-05	3,56E-05	1,13E-07	2,81E-07
Carbon dioxide, fossil	kg	5,65E-02	3,78E-02	2,75E-03	1,63E-03	1,13E-02	2,80E-03	1,38E-04	1,25E-04
Carbon dioxide, land transformation	kg	6,80E-07	1,70E-07	3,06E-07	3,33E-08	1,59E-07	1,13E-08	2,21E-10	1,11E-09
Carbon disulfide	kg	7,31E-08	2,22E-09	4,93E-08	8,89E-09	1,00E-08	2,58E-09	1,85E-11	9,20E-11
Carbon monoxide, biogenic	kg	8,23E-08	5,33E-09	3,31E-08	1,35E-08	1,79E-08	1,05E-08	1,84E-09	9,68E-11
Carbon monoxide, fossil	kg	1,08E-04	1,05E-05	3,08E-05	4,50E-06	6,10E-05	1,07E-06	3,89E-08	3,67E-07
Cerium-141	Bq	1,52E-07	4,89E-09	4,45E-09	3,96E-09	1,11E-07	2,67E-08	6,31E-11	5,16E-10
Cesium-134	Bq	7,29E-09	2,34E-10	2,13E-10	1,90E-10	5,34E-09	1,28E-09	3,02E-12	2,47E-11
Cesium-137	Bq	1,29E-07	4,15E-09	3,78E-09	3,36E-09	9,47E-08	2,27E-08	5,36E-11	4,38E-10
Chloramine	kg	1,89E-14	2,13E-16	7,52E-15	5,77E-15	1,51E-15	3,85E-15	3,06E-18	2,52E-17
Chlorine	kg	2,72E-08	3,49E-09	1,67E-08	4,96E-10	6,17E-09	3,03E-10	3,74E-11	3,71E-11

Chloroacetic acid	kg	6,51E-12	5,11E-14	1,10E-12	3,54E-14	1,71E-13	5,15E-12	7,19E-16	6,61E-15
Chloroform	kg	1,74E-11	3,16E-13	1,48E-11	4,42E-13	1,35E-12	4,02E-13	3,99E-15	2,33E-14
Chlorosilane, trimethyl-	kg	3,59E-12	2,00E-13	1,22E-12	8,05E-14	2,05E-12	3,88E-14	5,64E-16	3,75E-15
Chlorosulfonic acid	kg	3,05E-14	1,99E-16	1,88E-14	1,62E-16	6,27E-16	1,07E-14	2,99E-18	3,42E-17
Chromium	kg	2,16E-08	2,62E-09	3,37E-09	1,22E-09	1,36E-08	6,85E-10	7,54E-12	3,55E-11
Chromium-51	Bq	9,75E-09	3,14E-10	2,85E-10	2,54E-10	7,14E-09	1,71E-09	4,04E-12	3,31E-11
Chromium VI	kg	4,70E-10	3,20E-11	6,97E-11	3,07E-11	3,13E-10	2,41E-11	2,02E-13	8,39E-13
Cobalt	kg	1,78E-09	5,43E-10	1,79E-10	8,78E-11	6,91E-10	2,73E-10	3,78E-13	2,37E-12
Cobalt-58	Bq	1,36E-08	4,37E-10	3,97E-10	3,53E-10	9,95E-09	2,39E-09	5,63E-12	4,60E-11
Cobalt-60	Bq	1,20E-07	3,86E-09	3,51E-09	3,12E-09	8,79E-08	2,11E-08	4,97E-11	4,07E-10
Copper	kg	1,05E-07	8,56E-08	8,24E-09	3,99E-09	6,50E-09	9,11E-10	1,06E-11	1,11E-10
Cumene	kg	7,82E-09	1,09E-09	1,23E-09	3,38E-09	2,08E-09	4,06E-11	2,79E-12	9,12E-12
Cyanide	kg	8,32E-10	5,08E-11	2,64E-10	4,22E-11	1,87E-10	2,43E-11	2,63E-10	1,14E-12
Cyanoacetic acid	kg	2,50E-14	1,63E-16	1,54E-14	1,32E-16	5,13E-16	8,74E-15	2,45E-18	2,80E-17
Diethylamine	kg	2,00E-14	2,12E-15	9,92E-15	2,76E-15	2,13E-15	3,05E-15	2,75E-18	2,80E-17
Dimethyl malonate	kg	3,13E-14	2,05E-16	1,93E-14	1,66E-16	6,44E-16	1,10E-14	3,07E-18	3,51E-17
Dinitrogen monoxide	kg	1,77E-06	1,30E-06	5,72E-08	5,46E-08	2,46E-07	1,01E-07	1,42E-09	2,56E-09
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	2,54E-14	1,04E-15	8,21E-15	1,03E-15	1,43E-14	2,42E-16	5,38E-16	3,14E-17
Dipropylamine	kg	1,13E-14	1,35E-15	5,44E-15	1,75E-15	1,33E-15	1,44E-15	1,61E-18	1,63E-17
Ethane	kg	6,83E-07	2,45E-07	5,35E-08	2,80E-08	2,00E-07	1,55E-07	1,35E-10	9,52E-10
Ethane, 1,1-difluoro-, HFC-152a	kg	3,26E-12	7,20E-13	5,45E-13	2,67E-13	1,46E-12	2,55E-13	2,02E-15	6,85E-15
Ethane, 1,1,1-trichloro-, HCFC-140	kg	2,07E-14	2,23E-15	6,20E-15	3,58E-15	7,35E-15	1,25E-15	8,35E-18	4,08E-17
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	9,50E-08	9,26E-08	1,03E-10	7,17E-11	2,09E-09	7,31E-12	1,55E-11	1,89E-10
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	8,58E-13	2,27E-15	8,15E-13	1,69E-14	1,42E-14	7,89E-15	1,66E-16	1,02E-15
Ethane, 1,2-dichloro-	kg	5,42E-10	7,33E-11	1,47E-10	1,80E-10	1,29E-10	1,25E-11	2,18E-13	6,87E-13
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	5,73E-11	9,62E-12	8,73E-12	3,75E-12	2,96E-11	5,42E-12	3,20E-14	1,39E-13
Ethane, hexafluoro-, HFC-116	kg	1,02E-09	8,03E-12	9,28E-10	1,11E-11	6,40E-11	1,07E-11	1,49E-13	1,21E-12
Ethanol	kg	6,78E-09	8,74E-10	4,59E-10	5,35E-10	1,37E-09	3,53E-09	1,35E-12	4,60E-12
Ethene	kg	1,04E-07	3,32E-08	1,99E-08	4,56E-09	4,50E-08	8,70E-10	1,54E-11	1,71E-10
Ethene, chloro-	kg	1,84E-10	1,88E-11	7,20E-11	4,67E-11	3,90E-11	7,44E-12	7,57E-14	2,43E-13
Ethene, tetrachloro-	kg	5,01E-14	5,41E-15	1,64E-14	8,12E-15	1,71E-14	2,93E-15	2,02E-17	9,70E-17
Ethyl acetate	kg	3,24E-08	8,78E-11	3,08E-08	6,39E-10	5,43E-10	2,99E-10	6,28E-12	3,85E-11
Ethyl cellulose	kg	6,56E-11	1,73E-13	6,24E-11	1,29E-12	1,09E-12	6,03E-13	1,27E-14	7,80E-14
Ethylamine	kg	1,01E-14	1,12E-16	5,41E-15	1,50E-15	7,58E-16	2,31E-15	1,39E-18	1,24E-17
Ethylene diamine	kg	2,26E-13	1,25E-15	1,01E-14	1,99E-13	1,26E-14	2,49E-15	3,86E-17	3,98E-16
Ethylene oxide	kg	1,14E-10	1,39E-11	3,47E-11	3,58E-11	2,84E-11	7,71E-13	4,26E-14	1,34E-13
Ethyne	kg	2,19E-09	1,01E-10	7,51E-10	1,07E-10	1,19E-09	3,11E-11	4,25E-13	2,76E-12
Fluorine	kg	4,28E-09	6,97E-10	8,27E-10	2,97E-10	1,94E-09	5,10E-10	2,22E-12	8,88E-12
Fluosilicic acid	kg	1,13E-09	9,18E-12	1,02E-09	1,16E-11	7,36E-11	1,19E-11	1,61E-13	1,34E-12
Formaldehyde	kg	5,98E-08	2,18E-09	3,50E-09	5,86E-09	3,80E-08	6,94E-09	2,58E-10	3,09E-09
Formamide	kg	7,18E-15	9,30E-17	2,28E-15	2,99E-15	7,33E-16	1,08E-15	1,33E-18	1,01E-17
Formic acid	kg	2,38E-10	4,93E-11	1,46E-10	5,46E-12	3,48E-11	2,41E-12	3,35E-14	3,63E-13
Furan	kg	5,61E-11	1,40E-11	3,04E-11	1,32E-12	9,70E-12	5,78E-13	7,29E-15	8,94E-14
Heat, waste	MJ	8,33E-01	5,48E-01	4,32E-02	2,65E-02	1,64E-01	4,80E-02	1,58E-03	1,86E-03
Helium	kg	4,59E-08	2,77E-08	6,89E-10	9,60E-10	1,59E-08	4,99E-10	1,42E-11	1,77E-10
Heptane	kg	2,42E-07	1,53E-07	2,50E-09	3,46E-09	7,91E-08	2,62E-09	3,42E-11	5,16E-10
Hexane	kg	5,48E-07	3,30E-07	9,26E-09	9,59E-09	1,75E-07	2,24E-08	7,95E-11	1,12E-09
Hydrocarbons, aliphatic, alkanes, cyclic	kg	1,33E-10	1,87E-11	2,93E-11	3,91E-11	3,98E-11	5,83E-12	4,01E-14	1,59E-13
Hydrocarbons, aliphatic, alkanes, unspecified	kg	4,32E-07	3,35E-08	1,62E-07	1,56E-08	1,98E-07	2,30E-08	5,64E-11	5,41E-10
Hydrocarbons, aliphatic, unsaturated	kg	1,25E-08	2,07E-09	2,50E-09	1,07E-09	4,29E-09	2,51E-09	5,48E-12	1,64E-11
Hydrocarbons, aromatic	kg	1,18E-07	5,13E-09	3,89E-08	1,48E-08	5,73E-08	1,62E-09	1,58E-11	1,40E-10
Hydrocarbons, chlorinated	kg	8,59E-10	3,09E-11	3,94E-10	1,48E-11	4,12E-10	6,71E-12	1,16E-13	8,91E-13
Hydrogen	kg	6,89E-08	2,53E-08	1,22E-08	1,14E-08	1,76E-08	1,84E-09	4,70E-10	1,07E-10
Hydrogen-3, Tritium	Bq	6,96E-01	1,37E-01	1,20E-01	5,44E-02	2,92E-01	9,05E-02	3,90E-04	1,36E-03
Hydrogen chloride	kg	6,27E-07	9,94E-08	1,21E-07	4,21E-08	3,09E-07	5,48E-08	2,19E-10	7,95E-10
Hydrogen fluoride	kg	1,20E-07	1,58E-08	4,08E-08	7,30E-09	3,68E-08	1,96E-08	3,79E-11	1,45E-10
Hydrogen peroxide	kg	4,86E-11	1,30E-13	4,62E-11	9,58E-13	8,10E-13	4,47E-13	9,42E-15	5,77E-14
Hydrogen sulfide	kg	1,02E-07	4,98E-09	3,06E-08	4,85E-09	4,60E-08	1,50E-08	1,99E-11	1,15E-10
Iodine	kg	2,49E-09	4,98E-10	4,54E-10	2,18E-10	7,47E-10	5,72E-10	1,24E-12	3,24E-12
Iodine-129	Bq	1,25E-04	2,40E-05	2,08E-05	9,58E-06	5,38E-05	1,66E-05	6,96E-08	2,50E-07
Iodine-131	Bq	4,28E-03	1,21E-03	9,12E-04	4,22E-04	1,62E-03	1,03E-04	2,99E-06	7,69E-06
Iodine-133	Bq	9,52E-07	5,17E-08	8,25E-08	3,17E-08	6,35E-07	1,48E-07	4,10E-10	2,99E-09
Iodine-135	Bq	4,38E-07	5,98E-08	1,31E-07	2,65E-08	1,85E-07	3,43E-08	2,14E-10	9,62E-10
Iron	kg	1,01E-07	1,55E-08	1,80E-08	6,33E-09	5,11E-08	9,55E-09	4,80E-11	1,88E-10
Isocyanic acid	kg	6,47E-11	1,25E-11	1,40E-11	5,63E-12	2,68E-11	5,61E-12	4,42E-14	1,27E-13
Isoprene	kg	2,60E-12	6,48E-13	1,41E-12	6,13E-14	4,50E-13	2,68E-14	3,38E-16	4,15E-15
Isopropylamine	kg	3,65E-15	3,17E-17	2,32E-15	2,56E-17	1,59E-16	1,11E-15	3,88E-19	4,11E-18
Krypton-85	Bq	3,51E-02	9,59E-03	7,22E-03	3,36E-03	1,37E-02	1,06E-03	2,41E-05	6,53E-05
Krypton-85m	Bq	9,57E-03	4,44E-04	3,80E-04	2,88E-04	6,82E-03	1,60E-03	4,12E-06	3,16E-05
Krypton-87	Bq	2,41E-03	1,81E-04	1,46E-04	9,28E-05	1,62E-03	3,62E-04	1,12E-06	7,53E-06
Krypton-88	Bq	2,97E-03	1,77E-04	1,46E-04	1,01E-04	2,06E-03	4,74E-04	1,32E-06	9,57E-06
Krypton-89	Bq	1,16E-03	4,40E-05	3,88E-05	3,21E-05	8,38E-04	1,99E-04	4,87E-07	3,88E-06

Lactic acid	kg	8,87E-15	1,06E-15	4,26E-15	1,37E-15	1,04E-15	1,13E-15	1,26E-18	1,27E-17
Lanthanum-140	Bq	5,36E-08	1,73E-09	1,57E-09	1,40E-09	3,93E-08	9,43E-09	2,22E-11	1,82E-10
Lead	kg	2,90E-08	5,91E-09	1,05E-08	2,55E-09	9,16E-09	7,60E-10	5,79E-12	3,51E-11
Lead-210	Bq	7,60E-04	1,31E-04	1,37E-04	6,22E-05	2,54E-04	1,75E-04	3,55E-07	1,05E-06
m-Xylene	kg	1,19E-10	2,55E-11	2,10E-11	1,39E-11	4,17E-11	1,63E-11	7,02E-14	1,94E-13
Magnesium	kg	1,71E-08	1,63E-09	4,44E-09	1,06E-09	8,89E-09	1,06E-09	6,16E-12	2,75E-11
Manganese	kg	5,62E-09	4,69E-10	1,82E-09	3,05E-10	2,63E-09	3,87E-10	1,62E-12	8,09E-12
Manganese-54	Bq	4,99E-09	1,61E-10	1,46E-10	1,30E-10	3,66E-09	8,78E-10	2,07E-12	1,69E-11
Mercury	kg	3,28E-09	2,39E-10	1,03E-09	1,20E-10	1,84E-09	4,13E-11	1,50E-12	4,17E-12
Methane, biogenic	kg	3,64E-07	4,66E-08	4,72E-08	3,81E-08	9,81E-08	1,34E-07	1,80E-10	4,06E-10
Methane, bromo-, Halon 1001	kg	5,65E-19	9,58E-21	2,03E-19	2,71E-19	7,82E-20	3,07E-21	8,15E-23	7,21E-22
Methane, bromochlorodifluoro-, Halon 1211	kg	7,09E-11	6,68E-12	1,19E-11	4,74E-12	1,96E-11	2,79E-11	2,36E-14	6,91E-14
Methane, bromotrifluoro-, Halon 1301	kg	6,46E-10	3,97E-10	9,95E-12	2,23E-11	2,09E-10	6,82E-12	1,11E-13	1,57E-12
Methane, chlorodifluoro-, HCFC-22	kg	2,98E-10	2,67E-11	7,23E-11	1,94E-11	7,79E-11	1,01E-10	1,02E-13	3,06E-13
Methane, dichloro-, HCC-30	kg	9,81E-13	6,03E-14	5,68E-13	1,14E-13	1,88E-13	4,92E-14	2,98E-16	1,49E-15
Methane, dichlorodifluoro-, CFC-12	kg	2,44E-12	6,89E-14	2,12E-12	6,04E-14	1,27E-13	6,65E-14	5,53E-16	2,96E-15
Methane, dichlorofluoro-, HCFC-21	kg	5,64E-15	2,47E-17	5,32E-15	1,14E-16	1,14E-16	5,49E-17	1,11E-18	6,74E-18
Methane, fossil	kg	5,73E-05	1,98E-05	8,20E-06	3,76E-06	2,11E-05	4,33E-06	1,66E-08	1,42E-07
Methane, monochloro-, R-40	kg	6,02E-13	6,20E-14	1,87E-13	9,62E-14	2,21E-13	3,39E-14	2,31E-16	1,14E-15
Methane, tetrachloro-, CFC-10	kg	3,99E-11	5,88E-12	2,17E-11	2,32E-12	8,67E-12	9,99E-13	3,40E-13	5,34E-14
Methane, tetrafluoro-, CFC-14	kg	8,68E-09	7,08E-11	7,85E-09	8,97E-11	5,67E-10	9,17E-11	1,24E-12	1,03E-11
Methane, trichlorofluoro-, CFC-11	kg	9,15E-15	4,01E-17	8,64E-15	1,85E-16	1,86E-16	8,92E-17	1,80E-18	1,09E-17
Methane, trifluoro-, HFC-23	kg	1,79E-12	7,87E-15	1,69E-12	3,62E-14	3,64E-14	1,75E-14	3,53E-16	2,14E-15
Methanesulfonic acid	kg	2,52E-14	1,65E-16	1,55E-14	1,34E-16	5,19E-16	8,84E-15	2,47E-18	2,83E-17
Methanol	kg	2,57E-08	3,91E-09	3,53E-09	7,12E-09	7,11E-09	4,02E-09	1,10E-11	2,73E-11
Methyl acetate	kg	1,02E-15	6,90E-18	6,32E-16	5,15E-18	2,11E-17	3,58E-16	1,01E-19	1,15E-18
Methyl acrylate	kg	2,05E-11	5,42E-14	1,95E-11	4,04E-13	3,41E-13	1,89E-13	3,97E-15	2,44E-14
Methyl borate	kg	1,64E-15	2,01E-17	5,82E-16	6,07E-16	1,52E-16	2,81E-16	2,90E-19	2,27E-18
Methyl ethyl ketone	kg	3,24E-08	8,78E-11	3,08E-08	6,39E-10	5,43E-10	2,99E-10	6,28E-12	3,85E-11
Methyl formate	kg	8,14E-14	2,34E-16	7,62E-14	2,36E-15	1,51E-15	1,02E-15	1,58E-17	9,72E-17
Methyl lactate	kg	9,74E-15	1,16E-15	4,67E-15	1,50E-15	1,15E-15	1,24E-15	1,39E-18	1,40E-17
Methylamine	kg	5,03E-14	8,97E-16	4,38E-14	8,83E-16	1,34E-15	3,34E-15	8,76E-18	6,04E-17
Molybdenum	kg	5,90E-10	2,66E-10	3,97E-11	2,85E-11	1,80E-10	7,49E-11	1,48E-13	9,55E-13
Monoethanolamine	kg	9,17E-10	9,82E-12	7,64E-10	5,54E-11	7,72E-11	9,75E-12	1,76E-13	1,11E-12
Nickel	kg	2,45E-08	8,90E-09	5,36E-09	1,09E-09	6,59E-09	2,49E-09	4,72E-12	3,53E-11
Niobium-95	Bq	5,93E-10	1,91E-11	1,73E-11	1,54E-11	4,34E-10	1,04E-10	2,46E-13	2,01E-12
Nitrate	kg	7,57E-10	1,29E-10	1,26E-10	5,37E-11	3,50E-10	9,68E-11	4,01E-13	1,60E-12
Nitrobenzene	kg	6,00E-14	6,40E-15	2,97E-14	8,27E-15	6,42E-15	9,11E-15	8,26E-18	8,41E-17
Nitrogen oxides	kg	2,23E-04	1,32E-04	6,49E-06	3,03E-06	7,43E-05	5,95E-06	1,03E-07	1,22E-06
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	7,95E-05	1,24E-05	2,22E-06	1,72E-06	6,16E-05	1,33E-06	1,57E-08	1,87E-07
Noble gases, radioactive, unspecified	Bq	1,20E+03	2,31E+02	2,00E+02	9,21E+01	5,17E+02	1,60E+02	6,69E-01	2,40E+00
Ozone	kg	6,60E-08	8,20E-09	8,50E-09	4,79E-09	2,01E-08	2,43E-08	2,34E-11	8,14E-11
PAH, polycyclic aromatic hydrocarbons	kg	9,61E-09	4,73E-10	3,45E-09	2,61E-10	5,13E-09	2,56E-10	1,17E-12	4,25E-11
Particulates, < 2.5 um	kg	1,41E-05	4,29E-06	1,44E-06	4,30E-07	7,44E-06	3,81E-07	4,01E-09	7,33E-08
Particulates, > 10 um	kg	2,30E-05	3,98E-06	5,89E-06	7,96E-07	1,11E-05	1,19E-06	4,13E-09	3,11E-08
Particulates, > 2.5 um, and < 10um	kg	1,33E-05	3,30E-06	3,54E-06	3,72E-07	5,87E-06	1,56E-07	1,94E-09	1,94E-08
Pentane	kg	1,40E-06	8,36E-07	2,52E-08	2,45E-08	4,77E-07	3,88E-08	2,09E-10	2,88E-09
Phenol	kg	1,71E-09	6,38E-11	4,66E-10	5,14E-10	6,55E-10	1,35E-11	2,93E-13	1,75E-12
Phenol, 2,4-dichloro-	kg	7,22E-15	7,36E-16	4,25E-15	8,90E-17	5,81E-16	1,56E-15	8,00E-19	9,44E-18
Phenol, pentachloro-	kg	3,66E-11	6,56E-12	4,93E-12	3,17E-12	1,03E-11	1,16E-11	3,46E-14	4,12E-14
Phosphine	kg	1,56E-14	4,13E-17	1,49E-14	3,08E-16	2,59E-16	1,44E-16	3,03E-18	1,86E-17
Phosphorus	kg	6,31E-10	9,80E-11	1,41E-10	5,48E-11	2,73E-10	6,16E-11	1,90E-12	1,13E-12
Platinum	kg	3,15E-15	3,45E-16	2,62E-16	2,25E-16	9,98E-16	1,32E-15	1,03E-18	3,86E-18
Plutonium-238	Bq	1,71E-11	3,27E-12	2,84E-12	1,31E-12	7,34E-12	2,27E-12	9,49E-15	3,40E-14
Plutonium-alpha	Bq	3,91E-11	7,50E-12	6,50E-12	3,00E-12	1,68E-11	5,20E-12	2,18E-14	7,80E-14
Polonium-210	Bq	1,34E-03	2,30E-04	2,42E-04	1,10E-04	4,42E-04	3,13E-04	6,23E-07	1,82E-06
Polychlorinated biphenyls	kg	4,19E-11	1,42E-12	1,46E-11	1,42E-12	2,42E-11	1,39E-13	4,68E-15	5,01E-14
Potassium	kg	3,73E-08	7,00E-09	6,91E-09	3,65E-09	1,51E-08	4,62E-09	2,04E-11	6,54E-11
Potassium-40	Bq	2,09E-04	2,93E-05	3,25E-05	1,70E-05	5,74E-05	7,24E-05	7,76E-08	2,10E-07
Propanal	kg	5,76E-12	7,10E-13	1,95E-13	8,01E-14	4,70E-12	7,02E-14	9,66E-16	5,62E-15
Propane	kg	1,18E-06	6,88E-07	2,85E-08	2,27E-08	3,80E-07	5,62E-08	1,79E-10	2,35E-09
Propene	kg	6,19E-08	3,14E-08	8,35E-09	2,35E-09	1,89E-08	7,02E-10	9,40E-12	1,20E-10
Propionic acid	kg	7,69E-10	5,32E-11	1,33E-10	5,38E-11	2,02E-10	3,26E-10	2,75E-13	7,30E-13
Propylamine	kg	2,28E-15	2,95E-17	7,21E-16	9,47E-16	2,32E-16	3,42E-16	4,22E-19	3,21E-18
Propylene oxide	kg	7,62E-09	3,33E-11	7,45E-09	8,10E-12	1,15E-10	2,39E-12	7,57E-13	9,03E-12
Protactinium-234	Bq	1,85E-05	3,26E-06	2,88E-06	1,33E-06	8,62E-06	2,38E-06	1,01E-08	4,01E-08
Radioactive species, other beta emitters	Bq	5,36E-02	1,08E-04	9,75E-05	5,20E-02	1,23E-03	4,10E-05	8,20E-06	9,85E-05
Radium-226	Bq	7,90E-04	1,40E-04	1,27E-04	5,82E-05	3,42E-04	1,21E-04	4,16E-07	1,56E-06
Radium-228	Bq	1,41E-04	1,49E-05	3,01E-05	1,15E-05	6,05E-05	2,33E-05	5,83E-08	1,75E-07

Radon-220	Bq	7,17E-03	1,30E-03	1,29E-03	6,06E-04	2,01E-03	1,94E-03	3,25E-06	8,61E-06
Radon-222	Bq	2,44E+03	4,31E+02	3,77E+02	1,73E+02	1,14E+03	3,15E+02	1,33E+00	5,29E+00
Ruthenium-103	Bq	1,30E-10	4,19E-12	3,81E-12	3,39E-12	9,54E-11	2,29E-11	5,40E-14	4,42E-13
Scandium	kg	2,29E-10	3,96E-11	3,64E-11	1,61E-11	1,07E-10	2,89E-11	1,23E-13	4,91E-13
Selenium	kg	1,21E-09	4,05E-10	3,28E-10	6,05E-11	2,80E-10	1,30E-10	3,48E-13	1,86E-12
Silicon	kg	6,60E-08	4,64E-09	2,05E-08	3,85E-09	3,13E-08	2,74E-09	2,90E-09	9,62E-11
Silicon tetrafluoride	kg	1,93E-12	9,56E-13	2,18E-13	7,06E-14	6,44E-13	3,91E-14	9,97E-16	3,09E-15
Silver	kg	9,86E-12	1,76E-12	1,53E-12	7,08E-13	4,59E-12	1,24E-12	5,43E-15	2,13E-14
Silver-110	Bq	1,29E-09	4,15E-11	3,78E-11	3,36E-11	9,46E-10	2,27E-10	5,35E-13	4,38E-12
Sodium	kg	2,69E-08	1,19E-08	1,92E-09	1,26E-09	8,27E-09	2,84E-09	6,22E-10	4,46E-11
Sodium chlorate	kg	2,06E-11	1,06E-11	1,12E-12	1,98E-12	6,21E-12	6,22E-13	1,16E-14	3,55E-14
Sodium dichromate	kg	2,76E-11	3,69E-12	6,31E-12	4,44E-12	6,38E-12	6,67E-12	3,11E-14	4,07E-14
Sodium formate	kg	1,09E-12	4,47E-14	2,59E-13	3,06E-13	4,43E-13	3,41E-14	2,71E-15	1,18E-15
Sodium hydroxide	kg	1,81E-10	4,81E-13	1,72E-10	3,57E-12	3,01E-12	1,67E-12	3,51E-14	2,15E-13
Strontium	kg	1,32E-09	1,76E-10	2,79E-10	9,67E-11	5,26E-10	2,39E-10	9,24E-13	1,80E-12
Styrene	kg	1,42E-10	1,23E-11	9,10E-12	7,56E-12	1,12E-10	9,46E-13	2,02E-14	1,39E-13
Sulfate	kg	2,29E-07	3,88E-08	5,65E-08	3,51E-08	7,90E-08	1,91E-08	9,67E-11	3,80E-10
Sulfur dioxide	kg	9,99E-05	4,66E-05	8,34E-06	4,60E-06	3,08E-05	9,43E-06	1,63E-08	1,51E-07
Sulfur hexafluoride	kg	9,69E-10	1,24E-10	9,38E-11	7,71E-11	2,57E-10	4,15E-10	3,21E-13	9,60E-13
Sulfur trioxide	kg	5,03E-13	5,15E-14	2,51E-13	6,66E-14	5,20E-14	8,03E-14	6,83E-17	6,98E-16
Sulfuric acid	kg	3,79E-11	1,02E-13	3,61E-11	7,48E-13	6,34E-13	3,49E-13	7,35E-15	4,51E-14
t-Butyl methyl ether	kg	6,22E-11	4,92E-13	1,44E-12	8,43E-13	9,89E-12	4,94E-11	7,96E-15	7,62E-14
t-Butylamine	kg	1,97E-14	1,38E-16	1,22E-14	1,12E-16	5,03E-16	6,70E-15	1,96E-18	2,21E-17
Terpenes	kg	2,46E-11	6,13E-12	1,34E-11	5,80E-13	4,25E-12	2,54E-13	3,20E-15	3,92E-14
Thallium	kg	2,79E-11	6,77E-13	1,48E-12	3,07E-13	2,52E-11	1,80E-13	3,79E-14	2,31E-14
Thorium	kg	6,14E-12	2,51E-13	2,04E-12	3,08E-13	3,43E-12	1,08E-13	1,35E-15	7,77E-15
Thorium-228	Bq	4,10E-05	6,16E-06	7,33E-06	3,41E-06	1,29E-05	1,11E-05	1,72E-08	4,70E-08
Thorium-230	Bq	7,19E-05	1,38E-05	1,11E-05	5,00E-06	3,30E-05	8,93E-06	3,91E-08	1,54E-07
Thorium-232	Bq	5,83E-05	9,37E-06	9,95E-06	4,85E-06	1,69E-05	1,72E-05	2,45E-08	6,56E-08
Thorium-234	Bq	1,85E-05	3,26E-06	2,88E-06	1,33E-06	8,62E-06	2,38E-06	1,01E-08	4,01E-08
Tin	kg	7,77E-10	2,65E-11	4,02E-10	3,37E-11	2,91E-10	2,09E-11	1,74E-12	9,85E-13
Titanium	kg	6,35E-09	7,65E-10	9,87E-10	3,49E-10	2,52E-09	5,51E-10	1,16E-09	1,16E-11
Toluene	kg	1,70E-07	9,70E-08	4,91E-09	3,06E-09	6,01E-08	3,59E-09	1,36E-10	9,62E-10
Toluene, 2-chloro-	kg	2,28E-14	1,92E-15	1,19E-14	2,48E-15	2,00E-15	4,47E-15	2,94E-18	3,05E-17
Trimethylamine	kg	1,81E-15	1,23E-17	1,12E-15	9,17E-18	3,75E-17	6,33E-16	1,78E-19	2,03E-18
Tungsten	kg	2,53E-11	4,46E-12	3,90E-12	1,80E-12	1,18E-11	3,26E-12	1,38E-14	5,48E-14
Uranium	kg	4,96E-12	2,26E-13	1,51E-12	3,06E-13	2,79E-12	1,32E-13	1,44E-15	6,45E-15
Uranium-234	Bq	2,18E-04	3,96E-05	3,37E-05	1,54E-05	1,01E-04	2,78E-05	1,19E-07	4,72E-07
Uranium-235	Bq	1,04E-05	1,84E-06	1,61E-06	7,41E-07	4,86E-06	1,34E-06	5,70E-09	2,26E-08
Uranium-238	Bq	3,53E-04	6,27E-05	5,87E-05	2,68E-05	1,43E-04	6,17E-05	1,80E-07	6,36E-07
Uranium alpha	Bq	1,00E-03	1,77E-04	1,55E-04	7,14E-05	4,68E-04	1,30E-04	5,49E-07	2,18E-06
Vanadium	kg	3,19E-08	1,26E-08	1,87E-09	2,11E-09	8,11E-09	7,21E-09	8,32E-12	4,27E-11
Water	kg	1,33E-06	6,15E-08	5,11E-07	9,05E-08	5,27E-07	1,37E-07	2,70E-10	1,49E-09
Xenon-131m	Bq	1,22E-02	8,30E-04	6,78E-04	4,45E-04	8,36E-03	1,89E-03	5,58E-06	3,88E-05
Xenon-133	Bq	4,35E-01	2,63E-02	2,18E-02	1,49E-02	3,01E-01	6,90E-02	1,94E-04	1,40E-03
Xenon-133m	Bq	7,25E-04	1,15E-04	8,85E-05	4,54E-05	4,01E-04	7,19E-05	4,05E-07	1,88E-06
Xenon-135	Bq	1,75E-01	1,08E-02	8,90E-03	6,05E-03	1,21E-01	2,76E-02	7,84E-05	5,61E-04
Xenon-135m	Bq	1,09E-01	6,35E-03	5,27E-03	3,66E-03	7,57E-02	1,74E-02	4,84E-05	3,51E-04
Xenon-137	Bq	3,17E-03	1,21E-04	1,06E-04	8,78E-05	2,29E-03	5,45E-04	1,33E-06	1,06E-05
Xenon-138	Bq	2,42E-02	1,07E-03	9,23E-04	7,15E-04	1,73E-02	4,08E-03	1,04E-05	8,02E-05
Xylene	kg	1,34E-07	6,77E-08	7,72E-09	3,98E-09	4,44E-08	9,28E-09	5,26E-11	5,48E-10
Zinc	kg	9,27E-08	3,78E-08	2,07E-08	5,69E-09	2,73E-08	9,35E-10	4,99E-11	1,34E-10
Zinc-65	Bq	2,49E-08	8,02E-10	7,29E-10	6,49E-10	1,83E-08	4,38E-09	1,03E-11	8,46E-11
Zirconium	kg	4,81E-11	1,62E-12	1,80E-11	1,58E-12	2,66E-11	1,65E-13	5,40E-15	5,83E-14
Zirconium-95	Bq	2,44E-08	7,84E-10	7,13E-10	6,34E-10	1,79E-08	4,28E-09	1,01E-11	8,27E-11

Annex B – Case study 2 data inventory

			Life Cycle Processes						
SUBSTANCE	UNIT	TOTAL	Transport process	Manufacturing,Lorry	Maintenance, lorry	Construction, Road	Maintenance, road	Disposal, lorry	Disposal, road
1-Butanol	kg	4,74E-15	1,23E-16	3,31E-15	5,60E-17	2,11E-16	1,03E-15	6,09E-19	5,85E-18
1-Pentanol	kg	3,94E-15	6,38E-17	1,25E-15	1,63E-15	4,01E-16	5,90E-16	7,29E-19	5,55E-18
1-Pentene	kg	2,98E-15	4,82E-17	9,41E-16	1,24E-15	3,03E-16	4,46E-16	5,51E-19	4,19E-18
1-Propanol	kg	2,57E-13	8,34E-15	1,10E-13	2,15E-14	5,67E-14	5,97E-14	8,87E-17	4,27E-16
1,4-Butanediol	kg	3,86E-13	1,08E-15	3,63E-13	7,63E-15	7,38E-15	6,48E-15	7,39E-17	4,62E-16
2-Aminopropanol	kg	2,45E-15	5,28E-18	1,51E-15	2,34E-17	5,29E-17	8,56E-16	2,44E-19	2,77E-18
2-Butene, 2-methyl-	kg	6,61E-19	1,07E-20	2,09E-19	2,74E-19	6,72E-20	9,90E-20	1,22E-22	9,30E-22
2-Methyl-1-propanol	kg	9,85E-15	2,16E-16	4,04E-15	2,84E-15	8,55E-16	1,89E-15	1,58E-18	1,34E-17
2-Nitrobenzoic acid	kg	4,40E-15	8,96E-18	2,73E-15	2,23E-17	9,12E-17	1,54E-15	4,34E-19	4,96E-18
2-Propanol	kg	6,98E-09	4,74E-12	6,64E-09	1,39E-10	1,16E-10	6,42E-11	1,35E-12	8,30E-12
Acenaphthene	kg	3,43E-14	8,40E-15	2,10E-15	2,18E-15	5,62E-15	1,60E-14	5,84E-18	1,60E-17
Acetaldehyde	kg	2,40E-08	9,68E-10	4,14E-10	4,25E-10	1,84E-08	1,91E-09	1,37E-10	1,67E-09
Acetic acid	kg	4,45E-08	5,69E-09	5,53E-09	1,16E-08	1,20E-08	9,69E-09	1,44E-11	4,55E-11
Acetone	kg	1,29E-08	1,00E-09	8,41E-09	4,75E-10	9,96E-10	1,95E-09	2,53E-12	1,31E-11
Acetonitrile	kg	2,67E-11	4,52E-12	1,60E-11	7,03E-13	5,11E-12	3,05E-13	3,84E-15	4,71E-14
Acrolein	kg	1,05E-11	3,48E-13	4,30E-13	2,36E-13	9,21E-12	2,69E-13	2,13E-15	1,15E-14
Acrylic acid	kg	1,80E-11	1,23E-14	1,72E-11	3,61E-13	3,00E-13	1,66E-13	3,50E-15	2,15E-14
Actinides, radioactive, unspecified	Bq	2,01E-06	9,98E-08	6,41E-07	3,72E-07	7,61E-07	1,30E-07	8,64E-10	4,22E-09
Aerosols, radioactive, unspecified	Bq	2,48E-05	2,38E-06	5,17E-06	2,31E-06	1,11E-05	3,74E-06	1,59E-08	5,15E-08
Aldehydes, unspecified	kg	2,65E-10	8,85E-12	5,61E-11	9,90E-11	9,11E-11	9,61E-12	1,27E-13	4,24E-13
Aluminium	kg	9,66E-07	7,02E-08	3,43E-07	6,49E-08	3,88E-07	9,80E-08	2,29E-10	1,13E-09
Ammonia	kg	1,03E-06	2,48E-07	1,76E-07	4,76E-08	5,01E-07	5,84E-08	1,05E-09	1,56E-09
Ammonium carbonate	kg	5,85E-12	7,20E-13	1,23E-12	1,15E-12	1,51E-12	1,23E-12	1,79E-15	8,37E-15
Aniline	kg	4,03E-14	3,02E-15	2,05E-14	6,19E-15	4,75E-15	5,80E-15	5,90E-18	5,97E-17
Anthranilic acid	kg	3,21E-15	6,56E-18	1,99E-15	1,63E-17	6,65E-17	1,13E-15	3,17E-19	3,61E-18
Antimony	kg	4,62E-10	1,10E-11	3,44E-10	3,10E-11	5,64E-11	1,90E-11	1,31E-13	5,90E-13
Antimony-124	Bq	9,81E-10	8,59E-11	2,70E-11	2,41E-11	6,77E-10	1,63E-10	3,83E-13	3,14E-12
Antimony-125	Bq	1,02E-08	8,96E-10	2,82E-10	2,52E-10	7,07E-09	1,70E-09	4,00E-12	3,27E-11
Argon-41	Bq	8,59E-03	5,69E-04	2,31E-03	1,08E-03	4,29E-03	3,14E-04	7,66E-06	2,04E-05
Arsenic	kg	3,59E-09	1,43E-10	2,15E-09	2,15E-10	8,48E-10	2,28E-10	1,12E-12	5,25E-12
Arsine	kg	2,10E-16	1,43E-19	2,00E-16	4,20E-18	3,50E-18	1,94E-18	4,08E-20	2,50E-19
Barium	kg	1,40E-09	1,67E-10	2,82E-10	1,04E-10	5,53E-10	2,81E-10	8,88E-12	2,01E-12
Barium-140	Bq	6,66E-07	5,83E-08	1,84E-08	1,64E-08	4,60E-07	1,10E-07	2,60E-10	2,13E-09
Benzal chloride	kg	2,46E-18	2,97E-20	8,86E-19	1,19E-18	3,42E-19	1,34E-20	3,56E-22	3,15E-21
Benzaldehyde	kg	5,03E-12	1,22E-13	1,35E-13	6,58E-14	4,66E-12	3,94E-14	9,18E-16	5,38E-15
Benzene	kg	9,25E-08	5,61E-09	1,41E-08	8,32E-09	5,50E-08	9,04E-09	7,36E-11	4,16E-10
Benzene, 1-methyl-2-nitro-	kg	3,80E-15	7,73E-18	2,36E-15	1,92E-17	7,88E-17	1,33E-15	3,75E-19	4,28E-18
Benzene, 1,2-dichloro-	kg	8,30E-14	2,58E-16	4,94E-14	3,12E-15	2,25E-15	2,79E-14	8,74E-18	9,53E-17
Benzene, ethyl-	kg	9,13E-09	2,01E-10	2,61E-10	3,75E-10	7,95E-09	2,87E-10	3,45E-12	5,17E-11
Benzene, hexachloro-	kg	2,40E-11	9,01E-13	7,98E-12	8,28E-13	1,41E-11	7,99E-14	6,99E-14	2,84E-14
Benzene, pentachloro-	kg	2,75E-13	1,10E-14	1,84E-14	1,08E-14	6,13E-14	3,98E-15	1,69E-13	3,29E-16
Benzo(a)pyrene	kg	2,76E-10	1,85E-11	1,19E-10	1,07E-11	9,94E-11	2,77E-11	6,13E-14	6,01E-13
Beryllium	kg	2,01E-11	1,09E-12	4,69E-12	9,31E-13	1,17E-11	1,53E-12	3,22E-14	3,00E-14
Boron	kg	3,32E-08	3,68E-09	7,75E-09	3,47E-09	1,24E-08	5,84E-09	2,13E-11	5,58E-11
Boron trifluoride	kg	2,88E-18	1,96E-21	2,74E-18	5,75E-20	4,79E-20	2,65E-20	5,58E-22	3,43E-21
Bromine	kg	4,59E-09	6,59E-10	8,72E-10	4,21E-10	1,46E-09	1,15E-09	1,17E-11	6,19E-12
Butadiene	kg	2,09E-13	2,51E-16	1,96E-13	5,24E-15	5,09E-15	2,44E-15	4,08E-17	2,55E-16
Butane	kg	5,90E-07	1,52E-07	1,89E-08	2,10E-08	3,61E-07	3,48E-08	1,65E-10	2,30E-09
Butene	kg	9,05E-09	1,96E-10	2,61E-10	3,61E-10	7,92E-09	2,62E-10	3,42E-12	5,16E-11
Butyrolactone	kg	1,08E-13	7,85E-17	1,03E-13	2,16E-15	1,83E-15	9,98E-16	2,10E-17	1,28E-16
Cadmium	kg	1,45E-09	1,63E-10	7,27E-10	9,36E-11	3,93E-10	6,87E-11	6,03E-13	2,88E-12
Calcium	kg	3,01E-08	2,66E-09	5,38E-09	2,52E-09	1,42E-08	3,71E-09	1,59E-09	6,49E-11
Carbon-14	Bq	1,28E-01	1,19E-02	2,06E-02	9,78E-03	6,58E-02	1,93E-02	7,49E-05	3,05E-04
Carbon dioxide, biogenic	kg	2,07E-04	2,75E-05	3,11E-05	2,21E-05	9,04E-05	3,56E-05	1,13E-07	2,81E-07
Carbon dioxide, fossil	kg	5,55E-02	3,68E-02	2,75E-03	1,63E-03	1,13E-02	2,80E-03	1,38E-04	1,25E-04
Carbon dioxide, land transformation	kg	5,90E-07	7,93E-08	3,06E-07	3,35E-08	1,59E-07	1,13E-08	2,21E-10	1,11E-09
Carbon disulfide	kg	7,26E-08	1,62E-09	4,93E-08	8,92E-09	1,00E-08	2,58E-09	1,85E-11	9,20E-11
Carbon monoxide, biogenic	kg	8,37E-08	6,78E-09	3,31E-08	1,35E-08	1,79E-08	1,05E-08	1,84E-09	9,68E-11
Carbon monoxide, fossil	kg	1,09E-04	1,10E-05	3,08E-05	4,51E-06	6,10E-05	1,07E-06	3,89E-08	3,67E-07
Cerium-141	Bq	1,61E-07	1,41E-08	4,45E-09	3,97E-09	1,11E-07	2,67E-08	6,31E-11	5,16E-10
Cesium-134	Bq	7,73E-09	6,77E-10	2,13E-10	1,90E-10	5,34E-09	1,28E-09	3,02E-12	2,47E-11
Cesium-137	Bq	1,37E-07	1,20E-08	3,78E-09	3,37E-09	9,47E-08	2,27E-08	5,36E-11	4,38E-10
Chloramine	kg	1,89E-14	2,34E-16	7,52E-15	5,77E-15	1,51E-15	3,85E-15	3,06E-18	2,52E-17
Chlorine	kg	2,51E-08	1,44E-09	1,67E-08	5,01E-10	6,17E-09	3,03E-10	3,74E-11	3,71E-11
Chloroacetic acid	kg	6,47E-12	1,64E-14	1,10E-12	3,55E-14	1,71E-13	5,15E-12	7,19E-16	6,61E-15

Chloroform	kg	1,72E-11	1,66E-13	1,48E-11	4,46E-13	1,35E-12	4,02E-13	3,99E-15	2,33E-14
Chlorosilane, trimethyl-	kg	3,56E-12	1,73E-13	1,22E-12	8,13E-14	2,05E-12	3,88E-14	5,64E-16	3,75E-15
Chlorosulfonic acid	kg	3,03E-14	5,82E-17	1,88E-14	1,62E-16	6,27E-16	1,07E-14	2,99E-18	3,42E-17
Chromium	kg	2,07E-08	1,78E-09	3,37E-09	1,23E-09	1,36E-08	6,85E-10	7,54E-12	3,55E-11
Chromium-51	Bq	1,03E-08	9,05E-10	2,85E-10	2,54E-10	7,14E-09	1,71E-09	4,04E-12	3,31E-11
Chromium VI	kg	4,51E-10	1,29E-11	6,97E-11	3,10E-11	3,13E-10	2,41E-11	2,02E-13	8,39E-13
Cobalt	kg	1,39E-09	1,59E-10	1,79E-10	8,85E-11	6,91E-10	2,73E-10	3,78E-13	2,37E-12
Cobalt-58	Bq	1,44E-08	1,26E-09	3,97E-10	3,54E-10	9,95E-09	2,39E-09	5,63E-12	4,60E-11
Cobalt-60	Bq	1,27E-07	1,11E-08	3,51E-09	3,13E-09	8,79E-08	2,11E-08	4,97E-11	4,07E-10
Copper	kg	9,94E-08	7,96E-08	8,24E-09	3,99E-09	6,50E-09	9,11E-10	1,06E-11	1,11E-10
Cumene	kg	6,86E-09	1,33E-10	1,23E-09	3,38E-09	2,08E-09	4,06E-11	2,79E-12	9,12E-12
Cyanide	kg	8,14E-10	3,30E-11	2,64E-10	4,24E-11	1,87E-10	2,43E-11	2,63E-10	1,14E-12
Cyanoacetic acid	kg	2,49E-14	4,76E-17	1,54E-14	1,33E-16	5,13E-16	8,74E-15	2,45E-18	2,80E-17
Diethylamine	kg	1,92E-14	1,34E-15	9,92E-15	2,76E-15	2,13E-15	3,05E-15	2,75E-18	2,80E-17
Dimethyl malonate	kg	3,12E-14	5,97E-17	1,93E-14	1,66E-16	6,44E-16	1,10E-14	3,07E-18	3,51E-17
Dinitrogen monoxide	kg	1,70E-06	1,24E-06	5,72E-08	5,47E-08	2,46E-07	1,01E-07	1,42E-09	2,56E-09
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	2,53E-14	9,48E-16	8,21E-15	1,03E-15	1,43E-14	2,42E-16	5,38E-16	3,14E-17
Dipropylamine	kg	1,08E-14	8,54E-16	5,44E-15	1,75E-15	1,33E-15	1,44E-15	1,61E-18	1,63E-17
Ethane	kg	3,91E-06	3,47E-06	5,35E-08	2,83E-08	2,00E-07	1,55E-07	1,35E-10	9,52E-10
Ethane, 1,1-difluoro-, HFC-152a	kg	2,76E-12	2,18E-13	5,45E-13	2,69E-13	1,46E-12	2,55E-13	2,02E-15	6,85E-15
Ethane, 1,1,1-trichloro-, HCFC-140	kg	1,94E-14	9,64E-16	6,20E-15	3,59E-15	7,35E-15	1,25E-15	8,35E-18	4,08E-17
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	8,95E-08	8,70E-08	1,03E-10	7,18E-11	2,09E-09	7,31E-12	1,55E-11	1,89E-10
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	8,56E-13	5,83E-16	8,15E-13	1,71E-14	1,42E-14	7,89E-15	1,66E-16	1,02E-15
Ethane, 1,2-dichloro-	kg	4,81E-10	1,18E-11	1,47E-10	1,80E-10	1,29E-10	1,25E-11	2,18E-13	6,87E-13
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	5,17E-11	4,05E-12	8,73E-12	3,78E-12	2,96E-11	5,42E-12	3,20E-14	1,39E-13
Ethane, hexafluoro-, HFC-116	kg	1,02E-09	8,04E-12	9,28E-10	1,12E-11	6,40E-11	1,07E-11	1,49E-13	1,21E-12
Ethanol	kg	7,74E-09	1,84E-09	4,59E-10	5,36E-10	1,37E-09	3,53E-09	1,35E-12	4,60E-12
Ethene	kg	7,29E-08	2,36E-09	1,99E-08	4,59E-09	4,50E-08	8,70E-10	1,54E-11	1,71E-10
Ethene, chloro-	kg	1,70E-10	4,76E-12	7,20E-11	4,68E-11	3,90E-11	7,44E-12	7,57E-14	2,43E-13
Ethene, tetrachloro-	kg	4,70E-14	2,26E-15	1,64E-14	8,14E-15	1,71E-14	2,93E-15	2,02E-17	9,70E-17
Ethyl acetate	kg	3,24E-08	2,27E-11	3,08E-08	6,47E-10	5,43E-10	2,99E-10	6,28E-12	3,85E-11
Ethyl cellulose	kg	6,55E-11	4,46E-14	6,24E-11	1,31E-12	1,09E-12	6,03E-13	1,27E-14	7,80E-14
Ethylamine	kg	1,01E-14	1,00E-16	5,41E-15	1,50E-15	7,58E-16	2,31E-15	1,39E-18	1,24E-17
Ethylene diamine	kg	2,26E-13	1,55E-15	1,01E-14	1,99E-13	1,26E-14	2,49E-15	3,86E-17	3,98E-16
Ethylene oxide	kg	1,03E-10	3,20E-12	3,47E-11	3,58E-11	2,84E-11	7,71E-13	4,26E-14	1,34E-13
Ethyne	kg	2,17E-09	8,83E-11	7,51E-10	1,07E-10	1,19E-09	3,11E-11	4,25E-13	2,76E-12
Fluorine	kg	3,92E-09	3,30E-10	8,27E-10	2,99E-10	1,94E-09	5,10E-10	2,22E-12	8,88E-12
Fluosilicic acid	kg	1,13E-09	9,34E-12	1,02E-09	1,18E-11	7,36E-11	1,19E-11	1,61E-13	1,34E-12
Formaldehyde	kg	6,14E-08	3,76E-09	3,50E-09	5,87E-09	3,80E-08	6,94E-09	2,58E-10	3,09E-09
Formamide	kg	7,21E-15	1,17E-16	2,28E-15	2,99E-15	7,33E-16	1,08E-15	1,33E-18	1,01E-17
Formic acid	kg	2,19E-10	3,02E-11	1,46E-10	5,51E-12	3,48E-11	2,41E-12	3,35E-14	3,63E-13
Furan	kg	5,07E-11	8,58E-12	3,04E-11	1,34E-12	9,70E-12	5,78E-13	7,29E-15	8,94E-14
Heat, waste	MJ	8,23E-01	5,38E-01	4,32E-02	2,67E-02	1,64E-01	4,80E-02	1,58E-03	1,86E-03
Helium	kg	1,88E-08	5,69E-10	6,89E-10	9,87E-10	1,59E-08	4,99E-10	1,42E-11	1,77E-10
Heptane	kg	9,04E-08	1,95E-09	2,50E-09	3,61E-09	7,91E-08	2,62E-09	3,42E-11	5,16E-10
Hexane	kg	2,31E-07	1,28E-08	9,26E-09	9,91E-09	1,75E-07	2,24E-08	7,95E-11	1,12E-09
Hydrocarbons, aliphatic, alkanes, cyclic	kg	1,19E-10	4,45E-12	2,93E-11	3,91E-11	3,98E-11	5,83E-12	4,01E-14	1,59E-13
Hydrocarbons, aliphatic, alkanes, unspecified	kg	4,70E-07	7,07E-08	1,62E-07	1,56E-08	1,98E-07	2,30E-08	5,64E-11	5,41E-10
Hydrocarbons, aliphatic, unsaturated	kg	1,20E-08	1,59E-09	2,50E-09	1,08E-09	4,29E-09	2,51E-09	5,48E-12	1,64E-11
Hydrocarbons, aromatic	kg	1,45E-07	3,18E-08	3,89E-08	1,48E-08	5,73E-08	1,62E-09	1,58E-11	1,40E-10
Hydrocarbons, chlorinated	kg	8,55E-10	2,60E-11	3,94E-10	1,49E-11	4,12E-10	6,71E-12	1,16E-13	8,91E-13
Hydrogen	kg	5,02E-08	6,69E-09	1,22E-08	1,14E-08	1,76E-08	1,84E-09	4,70E-10	1,07E-10
Hydrogen-3, Tritium	Bq	6,17E-01	5,78E-02	1,20E-01	5,47E-02	2,92E-01	9,05E-02	3,90E-04	1,36E-03
Hydrogen chloride	kg	5,74E-07	4,63E-08	1,21E-07	4,23E-08	3,09E-07	5,48E-08	2,19E-10	7,95E-10
Hydrogen fluoride	kg	1,17E-07	1,20E-08	4,08E-08	7,34E-09	3,68E-08	1,96E-08	3,79E-11	1,45E-10
Hydrogen peroxide	kg	4,85E-11	3,35E-14	4,62E-11	9,70E-13	8,10E-13	4,47E-13	9,42E-15	5,77E-14
Hydrogen sulfide	kg	4,23E-07	3,26E-07	3,06E-08	4,87E-09	4,60E-08	1,50E-08	1,99E-11	1,15E-10
Iodine	kg	2,32E-09	3,26E-10	4,54E-10	2,19E-10	7,47E-10	5,72E-10	1,24E-12	3,24E-12
Iodine-129	Bq	1,12E-04	1,05E-05	2,08E-05	9,64E-06	5,38E-05	1,66E-05	6,96E-08	2,50E-07
Iodine-131	Bq	3,28E-03	2,15E-04	9,12E-04	4,25E-04	1,62E-03	1,03E-04	2,99E-06	7,69E-06
Iodine-133	Bq	9,82E-07	8,13E-08	8,25E-08	3,19E-08	6,35E-07	1,48E-07	4,10E-10	2,99E-09
Iodine-135	Bq	4,03E-07	2,51E-08	1,31E-07	2,67E-08	1,85E-07	3,43E-08	2,14E-10	9,62E-10
Iron	kg	9,23E-08	7,02E-09	1,80E-08	6,37E-09	5,11E-08	9,55E-09	4,80E-11	1,88E-10
Isocyanic acid	kg	5,65E-11	4,33E-12	1,40E-11	5,66E-12	2,68E-11	5,61E-12	4,42E-14	1,27E-13
Isoprene	kg	2,35E-12	3,98E-13	1,41E-12	6,20E-14	4,50E-13	2,68E-14	3,38E-16	4,15E-15
Isopropylamine	kg	3,63E-15	1,71E-17	2,32E-15	2,57E-17	1,59E-16	1,11E-15	3,88E-19	4,11E-18
Krypton-85	Bq	2,73E-02	1,82E-03	7,22E-03	3,38E-03	1,37E-02	1,06E-03	2,41E-05	6,53E-05
Krypton-85m	Bq	9,99E-03	8,66E-04	3,80E-04	2,90E-04	6,82E-03	1,60E-03	4,12E-06	3,16E-05
Krypton-87	Bq	2,44E-03	2,07E-04	1,46E-04	9,32E-05	1,62E-03	3,62E-04	1,12E-06	7,53E-06
Krypton-88	Bq	3,06E-03	2,62E-04	1,46E-04	1,01E-04	2,06E-03	4,74E-04	1,32E-06	9,57E-06
Krypton-89	Bq	1,22E-03	1,06E-04	3,88E-05	3,22E-05	8,38E-04	1,99E-04	4,87E-07	3,88E-06
Lactic acid	kg	8,48E-15	6,69E-16	4,26E-15	1,37E-15	1,04E-15	1,13E-15	1,26E-18	1,27E-17
Lanthanum-140	Bq	5,69E-08	4,98E-09	1,57E-09	1,40E-09	3,93E-08	9,43E-09	2,22E-11	1,82E-10
Lead	kg	2,79E-08	4,85E-09	1,05E-08	2,55E-09	9,16E-09	7,60E-10	5,79E-12	3,51E-11

Lead-210	Bq	7,28E-04	9,85E-05	1,37E-04	6,25E-05	2,54E-04	1,75E-04	3,55E-07	1,05E-06
m-Xylene	kg	1,08E-10	1,50E-11	2,10E-11	1,39E-11	4,17E-11	1,63E-11	7,02E-14	1,94E-13
Magnesium	kg	1,64E-08	9,51E-10	4,44E-09	1,06E-09	8,89E-09	1,06E-09	6,16E-12	2,75E-11
Manganese	kg	5,49E-09	3,38E-10	1,82E-09	3,06E-10	2,63E-09	3,87E-10	1,62E-12	8,09E-12
Manganese-54	Bq	5,30E-09	4,64E-10	1,46E-10	1,30E-10	3,66E-09	8,78E-10	2,07E-12	1,69E-11
Mercury	kg	3,21E-09	1,65E-10	1,03E-09	1,21E-10	1,84E-09	4,13E-11	1,50E-12	4,17E-12
Methane, biogenic	kg	4,03E-07	8,52E-08	4,72E-08	3,82E-08	9,81E-08	1,34E-07	1,80E-10	4,06E-10
Methane, bromo-, Halon 1001	kg	5,63E-19	6,80E-21	2,03E-19	2,71E-19	7,82E-20	3,07E-21	8,15E-23	7,21E-22
Methane, bromochlorodifluoro-, Halon 1211	kg	8,22E-10	7,58E-10	1,19E-11	4,77E-12	1,96E-11	2,79E-11	2,36E-14	6,91E-14
Methane, bromotrifluoro-, Halon 1301	kg	2,55E-10	5,14E-12	9,95E-12	2,27E-11	2,09E-10	6,82E-12	1,11E-13	1,57E-12
Methane, chlorodifluoro-, HCFC-22	kg	2,72E-09	2,45E-09	7,23E-11	1,95E-11	7,79E-11	1,01E-10	1,02E-13	3,06E-13
Methane, dichloro-, HCC-30	kg	9,44E-13	2,30E-14	5,68E-13	1,14E-13	1,88E-13	4,92E-14	2,98E-16	1,49E-15
Methane, dichlorodifluoro-, CFC-12	kg	3,35E-12	9,71E-13	2,12E-12	6,11E-14	1,27E-13	6,65E-14	5,53E-16	2,96E-15
Methane, dichlorofluoro-, HCFC-21	kg	5,62E-15	6,83E-18	5,32E-15	1,15E-16	1,14E-16	5,49E-17	1,11E-18	6,74E-18
Methane, fossil	kg	1,18E-04	8,01E-05	8,20E-06	3,78E-06	2,11E-05	4,33E-06	1,66E-08	1,42E-07
Methane, monochloro-, R-40	kg	5,68E-13	2,78E-14	1,87E-13	9,64E-14	2,21E-13	3,39E-14	2,31E-16	1,14E-15
Methane, tetrachloro-, CFC-10	kg	3,61E-11	2,01E-12	2,17E-11	2,33E-12	8,67E-12	9,99E-13	3,40E-13	5,34E-14
Methane, tetrafluoro-, CFC-14	kg	8,68E-09	7,19E-11	7,85E-09	9,05E-11	5,67E-10	9,17E-11	1,24E-12	1,03E-11
Methane, trichlorofluoro-, CFC-11	kg	9,13E-15	1,11E-17	8,64E-15	1,87E-16	1,86E-16	8,92E-17	1,80E-18	1,09E-17
Methane, trifluoro-, HFC-23	kg	1,79E-12	2,17E-15	1,69E-12	3,67E-14	3,64E-14	1,75E-14	3,53E-16	2,14E-15
Methanesulfonic acid	kg	2,51E-14	4,81E-17	1,55E-14	1,34E-16	5,19E-16	8,84E-15	2,47E-18	2,83E-17
Methanol	kg	2,42E-08	2,42E-09	3,53E-09	7,13E-09	7,11E-09	4,02E-09	1,10E-11	2,73E-11
Methyl acetate	kg	1,02E-15	2,07E-18	6,32E-16	5,16E-18	2,11E-17	3,58E-16	1,01E-19	1,15E-18
Methyl acrylate	kg	2,05E-11	1,39E-14	1,95E-11	4,09E-13	3,41E-13	1,89E-13	3,97E-15	2,44E-14
Methyl borate	kg	1,65E-15	2,40E-17	5,82E-16	6,07E-16	1,52E-16	2,81E-16	2,90E-19	2,27E-18
Methyl ethyl ketone	kg	3,24E-08	2,27E-11	3,08E-08	6,47E-10	5,43E-10	2,99E-10	6,28E-12	3,85E-11
Methyl formate	kg	8,13E-14	8,48E-17	7,62E-14	2,38E-15	1,51E-15	1,02E-15	1,58E-17	9,72E-17
Methyl lactate	kg	9,31E-15	7,35E-16	4,67E-15	1,51E-15	1,15E-15	1,24E-15	1,39E-18	1,40E-17
Methylamine	kg	4,99E-14	4,94E-16	4,38E-14	8,93E-16	1,34E-15	3,34E-15	8,76E-18	6,04E-17
Molybdenum	kg	3,67E-10	4,22E-11	3,97E-11	2,88E-11	1,80E-10	7,49E-11	1,48E-13	9,55E-13
Monoethanolamine	kg	9,14E-10	6,42E-12	7,64E-10	5,56E-11	7,72E-11	9,75E-12	1,76E-13	1,11E-12
Nickel	kg	1,83E-08	2,76E-09	5,36E-09	1,10E-09	6,59E-09	2,49E-09	4,72E-12	3,53E-11
Niobium-95	Bq	6,29E-10	5,50E-11	1,73E-11	1,55E-11	4,34E-10	1,04E-10	2,46E-13	2,01E-12
Nitrate	kg	6,91E-10	6,19E-11	1,26E-10	5,41E-11	3,50E-10	9,68E-11	4,01E-13	1,60E-12
Nitrobenzene	kg	5,77E-14	4,04E-15	2,97E-14	8,28E-15	6,42E-15	9,11E-15	8,26E-18	8,41E-17
Nitrogen oxides	kg	2,12E-04	1,21E-04	6,49E-06	3,05E-06	7,43E-05	5,95E-06	1,03E-07	1,22E-06
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	7,99E-05	1,28E-05	2,22E-06	1,80E-06	6,16E-05	1,33E-06	1,57E-08	1,87E-07
Noble gases, radioactive, unspecified	Bq	1,07E+03	1,01E+02	2,00E+02	9,26E+01	5,17E+02	1,60E+02	6,69E-01	2,40E+00
Ozone	kg	7,19E-08	1,41E-08	8,50E-09	4,81E-09	2,01E-08	2,43E-08	2,34E-11	8,14E-11
PAH, polycyclic aromatic hydrocarbons	kg	9,44E-09	2,96E-10	3,45E-09	2,62E-10	5,13E-09	2,56E-10	1,17E-12	4,25E-11
Particulates, < 2.5 um	kg	1,26E-05	2,86E-06	1,44E-06	4,33E-07	7,44E-06	3,81E-07	4,01E-09	7,33E-08
Particulates, > 10 um	kg	2,26E-05	3,64E-06	5,89E-06	7,99E-07	1,11E-05	1,19E-06	4,13E-09	3,11E-08
Particulates, > 2.5 um, and < 10um	kg	1,31E-05	3,11E-06	3,54E-06	3,73E-07	5,87E-06	1,56E-07	1,94E-09	1,94E-08
Pentane	kg	5,97E-07	2,76E-08	2,52E-08	2,54E-08	4,77E-07	3,88E-08	2,09E-10	2,88E-09
Phenol	kg	1,71E-09	5,50E-11	4,66E-10	5,14E-10	6,55E-10	1,35E-11	2,93E-13	1,75E-12
Phenol, 2,4-dichloro-	kg	6,93E-15	4,43E-16	4,25E-15	8,98E-17	5,81E-16	1,56E-15	8,00E-19	9,44E-18
Phenol, pentachloro-	kg	3,66E-11	6,56E-12	4,93E-12	3,19E-12	1,03E-11	1,16E-11	3,46E-14	4,12E-14
Phosphine	kg	1,56E-14	1,06E-17	1,49E-14	3,12E-16	2,59E-16	1,44E-16	3,03E-18	1,86E-17
Phosphorus	kg	5,91E-10	5,70E-11	1,41E-10	5,50E-11	2,73E-10	6,16E-11	1,90E-12	1,13E-12
Platinum	kg	3,52E-15	7,09E-16	2,62E-16	2,26E-16	9,98E-16	1,32E-15	1,03E-18	3,86E-18
Plutonium-238	Bq	1,52E-11	1,43E-12	2,84E-12	1,32E-12	7,34E-12	2,27E-12	9,49E-15	3,40E-14
Plutonium-alpha	Bq	3,49E-11	3,28E-12	6,50E-12	3,01E-12	1,68E-11	5,20E-12	2,18E-14	7,80E-14
Polonium-210	Bq	1,29E-03	1,76E-04	2,42E-04	1,11E-04	4,42E-04	3,13E-04	6,23E-07	1,82E-06
Polychlorinated biphenyls	kg	4,20E-11	1,55E-12	1,46E-11	1,42E-12	2,42E-11	1,39E-13	4,68E-15	5,01E-14
Potassium	kg	3,43E-08	3,94E-09	6,91E-09	3,67E-09	1,51E-08	4,62E-09	2,04E-11	6,54E-11
Potassium-40	Bq	2,19E-04	3,91E-05	3,25E-05	1,71E-05	5,74E-05	7,24E-05	7,76E-08	2,10E-07
Propanal	kg	5,18E-12	1,28E-13	1,95E-13	8,08E-14	4,70E-12	7,02E-14	9,66E-16	5,62E-15
Propane	kg	1,35E-06	8,60E-07	2,85E-08	2,33E-08	3,80E-07	5,62E-08	1,79E-10	2,35E-09
Propene	kg	3,12E-08	6,84E-10	8,35E-09	2,38E-09	1,89E-08	7,02E-10	9,40E-12	1,20E-10
Propionic acid	kg	9,09E-10	1,93E-10	1,33E-10	5,43E-11	2,02E-10	3,26E-10	2,75E-13	7,30E-13
Propylamine	kg	2,28E-15	3,70E-17	7,21E-16	9,47E-16	2,32E-16	3,42E-16	4,22E-19	3,21E-18
Propylene oxide	kg	7,59E-09	1,88E-12	7,45E-09	8,17E-12	1,15E-10	2,39E-12	7,57E-13	9,03E-12
Protactinium-234	Bq	1,68E-05	1,52E-06	2,88E-06	1,34E-06	8,62E-06	2,38E-06	1,01E-08	4,01E-08
Radioactive species, other beta emitters	Bq	5,35E-02	3,47E-05	9,75E-05	5,20E-02	1,23E-03	4,10E-05	8,20E-06	9,85E-05
Radium-226	Bq	7,25E-04	7,43E-05	1,27E-04	5,85E-05	3,42E-04	1,21E-04	4,16E-07	1,56E-06
Radium-228	Bq	1,40E-04	1,39E-05	3,01E-05	1,15E-05	6,05E-05	2,33E-05	5,83E-08	1,75E-07
Radon-220	Bq	6,98E-03	1,11E-03	1,29E-03	6,09E-04	2,01E-03	1,94E-03	3,25E-06	8,61E-06
Radon-222	Bq	2,21E+03	2,00E+02	3,77E+02	1,75E+02	1,14E+03	3,15E+02	1,33E+00	5,29E+00
Ruthenium-103	Bq	1,38E-10	1,21E-11	3,81E-12	3,40E-12	9,54E-11	2,29E-11	5,40E-14	4,42E-13
Scandium	kg	2,08E-10	1,85E-11	3,64E-11	1,62E-11	1,07E-10	2,89E-11	1,23E-13	4,91E-13
Selenium	kg	9,74E-10	1,72E-10	3,28E-10	6,10E-11	2,80E-10	1,30E-10	3,48E-13	1,86E-12

Silicon	kg	6,43E-08	2,93E-09	2,05E-08	3,87E-09	3,13E-08	2,74E-09	2,90E-09	9,62E-11
Silicon tetrafluoride	kg	1,23E-12	2,50E-13	2,18E-13	7,19E-14	6,44E-13	3,91E-14	9,97E-16	3,09E-15
Silver	kg	8,90E-12	8,02E-13	1,53E-12	7,12E-13	4,59E-12	1,24E-12	5,43E-15	2,13E-14
Silver-110	Bq	1,37E-09	1,20E-10	3,78E-11	3,37E-11	9,46E-10	2,27E-10	5,35E-13	4,38E-12
Sodium	kg	1,67E-08	1,71E-09	1,92E-09	1,27E-09	8,27E-09	2,84E-09	6,22E-10	4,46E-11
Sodium chlorate	kg	1,28E-11	2,76E-12	1,12E-12	2,00E-12	6,21E-12	6,22E-13	1,16E-14	3,55E-14
Sodium dichromate	kg	2,78E-11	3,90E-12	6,31E-12	4,45E-12	6,38E-12	6,67E-12	3,11E-14	4,07E-14
Sodium formate	kg	1,08E-12	3,46E-14	2,59E-13	3,07E-13	4,43E-13	3,41E-14	2,71E-15	1,18E-15
Sodium hydroxide	kg	1,81E-10	1,24E-13	1,72E-10	3,62E-12	3,01E-12	1,67E-12	3,51E-14	2,15E-13
Strontium	kg	1,29E-09	1,43E-10	2,79E-10	9,71E-11	5,26E-10	2,39E-10	9,24E-13	1,80E-12
Styrene	kg	1,39E-10	9,22E-12	9,10E-12	7,58E-12	1,12E-10	9,46E-13	2,02E-14	1,39E-13
Sulfate	kg	2,05E-07	1,48E-08	5,65E-08	3,52E-08	7,90E-08	1,91E-08	9,67E-11	3,80E-10
Sulfur dioxide	kg	7,57E-05	2,24E-05	8,34E-06	4,65E-06	3,08E-05	9,43E-06	1,63E-08	1,51E-07
Sulfur hexafluoride	kg	1,08E-09	2,31E-10	9,38E-11	7,74E-11	2,57E-10	4,15E-10	3,21E-13	9,60E-13
Sulfur trioxide	kg	4,84E-13	3,25E-14	2,51E-13	6,67E-14	5,20E-14	8,03E-14	6,83E-17	6,98E-16
Sulfuric acid	kg	3,79E-11	2,64E-14	3,61E-11	7,57E-13	6,34E-13	3,49E-13	7,35E-15	4,51E-14
t-Butyl methyl ether	kg	6,20E-11	3,50E-13	1,44E-12	8,46E-13	9,89E-12	4,94E-11	7,96E-15	7,62E-14
t-Butylamine	kg	1,96E-14	4,91E-17	1,22E-14	1,12E-16	5,03E-16	6,70E-15	1,96E-18	2,21E-17
Terpenes	kg	2,23E-11	3,76E-12	1,34E-11	5,86E-13	4,25E-12	2,54E-13	3,20E-15	3,92E-14
Thallium	kg	2,77E-11	4,30E-13	1,48E-12	3,09E-13	2,52E-11	1,80E-13	3,79E-14	2,31E-14
Thorium	kg	6,12E-12	2,29E-13	2,04E-12	3,09E-13	3,43E-12	1,08E-13	1,35E-15	7,77E-15
Thorium-228	Bq	4,10E-05	6,14E-06	7,33E-06	3,43E-06	1,29E-05	1,11E-05	1,72E-08	4,70E-08
Thorium-230	Bq	6,43E-05	6,06E-06	1,11E-05	5,03E-06	3,30E-05	8,93E-06	3,91E-08	1,54E-07
Thorium-232	Bq	5,84E-05	9,39E-06	9,95E-06	4,88E-06	1,69E-05	1,72E-05	2,45E-08	6,56E-08
Thorium-234	Bq	1,68E-05	1,52E-06	2,88E-06	1,34E-06	8,62E-06	2,38E-06	1,01E-08	4,01E-08
Tin	kg	7,72E-10	2,11E-11	4,02E-10	3,39E-11	2,91E-10	2,09E-11	1,74E-12	9,85E-13
Titanium	kg	5,96E-09	3,77E-10	9,87E-10	3,51E-10	2,52E-09	5,51E-10	1,16E-09	1,16E-11
Toluene	kg	7,51E-08	2,23E-09	4,91E-09	3,16E-09	6,01E-08	3,59E-09	1,36E-10	9,62E-10
Toluene, 2-chloro-	kg	2,21E-14	1,20E-15	1,19E-14	2,48E-15	2,00E-15	4,47E-15	2,94E-18	3,05E-17
Trimethylamine	kg	1,81E-15	3,72E-18	1,12E-15	9,19E-18	3,75E-17	6,33E-16	1,78E-19	2,03E-18
Tungsten	kg	2,29E-11	2,07E-12	3,90E-12	1,81E-12	1,18E-11	3,26E-12	1,38E-14	5,48E-14
Uranium	kg	4,93E-12	1,89E-13	1,51E-12	3,07E-13	2,79E-12	1,32E-13	1,44E-15	6,45E-15
Uranium-234	Bq	1,97E-04	1,81E-05	3,37E-05	1,55E-05	1,01E-04	2,78E-05	1,19E-07	4,72E-07
Uranium-235	Bq	9,44E-06	8,55E-07	1,61E-06	7,45E-07	4,86E-06	1,34E-06	5,70E-09	2,26E-08
Uranium-238	Bq	3,28E-04	3,69E-05	5,87E-05	2,69E-05	1,43E-04	6,17E-05	1,80E-07	6,36E-07
Uranium alpha	Bq	9,10E-04	8,25E-05	1,55E-04	7,18E-05	4,68E-04	1,30E-04	5,49E-07	2,18E-06
Vanadium	kg	2,32E-08	3,83E-09	1,87E-09	2,12E-09	8,11E-09	7,21E-09	8,32E-12	4,27E-11
Water	kg	1,37E-06	9,82E-08	5,11E-07	9,07E-08	5,27E-07	1,37E-07	2,70E-10	1,49E-09
Xenon-131m	Bq	1,25E-02	1,06E-03	6,78E-04	4,47E-04	8,36E-03	1,89E-03	5,58E-06	3,88E-05
Xenon-133	Bq	4,47E-01	3,83E-02	2,18E-02	1,49E-02	3,01E-01	6,90E-02	1,94E-04	1,40E-03
Xenon-133m	Bq	6,61E-04	5,17E-05	8,85E-05	4,57E-05	4,01E-04	7,19E-05	4,05E-07	1,88E-06
Xenon-135	Bq	1,79E-01	1,54E-02	8,90E-03	6,07E-03	1,21E-01	2,76E-02	7,84E-05	5,61E-04
Xenon-135m	Bq	1,12E-01	9,62E-03	5,27E-03	3,67E-03	7,57E-02	1,74E-02	4,84E-05	3,51E-04
Xenon-137	Bq	3,34E-03	2,91E-04	1,06E-04	8,81E-05	2,29E-03	5,45E-04	1,33E-06	1,06E-05
Xenon-138	Bq	2,53E-02	2,20E-03	9,23E-04	7,17E-04	1,73E-02	4,08E-03	1,04E-05	8,02E-05
Xylene	kg	7,10E-08	4,97E-09	7,72E-09	4,05E-09	4,44E-08	9,28E-09	5,26E-11	5,48E-10
Zinc	kg	8,97E-08	3,48E-08	2,07E-08	5,70E-09	2,73E-08	9,35E-10	4,99E-11	1,34E-10
Zinc-65	Bq	2,64E-08	2,32E-09	7,29E-10	6,51E-10	1,83E-08	4,38E-09	1,03E-11	8,46E-11
Zirconium	kg	4,82E-11	1,73E-12	1,80E-11	1,58E-12	2,66E-11	1,65E-13	5,40E-15	5,83E-14
Zirconium-95	Bq	2,58E-08	2,26E-09	7,13E-10	6,36E-10	1,79E-08	4,28E-09	1,01E-11	8,27E-11

Annex C – Case study 3 data inventory

			Life Cycle Processes									
SUBSTANCE	UNIT	TOTAL	Field Emissions	Ploghing	Roughing harrowing	Fertilization	Finishing harrowing	Seeding	Weeding	Hoeing	Plant protection treatments	Harvesting
1-Propanol	kg	1,33E-12	0,00E+00	0,00E+00	0,00E+00	1,26E-12	0,00E+00	3,53E-14	2,48E-14	0,00E+00	1,01E-14	0,00E+00
1,4-Butanediol	kg	2,53E-12	0,00E+00	0,00E+00	0,00E+00	2,49E-12	0,00E+00	3,33E-14	4,61E-15	0,00E+00	2,75E-15	0,00E+00
2-Propanol	kg	4,74E-08	0,00E+00	0,00E+00	0,00E+00	4,66E-08	0,00E+00	6,23E-10	8,53E-11	0,00E+00	5,10E-11	0,00E+00
Acenaphthene	kg	1,22E-13	0,00E+00	0,00E+00	0,00E+00	1,16E-13	0,00E+00	2,00E-15	2,28E-15	0,00E+00	9,34E-16	0,00E+00
Acetaldehyde	kg	4,09E-07	0,00E+00	1,07E-07	2,57E-08	1,82E-07	1,07E-08	1,74E-08	8,00E-09	8,57E-09	6,44E-09	4,28E-08
Acetic acid	kg	4,27E-07	0,00E+00	0,00E+00	0,00E+00	4,03E-07	0,00E+00	1,20E-08	9,31E-09	0,00E+00	2,89E-09	0,00E+00
Acetone	kg	1,23E-07	0,00E+00	0,00E+00	0,00E+00	1,18E-07	0,00E+00	1,96E-09	2,36E-09	0,00E+00	7,63E-10	0,00E+00
Acetonitrile	kg	1,04E-08	0,00E+00	0,00E+00	0,00E+00	1,04E-08	0,00E+00	3,75E-11	5,75E-13	0,00E+00	1,84E-13	0,00E+00
Acrolein	kg	2,68E-08	0,00E+00	1,29E-08	3,10E-09	4,67E-10	1,29E-09	1,39E-09	6,92E-10	1,03E-09	6,91E-10	5,17E-09
Acrylic acid	kg	1,23E-10	0,00E+00	0,00E+00	0,00E+00	1,21E-10	0,00E+00	1,61E-12	2,21E-13	0,00E+00	1,32E-13	0,00E+00
Actinides, radioactive, unspecified	Bq	1,58E-05	0,00E+00	0,00E+00	0,00E+00	1,47E-05	0,00E+00	8,33E-07	2,23E-07	0,00E+00	9,24E-08	0,00E+00
Aerosols, radioactive, unspecified	Bq	3,15E-04	0,00E+00	0,00E+00	0,00E+00	2,96E-04	0,00E+00	1,05E-05	5,74E-06	0,00E+00	2,35E-06	0,00E+00
Aldehydes, unspecified	kg	1,17E-06	0,00E+00	5,63E-07	1,35E-07	2,06E-08	5,63E-08	5,97E-08	3,01E-08	4,51E-08	3,01E-08	2,25E-07
Aluminum	kg	4,39E-06	0,00E+00	0,00E+00	0,00E+00	4,17E-06	0,00E+00	1,76E-07	3,39E-08	0,00E+00	1,53E-08	0,00E+00
Americium-241	Bq	4,32E-09	0,00E+00	0,00E+00	0,00E+00	4,32E-09	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Ammonia	kg	6,76E-05	0,00E+00	4,79E-08	1,15E-08	3,95E-06	4,79E-09	6,35E-05	2,56E-08	3,83E-09	1,28E-08	1,92E-08
Ammonium carbonate	kg	3,03E-11	0,00E+00	0,00E+00	0,00E+00	2,34E-11	0,00E+00	3,52E-12	2,40E-12	0,00E+00	9,56E-13	0,00E+00
Antimony	kg	4,72E-09	0,00E+00	4,55E-11	1,09E-11	4,40E-09	4,55E-12	1,81E-10	3,63E-11	3,64E-12	1,75E-11	1,82E-11
Antimony-124	Bq	2,81E-09	0,00E+00	0,00E+00	0,00E+00	2,00E-09	0,00E+00	7,81E-10	2,45E-11	0,00E+00	1,03E-11	0,00E+00
Antimony-125	Bq	2,87E-08	0,00E+00	0,00E+00	0,00E+00	2,02E-08	0,00E+00	8,15E-09	2,55E-10	0,00E+00	1,07E-10	0,00E+00
Argon-41	Bq	1,62E-01	0,00E+00	0,00E+00	0,00E+00	1,54E-01	0,00E+00	3,74E-03	3,03E-03	0,00E+00	1,24E-03	0,00E+00
Arsenic	kg	3,59E-08	0,00E+00	9,47E-11	2,27E-11	3,36E-08	9,47E-12	1,52E-09	4,34E-10	7,57E-12	1,68E-10	3,79E-11
Arsine	kg	1,43E-15	0,00E+00	0,00E+00	0,00E+00	1,41E-15	0,00E+00	1,88E-17	2,57E-18	0,00E+00	1,53E-18	0,00E+00
Barium	kg	1,13E-08	0,00E+00	0,00E+00	0,00E+00	1,09E-08	0,00E+00	2,05E-10	1,24E-10	0,00E+00	5,10E-11	0,00E+00
Barium-140	Bq	1,87E-06	0,00E+00	0,00E+00	0,00E+00	1,31E-06	0,00E+00	5,30E-07	1,66E-08	0,00E+00	6,98E-09	0,00E+00
Benzal chloride	kg	7,70E-18	0,00E+00	0,00E+00	0,00E+00	7,07E-18	0,00E+00	6,04E-19	1,69E-20	0,00E+00	8,97E-21	0,00E+00
Benzaldehyde	kg	1,88E-11	0,00E+00	0,00E+00	0,00E+00	4,11E-12	0,00E+00	1,26E-11	1,30E-12	0,00E+00	7,72E-13	0,00E+00
Benzene	kg	8,98E-07	0,00E+00	1,30E-07	3,13E-08	5,92E-07	1,30E-08	4,32E-08	1,55E-08	1,04E-08	9,98E-09	5,21E-08
Benzene, ethyl-	kg	2,14E-08	0,00E+00	0,00E+00	0,00E+00	1,78E-08	0,00E+00	2,29E-09	1,04E-09	0,00E+00	3,13E-10	0,00E+00
Benzene, hexachloro-	kg	4,13E-11	0,00E+00	0,00E+00	0,00E+00	3,98E-11	0,00E+00	1,25E-12	1,64E-13	0,00E+00	8,13E-14	0,00E+00
Benzene, pentachloro-	kg	1,49E-12	0,00E+00	0,00E+00	0,00E+00	1,33E-12	0,00E+00	1,56E-13	6,14E-15	0,00E+00	3,52E-15	0,00E+00
Benzo(a)pyrene	kg	1,23E-09	0,00E+00	0,00E+00	0,00E+00	1,14E-09	0,00E+00	6,84E-11	1,65E-11	0,00E+00	6,79E-12	0,00E+00
Beryllium	kg	9,39E-11	0,00E+00	6,59E-12	1,58E-12	7,78E-11	6,59E-13	2,97E-12	5,95E-13	5,27E-13	4,71E-13	2,64E-12
Boron	kg	4,61E-07	0,00E+00	0,00E+00	0,00E+00	4,42E-07	0,00E+00	6,91E-09	8,43E-09	0,00E+00	3,45E-09	0,00E+00
Boron trifluoride	kg	1,07E-17	0,00E+00	0,00E+00	0,00E+00	1,05E-17	0,00E+00	1,40E-19	1,92E-20	0,00E+00	1,14E-20	0,00E+00
Bromine	kg	4,99E-08	0,00E+00	0,00E+00	0,00E+00	4,79E-08	0,00E+00	7,04E-10	9,29E-10	0,00E+00	3,80E-10	0,00E+00
Butadiene	kg	1,13E-08	0,00E+00	5,46E-09	1,31E-09	1,92E-10	5,46E-10	5,79E-10	2,92E-10	4,37E-10	2,92E-10	2,18E-09
Butane	kg	1,43E-06	0,00E+00	0,00E+00	0,00E+00	1,25E-06	0,00E+00	1,15E-07	5,14E-08	0,00E+00	1,60E-08	0,00E+00
Butanol	kg	7,85E-15	0,00E+00	0,00E+00	0,00E+00	7,73E-15	0,00E+00	1,03E-16	1,43E-17	0,00E+00	8,52E-18	0,00E+00
Butene	kg	2,27E-08	0,00E+00	0,00E+00	0,00E+00	1,91E-08	0,00E+00	2,26E-09	1,04E-09	0,00E+00	3,10E-10	0,00E+00
Butyrolactone	kg	7,33E-13	0,00E+00	0,00E+00	0,00E+00	7,21E-13	0,00E+00	9,65E-15	1,34E-15	0,00E+00	7,95E-16	0,00E+00
Cadmium	kg	1,43E-08	0,00E+00	1,44E-10	3,45E-11	1,26E-08	1,44E-11	6,57E-10	5,38E-10	1,15E-11	1,76E-10	5,75E-11
Calcium	kg	1,46E-07	0,00E+00	0,00E+00	0,00E+00	1,40E-07	0,00E+00	3,25E-09	2,42E-09	0,00E+00	8,69E-10	0,00E+00
Carbon-14	Bq	1,32E+00	0,00E+00	0,00E+00	0,00E+00	1,22E+00	0,00E+00	6,72E-02	2,33E-02	0,00E+00	9,53E-03	0,00E+00
Carbon dioxide	kg	2,49E-04	0,00E+00	0,00E+00	0,00E+00	2,49E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Carbon dioxide, biogenic	kg	2,41E-03	0,00E+00	7,31E-06	1,75E-06	2,24E-03	7,31E-07	1,10E-04	2,88E-05	5,85E-07	1,31E-05	2,92E-06
Carbon dioxide, fossil	kg	1,82E-01	0,00E+00	2,58E-02	6,20E-03	1,19E-01	2,58E-03	9,65E-03	3,62E-03	2,07E-03	2,17E-03	1,03E-02
Carbon dioxide, land transformation	kg	1,52E-04	0,00E+00	0,00E+00	0,00E+00	1,51E-04	0,00E+00	5,89E-07	7,32E-08	0,00E+00	2,92E-08	0,00E+00
Carbon disulfide	kg	8,56E-07	0,00E+00	0,00E+00	0,00E+00	8,09E-07	0,00E+00	3,86E-08	5,67E-09	0,00E+00	2,51E-09	0,00E+00
Carbon monoxide	kg	2,60E-04	0,00E+00	1,25E-04	3,01E-05	5,13E-06	1,25E-05	1,33E-05	6,70E-06	1,00E-05	6,70E-06	5,02E-05
Carbon monoxide, biogenic	kg	1,00E-05	0,00E+00	0,00E+00	0,00E+00	9,22E-06	0,00E+00	6,55E-07	9,12E-08	0,00E+00	7,77E-08	0,00E+00
Carbon monoxide, fossil	kg	2,38E-04	0,00E+00	0,00E+00	0,00E+00	2,17E-04	0,00E+00	1,88E-05	1,24E-06	0,00E+00	5,00E-07	0,00E+00
Cerium-141	Bq	4,52E-07	0,00E+00	0,00E+00	0,00E+00	3,18E-07	0,00E+00	1,29E-07	4,02E-09	0,00E+00	1,69E-09	0,00E+00
Cerium-144	Bq	4,60E-08	0,00E+00	0,00E+00	0,00E+00	4,60E-08	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Cesium-134	Bq	1,86E-07	0,00E+00	0,00E+00	0,00E+00	1,80E-07	0,00E+00	6,16E-09	1,93E-10	0,00E+00	8,10E-11	0,00E+00
Cesium-137	Bq	7,01E-07	0,00E+00	0,00E+00	0,00E+00	5,87E-07	0,00E+00	1,09E-07	3,42E-09	0,00E+00	1,44E-09	0,00E+00
Chlorine	kg	4,91E-08	0,00E+00	1,80E-09	4,31E-10	4,30E-08	1,80E-10	1,92E-09	5,92E-10	1,44E-10	3,10E-10	7,19E-10
Chloroform	kg	1,19E-10	0,00E+00	0,00E+00	0,00E+00	1,16E-10	0,00E+00	2,47E-12	4,93E-13	0,00E+00	2,63E-13	0,00E+00
Chlorosilane, trimethyl-	kg	2,20E-12	0,00E+00	0,00E+00	0,00E+00	2,17E-12	0,00E+00	2,89E-14	3,97E-15	0,00E+00	2,37E-15	0,00E+00
Chromium	kg	2,67E-07	0,00E+00	1,08E-10	2,59E-11	2,50E-07	1,08E-11	1,59E-08	8,82E-10	8,63E-12	4,25E-10	4,31E-11
Chromium-51	Bq	2,98E-08	0,00E+00	0,00E+00	0,00E+00	2,12E-08	0,00E+00	8,24E-09	2,58E-10	0,00E+00	1,08E-10	0,00E+00
Chromium VI	kg	6,63E-09	0,00E+00	0,00E+00	0,00E+00	6,21E-09	0,00E+00	3,90E-10	1,93E-11	0,00E+00	9,76E-12	0,00E+00

Cobalt	kg	1,08E-08	0,00E+00	1,32E-10	3,16E-11	9,15E-09	1,32E-11	6,89E-10	5,18E-10	1,05E-11	1,66E-10	5,27E-11
Cobalt-57	Bq	3,96E-13	0,00E+00	0,00E+00	0,00E+00	3,96E-13	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Cobalt-58	Bq	4,69E-08	0,00E+00	0,00E+00	0,00E+00	3,49E-08	0,00E+00	1,15E-08	3,59E-10	0,00E+00	1,51E-10	0,00E+00
Cobalt-60	Bq	3,66E-07	0,00E+00	0,00E+00	0,00E+00	2,60E-07	0,00E+00	1,01E-07	3,17E-09	0,00E+00	1,33E-09	0,00E+00
Copper	kg	1,51E-07	0,00E+00	0,00E+00	0,00E+00	1,34E-07	0,00E+00	1,46E-08	1,53E-09	0,00E+00	5,83E-10	0,00E+00
Cumene	kg	8,07E-09	0,00E+00	0,00E+00	0,00E+00	7,41E-09	0,00E+00	5,57E-10	7,46E-11	0,00E+00	2,58E-11	0,00E+00
Curium-242	Bq	2,27E-14	0,00E+00	0,00E+00	0,00E+00	2,27E-14	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Curium-244	Bq	2,06E-13	0,00E+00	0,00E+00	0,00E+00	2,06E-13	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Curium alpha	Bq	6,85E-09	0,00E+00	0,00E+00	0,00E+00	6,85E-09	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Cyanide	kg	2,34E-08	0,00E+00	0,00E+00	0,00E+00	2,26E-08	0,00E+00	4,01E-10	2,54E-10	0,00E+00	1,51E-10	0,00E+00
Dinitrogen monoxide	kg	2,75E-03	2,64E-03	3,36E-09	8,05E-10	2,59E-06	3,36E-10	1,02E-04	5,46E-08	2,68E-10	1,99E-08	1,34E-09
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	kg	5,55E-14	0,00E+00	3,00E-17	7,19E-18	5,14E-14	3,00E-18	3,45E-15	4,42E-16	2,40E-18	2,25E-16	1,20E-17
Ethane	kg	3,25E-06	0,00E+00	0,00E+00	0,00E+00	3,02E-06	0,00E+00	1,09E-07	8,50E-08	0,00E+00	3,35E-08	0,00E+00
Ethane, 1,1-difluoro-, HFC-152a	kg	3,80E-11	0,00E+00	0,00E+00	0,00E+00	3,60E-11	0,00E+00	1,01E-12	7,09E-13	0,00E+00	2,90E-13	0,00E+00
Ethane, 1,1,1-trichloro-, HCFC-140	kg	1,53E-13	0,00E+00	0,00E+00	0,00E+00	1,42E-13	0,00E+00	8,05E-15	2,15E-15	0,00E+00	8,92E-16	0,00E+00
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	4,45E-11	0,00E+00	0,00E+00	0,00E+00	4,19E-11	0,00E+00	1,69E-12	5,83E-13	0,00E+00	2,49E-13	0,00E+00
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	5,82E-12	0,00E+00	0,00E+00	0,00E+00	5,72E-12	0,00E+00	7,65E-14	1,05E-14	0,00E+00	6,26E-15	0,00E+00
Ethane, 1,2-dichloro-	kg	2,15E-07	0,00E+00	0,00E+00	0,00E+00	2,14E-07	0,00E+00	8,64E-10	5,24E-11	0,00E+00	2,16E-11	0,00E+00
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	5,44E-10	0,00E+00	0,00E+00	0,00E+00	5,01E-10	0,00E+00	2,92E-11	9,41E-12	0,00E+00	3,85E-12	0,00E+00
Ethane, dichloro-	kg	1,27E-12	0,00E+00	0,00E+00	0,00E+00	1,27E-12	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Ethane, hexafluoro-, HFC-116	kg	3,29E-09	0,00E+00	0,00E+00	0,00E+00	3,08E-09	0,00E+00	1,98E-10	7,86E-12	0,00E+00	4,19E-12	0,00E+00
Ethanol	kg	4,30E-08	0,00E+00	0,00E+00	0,00E+00	3,56E-08	0,00E+00	1,76E-09	4,34E-09	0,00E+00	1,33E-09	0,00E+00
Ethene	kg	4,10E-07	0,00E+00	0,00E+00	0,00E+00	3,91E-07	0,00E+00	1,40E-08	3,36E-09	0,00E+00	1,63E-09	0,00E+00
Ethene, chloro-	kg	2,07E-09	0,00E+00	0,00E+00	0,00E+00	1,94E-09	0,00E+00	7,81E-11	3,67E-11	0,00E+00	1,56E-11	0,00E+00
Ethene, tetrachloro-	kg	1,18E-11	0,00E+00	5,51E-12	1,32E-12	5,46E-13	5,51E-13	6,03E-13	3,00E-13	4,41E-13	2,97E-13	2,20E-12
Ethene, trichloro-	kg	1,09E-11	0,00E+00	5,27E-12	1,27E-12	1,85E-13	5,27E-13	5,59E-13	2,82E-13	4,22E-13	2,82E-13	2,11E-12
Ethyl acetate	kg	2,20E-07	0,00E+00	0,00E+00	0,00E+00	2,16E-07	0,00E+00	2,89E-09	3,98E-10	0,00E+00	2,38E-10	0,00E+00
Ethyl cellulose	kg	4,45E-10	0,00E+00	0,00E+00	0,00E+00	4,38E-10	0,00E+00	5,85E-12	8,02E-13	0,00E+00	4,79E-13	0,00E+00
Ethylene diamine	kg	8,03E-14	0,00E+00	0,00E+00	0,00E+00	7,57E-14	0,00E+00	4,23E-15	2,63E-16	0,00E+00	1,23E-16	0,00E+00
Ethylene oxide	kg	2,34E-10	0,00E+00	0,00E+00	0,00E+00	2,24E-10	0,00E+00	8,55E-12	1,28E-12	0,00E+00	5,12E-13	0,00E+00
Ethyne	kg	4,46E-08	0,00E+00	0,00E+00	0,00E+00	4,38E-08	0,00E+00	6,78E-10	3,21E-11	0,00E+00	1,55E-11	0,00E+00
Fluorine	kg	5,52E-09	0,00E+00	0,00E+00	0,00E+00	5,22E-09	0,00E+00	2,40E-10	3,80E-11	0,00E+00	1,67E-11	0,00E+00
Fluosilicic acid	kg	3,37E-09	0,00E+00	0,00E+00	0,00E+00	3,13E-09	0,00E+00	2,26E-10	8,32E-12	0,00E+00	4,39E-12	0,00E+00
Formaldehyde	kg	8,33E-07	0,00E+00	1,65E-07	3,95E-08	4,65E-07	1,65E-08	4,13E-08	1,61E-08	1,32E-08	1,12E-08	6,59E-08
Formic acid	kg	7,01E-08	0,00E+00	0,00E+00	0,00E+00	6,99E-08	0,00E+00	2,55E-10	4,34E-12	0,00E+00	1,53E-12	0,00E+00
Furan	kg	1,98E-08	0,00E+00	0,00E+00	0,00E+00	1,98E-08	0,00E+00	7,13E-11	1,09E-12	0,00E+00	3,50E-13	0,00E+00
Heat, waste	MJ	2,05E+00	0,00E+00	0,00E+00	0,00E+00	1,88E+00	0,00E+00	1,22E-01	3,67E-02	0,00E+00	1,32E-02	0,00E+00
Helium	kg	6,70E-08	0,00E+00	0,00E+00	0,00E+00	5,66E-08	0,00E+00	7,97E-09	1,90E-09	0,00E+00	5,77E-10	0,00E+00
Heptane	kg	2,10E-07	0,00E+00	0,00E+00	0,00E+00	1,74E-07	0,00E+00	2,25E-08	1,04E-08	0,00E+00	3,10E-09	0,00E+00
Hexane	kg	9,81E-07	0,00E+00	0,00E+00	0,00E+00	8,96E-07	0,00E+00	5,22E-08	2,46E-08	0,00E+00	7,62E-09	0,00E+00
Hydrocarbons, aliphatic, alkanes, cyclic	kg	4,42E-09	0,00E+00	0,00E+00	0,00E+00	4,39E-09	0,00E+00	2,48E-11	1,43E-12	0,00E+00	5,26E-13	0,00E+00
Hydrocarbons, aliphatic, alkanes, unspecified	kg	9,36E-07	0,00E+00	0,00E+00	0,00E+00	8,47E-07	0,00E+00	6,54E-08	1,76E-08	0,00E+00	6,23E-09	0,00E+00
Hydrocarbons, aliphatic, alkenes, unspecified	kg	9,00E-11	0,00E+00	0,00E+00	0,00E+00	9,00E-11	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Hydrocarbons, aliphatic, unsaturated	kg	1,34E-07	0,00E+00	0,00E+00	0,00E+00	1,28E-07	0,00E+00	2,67E-09	2,34E-09	0,00E+00	9,17E-10	0,00E+00
Hydrocarbons, aromatic	kg	2,60E-07	0,00E+00	0,00E+00	0,00E+00	2,44E-07	0,00E+00	9,49E-09	4,81E-09	0,00E+00	1,76E-09	0,00E+00
Hydrocarbons, chlorinated	kg	3,75E-09	0,00E+00	0,00E+00	0,00E+00	2,76E-09	0,00E+00	9,84E-10	6,88E-12	0,00E+00	3,74E-12	0,00E+00
Hydrogen	kg	3,41E-07	0,00E+00	0,00E+00	0,00E+00	3,18E-07	0,00E+00	1,63E-08	5,12E-09	0,00E+00	2,36E-09	0,00E+00
Hydrogen-3, Tritium	Bq	7,49E+00	0,00E+00	0,00E+00	0,00E+00	7,01E+00	0,00E+00	2,84E-01	1,35E-01	0,00E+00	5,54E-02	0,00E+00
Hydrogen chloride	kg	5,33E-06	0,00E+00	3,00E-08	7,19E-09	5,05E-06	3,00E-09	1,13E-07	8,04E-08	2,40E-09	3,20E-08	1,20E-08
Hydrogen fluoride	kg	1,07E-05	0,00E+00	3,95E-09	9,49E-10	1,07E-05	3,95E-10	4,25E-08	1,45E-08	3,16E-10	5,89E-09	1,58E-09
Hydrogen peroxide	kg	3,30E-10	0,00E+00	0,00E+00	0,00E+00	3,24E-10	0,00E+00	4,33E-12	5,95E-13	0,00E+00	3,55E-13	0,00E+00
Hydrogen sulfide	kg	4,74E-07	0,00E+00	0,00E+00	0,00E+00	4,41E-07	0,00E+00	1,88E-08	1,03E-08	0,00E+00	4,06E-09	0,00E+00
Iodine	kg	2,65E-08	0,00E+00	0,00E+00	0,00E+00	2,54E-08	0,00E+00	3,63E-10	4,93E-10	0,00E+00	2,02E-10	0,00E+00
Iodine-129	Bq	1,32E-03	0,00E+00	0,00E+00	0,00E+00	1,23E-03	0,00E+00	5,30E-05	2,36E-05	0,00E+00	9,68E-06	0,00E+00
Iodine-131	Bq	6,39E-02	0,00E+00	0,00E+00	0,00E+00	6,08E-02	0,00E+00	1,38E-03	1,20E-03	0,00E+00	4,91E-04	0,00E+00
Iodine-133	Bq	4,10E-06	0,00E+00	0,00E+00	0,00E+00	3,31E-06	0,00E+00	7,21E-07	4,71E-08	0,00E+00	1,96E-08	0,00E+00
Iodine-135	Bq	4,00E-06	0,00E+00	0,00E+00	0,00E+00	3,73E-06	0,00E+00	1,89E-07	5,92E-08	0,00E+00	2,44E-08	0,00E+00
Iron	kg	2,37E-07	0,00E+00	0,00E+00	0,00E+00	2,28E-07	0,00E+00	6,20E-09	2,84E-09	0,00E+00	9,05E-10	0,00E+00
Iron-59	Bq	8,98E-12	0,00E+00	0,00E+00	0,00E+00	8,98E-12	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Isocyanic acid	kg	9,83E-10	0,00E+00	0,00E+00	0,00E+00	9,45E-10	0,00E+00	2,29E-11	1,06E-11	0,00E+00	4,49E-12	0,00E+00
Isoprene	kg	9,21E-10	0,00E+00	0,00E+00	0,00E+00	9,17E-10	0,00E+00	3,31E-12	5,07E-14	0,00E+00	1,62E-14	0,00E+00
Kerosene	kg	2,48E-10	0,00E+00	1,20E-10	2,88E-11	4,19E-12	1,20E-11	1,27E-11	6,40E-12	9,59E-12	6,40E-12	4,79E-11
Krypton-85	Bq	2,17E+01	0,00E+00	0,00E+00	0,00E+00	2,17E+01	0,00E+00	1,21E-02	9,50E-03	0,00E+00	3,88E-03	0,00E+00
Krypton-85m	Bq	3,50E-02	0,00E+00	0,00E+00	0,00E+00	2,66E-02	0,00E+00	7,80E-03	3,91E-04	0,00E+00	1,63E-04	0,00E+00
Krypton-87	Bq	1,21E-02	0,00E+00	0,00E+00	0,00E+00	1,01E-02	0,00E+00	1,82E-03	1,69E-04	0,00E+00	6,96E-05	0,00E+00

Krypton-88	Bq	1,37E-02	0,00E+00	0,00E+00	0,00E+00	1,11E-02	0,00E+00	2,34E-03	1,61E-04	0,00E+00	6,65E-05	0,00E+00
Krypton-89	Bq	3,77E-03	0,00E+00	0,00E+00	0,00E+00	2,75E-03	0,00E+00	9,63E-04	3,74E-05	0,00E+00	1,56E-05	0,00E+00
Lanthanum	kg	2,43E-13	0,00E+00	0,00E+00	0,00E+00	2,43E-13	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Lanthanum-140	Bq	1,60E-07	0,00E+00	0,00E+00	0,00E+00	1,13E-07	0,00E+00	4,53E-08	1,42E-09	0,00E+00	5,96E-10	0,00E+00
Lead	kg	1,30E-07	0,00E+00	1,68E-10	4,03E-11	1,21E-07	1,68E-11	6,48E-09	1,58E-09	1,34E-11	5,93E-10	6,71E-11
Lead-210	Bq	1,97E-01	0,00E+00	0,00E+00	0,00E+00	1,96E-01	0,00E+00	8,06E-04	1,27E-04	0,00E+00	5,23E-05	0,00E+00
m-Xylene	kg	1,67E-09	0,00E+00	0,00E+00	0,00E+00	1,61E-09	0,00E+00	2,77E-11	2,49E-11	0,00E+00	1,02E-11	0,00E+00
Magnesium	kg	1,56E-07	0,00E+00	0,00E+00	0,00E+00	1,52E-07	0,00E+00	3,58E-09	2,55E-10	0,00E+00	1,18E-10	0,00E+00
Manganese	kg	2,53E-08	0,00E+00	1,32E-10	3,16E-11	2,37E-08	1,32E-11	1,02E-09	2,07E-10	1,05E-11	9,35E-11	5,27E-11
Manganese-54	Bq	1,51E-08	0,00E+00	0,00E+00	0,00E+00	1,07E-08	0,00E+00	4,22E-09	1,32E-10	0,00E+00	5,55E-11	0,00E+00
Mercury	kg	9,27E-09	0,00E+00	3,12E-11	7,48E-12	8,82E-09	3,12E-12	2,52E-10	1,00E-10	2,49E-12	4,36E-11	1,25E-11
Metals, unspecified	kg	6,19E-09	0,00E+00	3,00E-09	7,19E-10	1,05E-10	3,00E-10	3,18E-10	1,60E-10	2,40E-10	1,60E-10	1,20E-09
Methane	kg	1,05E-05	0,00E+00	4,85E-06	1,16E-06	5,93E-07	4,85E-07	5,14E-07	2,59E-07	3,88E-07	2,59E-07	1,94E-06
Methane, biogenic	kg	3,34E-06	0,00E+00	0,00E+00	0,00E+00	3,25E-06	0,00E+00	3,41E-08	3,45E-08	0,00E+00	2,21E-08	0,00E+00
Methane, bromo-, Halon 1001	kg	1,76E-18	0,00E+00	0,00E+00	0,00E+00	1,62E-18	0,00E+00	1,38E-19	3,86E-21	0,00E+00	2,05E-21	0,00E+00
Methane, bromochlorodifluoro-, Halon 1211	kg	7,83E-10	0,00E+00	0,00E+00	0,00E+00	7,34E-10	0,00E+00	2,20E-11	1,88E-11	0,00E+00	7,38E-12	0,00E+00
Methane, bromotrifluoro-, Halon 1301	kg	6,36E-10	0,00E+00	0,00E+00	0,00E+00	5,32E-10	0,00E+00	6,97E-11	2,69E-11	0,00E+00	8,05E-12	0,00E+00
Methane, chlorodifluoro-, HCFC-22	kg	3,21E-09	0,00E+00	0,00E+00	0,00E+00	3,02E-09	0,00E+00	8,44E-11	7,19E-11	0,00E+00	2,85E-11	0,00E+00
Methane, chlorotrifluoro-, CFC-13	kg	2,40E-14	0,00E+00	0,00E+00	0,00E+00	2,40E-14	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Methane, dichloro-, HCC-30	kg	5,88E-11	0,00E+00	2,52E-11	6,04E-12	7,30E-12	2,52E-12	2,90E-12	1,41E-12	2,01E-12	1,37E-12	1,01E-11
Methane, dichlorodifluoro-, CFC-12	kg	1,81E-11	0,00E+00	0,00E+00	0,00E+00	1,76E-11	0,00E+00	4,17E-13	1,15E-13	0,00E+00	5,34E-14	0,00E+00
Methane, dichlorofluoro-, HCFC-21	kg	5,00E-10	0,00E+00	0,00E+00	0,00E+00	5,00E-10	0,00E+00	5,12E-16	1,08E-16	0,00E+00	7,46E-17	0,00E+00
Methane, fossil	kg	2,09E-04	0,00E+00	1,12E-06	2,69E-07	1,90E-04	1,12E-07	1,04E-05	4,38E-06	8,98E-08	1,71E-06	4,49E-07
Methane, monochloro-, R-40	kg	4,15E-12	0,00E+00	0,00E+00	0,00E+00	3,86E-12	0,00E+00	2,15E-13	5,75E-14	0,00E+00	2,39E-14	0,00E+00
Methane, tetrachloro-, CFC-10	kg	3,04E-10	0,00E+00	2,28E-11	5,46E-12	2,52E-10	2,28E-12	6,34E-12	2,26E-12	1,82E-12	1,66E-12	9,11E-12
Methane, tetrafluoro-, CFC-14	kg	2,60E-08	0,00E+00	0,00E+00	0,00E+00	2,42E-08	0,00E+00	1,74E-09	6,41E-11	0,00E+00	3,38E-11	0,00E+00
Methane, trichlorofluoro-, CFC-11	kg	2,40E-13	0,00E+00	0,00E+00	0,00E+00	2,39E-13	0,00E+00	8,32E-16	1,75E-16	0,00E+00	1,21E-16	0,00E+00
Methane, trifluoro-, HFC-23	kg	1,23E-11	0,00E+00	0,00E+00	0,00E+00	1,20E-11	0,00E+00	1,63E-13	3,43E-14	0,00E+00	2,37E-14	0,00E+00
Methanol	kg	2,09E-07	0,00E+00	0,00E+00	0,00E+00	1,85E-07	0,00E+00	1,37E-08	7,32E-09	0,00E+00	2,21E-09	0,00E+00
Methyl acrylate	kg	1,39E-10	0,00E+00	0,00E+00	0,00E+00	1,37E-10	0,00E+00	1,83E-12	2,51E-13	0,00E+00	1,50E-13	0,00E+00
Methyl amine	kg	2,64E-13	0,00E+00	0,00E+00	0,00E+00	2,60E-13	0,00E+00	3,48E-15	4,81E-16	0,00E+00	2,87E-16	0,00E+00
Methyl borate	kg	4,70E-17	0,00E+00	0,00E+00	0,00E+00	4,62E-17	0,00E+00	6,17E-19	8,44E-20	0,00E+00	5,04E-20	0,00E+00
Methyl ethyl ketone	kg	2,20E-07	0,00E+00	0,00E+00	0,00E+00	2,16E-07	0,00E+00	2,89E-09	3,98E-10	0,00E+00	2,38E-10	0,00E+00
Methyl formate	kg	5,39E-13	0,00E+00	0,00E+00	0,00E+00	5,31E-13	0,00E+00	7,09E-15	9,71E-16	0,00E+00	5,81E-16	0,00E+00
Molybdenum	kg	2,81E-09	0,00E+00	0,00E+00	0,00E+00	2,39E-09	0,00E+00	1,10E-10	2,35E-10	0,00E+00	7,11E-11	0,00E+00
Monoethanolamine	kg	6,70E-09	0,00E+00	0,00E+00	0,00E+00	6,58E-09	0,00E+00	1,01E-10	1,37E-11	0,00E+00	7,85E-12	0,00E+00
N-Nitrodimethylamine	kg	2,45E-12	0,00E+00	1,19E-12	2,85E-13	4,15E-14	1,19E-13	1,26E-13	6,34E-14	9,49E-14	6,34E-14	4,75E-13
Naphthalene	kg	1,73E-11	0,00E+00	8,39E-12	2,01E-12	2,94E-13	8,39E-13	8,89E-13	4,48E-13	6,71E-13	4,48E-13	3,36E-12
Neptunium-237	Bq	2,27E-13	0,00E+00	0,00E+00	0,00E+00	2,27E-13	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Nickel	kg	1,86E-07	0,00E+00	2,04E-09	4,89E-10	1,62E-07	2,04E-10	7,43E-09	9,77E-09	1,63E-10	3,07E-09	8,15E-10
Niobium-95	Bq	1,80E-09	0,00E+00	0,00E+00	0,00E+00	1,28E-09	0,00E+00	5,01E-10	1,57E-11	0,00E+00	6,59E-12	0,00E+00
Nitrate	kg	1,80E-10	0,00E+00	0,00E+00	0,00E+00	1,70E-10	0,00E+00	7,56E-12	1,52E-12	0,00E+00	6,85E-13	0,00E+00
Nitrogen	kg	5,46E-10	0,00E+00	0,00E+00	0,00E+00	5,46E-10	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Nitrogen oxides	kg	2,01E-03	5,55E-04	4,54E-04	1,09E-04	4,48E-04	4,54E-05	1,21E-04	2,85E-05	3,63E-05	2,58E-05	1,82E-04
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1,86E-04	0,00E+00	6,02E-05	1,44E-05	5,37E-05	6,02E-06	1,47E-05	4,32E-06	4,81E-06	3,58E-06	2,41E-05
Noble gases, radioactive, unspecified	Bq	1,26E+04	0,00E+00	0,00E+00	0,00E+00	1,18E+04	0,00E+00	5,10E+02	2,27E+02	0,00E+00	9,30E+01	0,00E+00
Organic substances, unspecified	kg	7,43E-07	0,00E+00	3,59E-07	8,63E-08	1,26E-08	3,59E-08	3,81E-08	1,92E-08	2,88E-08	1,92E-08	1,44E-07
Ozone	kg	4,50E-07	0,00E+00	0,00E+00	0,00E+00	4,22E-07	0,00E+00	1,58E-08	8,64E-09	0,00E+00	3,85E-09	0,00E+00
PAH, polycyclic aromatic hydrocarbons	kg	7,39E-08	0,00E+00	2,35E-08	5,63E-09	2,22E-08	2,35E-09	6,34E-09	1,36E-09	1,88E-09	1,30E-09	9,38E-09
Paraffins	kg	8,21E-14	0,00E+00	0,00E+00	0,00E+00	7,99E-14	0,00E+00	1,97E-15	1,78E-16	0,00E+00	9,57E-17	0,00E+00
Particulates, < 10 um (mobile)	kg	1,17E-07	0,00E+00	0,00E+00	0,00E+00	1,17E-07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Particulates, < 10 um (stationary)	kg	4,03E-08	0,00E+00	0,00E+00	0,00E+00	4,03E-08	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Particulates, < 2.5 um	kg	8,99E-05	0,00E+00	0,00E+00	0,00E+00	8,35E-05	0,00E+00	5,39E-06	7,99E-07	0,00E+00	2,69E-07	0,00E+00
Particulates, > 10 um	kg	2,17E-04	0,00E+00	0,00E+00	0,00E+00	2,12E-04	0,00E+00	3,23E-06	8,05E-07	0,00E+00	3,35E-07	0,00E+00
Particulates, > 10 um (process)	kg	7,67E-08	0,00E+00	0,00E+00	0,00E+00	7,67E-08	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Particulates, > 2.5 um, and < 10um	kg	1,59E-04	0,00E+00	1,39E-05	3,33E-06	1,29E-04	1,39E-06	3,36E-06	9,44E-07	1,11E-06	8,23E-07	5,54E-06
Particulates, unspecified	kg	4,11E-06	0,00E+00	1,99E-06	4,77E-07	6,96E-08	1,99E-07	2,11E-07	1,06E-07	1,59E-07	1,06E-07	7,96E-07
Pentane	kg	1,87E-06	0,00E+00	0,00E+00	0,00E+00	1,65E-06	0,00E+00	1,43E-07	6,05E-08	0,00E+00	1,86E-08	0,00E+00
Phenol	kg	6,74E-09	0,00E+00	1,44E-10	3,45E-11	6,25E-09	1,44E-11	1,83E-10	2,09E-11	1,15E-11	1,49E-11	5,75E-11
Phenol, pentachloro-	kg	3,44E-10	0,00E+00	0,00E+00	0,00E+00	3,28E-10	0,00E+00	6,76E-12	6,50E-12	0,00E+00	2,66E-12	0,00E+00

Phosphine	kg	1,06E-13	0,00E+00	0,00E+00	0,00E+00	1,04E-13	0,00E+00	1,39E-15	1,91E-16	0,00E+00	1,14E-16	0,00E+00
Phosphorus	kg	6,93E-09	0,00E+00	0,00E+00	0,00E+00	6,60E-09	0,00E+00	1,48E-10	1,20E-10	0,00E+00	5,99E-11	0,00E+00
Phosphorus, total	kg	1,03E-11	0,00E+00	0,00E+00	0,00E+00	1,03E-11	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Platinum	kg	6,12E-13	0,00E+00	0,00E+00	0,00E+00	6,11E-13	0,00E+00	5,87E-16	3,26E-16	0,00E+00	1,33E-16	0,00E+00
Plutonium-238	Bq	1,80E-10	0,00E+00	0,00E+00	0,00E+00	1,68E-10	0,00E+00	7,24E-12	3,23E-12	0,00E+00	1,32E-12	0,00E+00
Plutonium-241	Bq	3,77E-07	0,00E+00	0,00E+00	0,00E+00	3,77E-07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Plutonium-alpha	Bq	1,41E-08	0,00E+00	0,00E+00	0,00E+00	1,41E-08	0,00E+00	1,66E-11	7,40E-12	0,00E+00	3,03E-12	0,00E+00
Polonium-210	Bq	2,15E-01	0,00E+00	0,00E+00	0,00E+00	2,14E-01	0,00E+00	9,54E-04	2,25E-04	0,00E+00	9,22E-05	0,00E+00
Polychlorinated biphenyls	kg	7,11E-11	0,00E+00	0,00E+00	0,00E+00	6,75E-11	0,00E+00	3,20E-12	2,81E-13	0,00E+00	1,36E-13	0,00E+00
Potassium	kg	3,79E-07	0,00E+00	0,00E+00	0,00E+00	3,65E-07	0,00E+00	6,54E-09	4,91E-09	0,00E+00	2,02E-09	0,00E+00
Potassium-40	Bq	3,61E-03	0,00E+00	0,00E+00	0,00E+00	3,53E-03	0,00E+00	3,62E-05	2,86E-05	0,00E+00	1,18E-05	0,00E+00
Promethium-147	Bq	1,17E-07	0,00E+00	0,00E+00	0,00E+00	1,17E-07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Propanal	kg	1,95E-11	0,00E+00	0,00E+00	0,00E+00	4,72E-12	0,00E+00	1,27E-11	1,31E-12	0,00E+00	7,77E-13	0,00E+00
Propane	kg	1,96E-06	0,00E+00	0,00E+00	0,00E+00	1,75E-06	0,00E+00	1,26E-07	6,76E-08	0,00E+00	2,22E-08	0,00E+00
Propene	kg	9,01E-07	0,00E+00	3,60E-07	8,64E-08	1,60E-07	3,60E-08	4,41E-08	2,15E-08	2,88E-08	1,99E-08	1,44E-07
Propionic acid	kg	9,21E-09	0,00E+00	0,00E+00	0,00E+00	8,91E-09	0,00E+00	2,37E-10	4,71E-11	0,00E+00	1,94E-11	0,00E+00
Propylene oxide	kg	3,35E-09	0,00E+00	0,00E+00	0,00E+00	3,26E-09	0,00E+00	6,31E-11	1,61E-11	0,00E+00	5,51E-12	0,00E+00
Protactinium-234	Bq	1,81E-04	0,00E+00	0,00E+00	0,00E+00	1,68E-04	0,00E+00	8,66E-06	3,20E-06	0,00E+00	1,31E-06	0,00E+00
Radioactive species, other beta emitters	Bq	2,57E-02	0,00E+00	0,00E+00	0,00E+00	1,85E-02	0,00E+00	7,11E-03	5,67E-05	0,00E+00	2,48E-05	0,00E+00
Radioactive species, unspecified	Bq	1,76E+01	0,00E+00	8,51E+00	2,04E+00	2,98E-01	8,51E-01	9,02E-01	4,54E-01	6,81E-01	4,54E-01	3,40E+00
Radium-226	Bq	3,32E-01	0,00E+00	0,00E+00	0,00E+00	3,30E-01	0,00E+00	1,42E-03	1,35E-04	0,00E+00	5,55E-05	0,00E+00
Radium-228	Bq	2,97E-03	0,00E+00	0,00E+00	0,00E+00	2,90E-03	0,00E+00	5,31E-05	1,30E-05	0,00E+00	5,53E-06	0,00E+00
Radon-220	Bq	6,88E-02	0,00E+00	0,00E+00	0,00E+00	6,59E-02	0,00E+00	1,14E-03	1,29E-03	0,00E+00	5,27E-04	0,00E+00
Radon-222	Bq	2,41E+04	0,00E+00	0,00E+00	0,00E+00	2,23E+04	0,00E+00	1,14E+03	4,23E+02	0,00E+00	1,73E+02	0,00E+00
Ruthenium-103	Bq	3,89E-10	0,00E+00	0,00E+00	0,00E+00	2,75E-10	0,00E+00	1,10E-10	3,44E-12	0,00E+00	1,45E-12	0,00E+00
Ruthenium-106	Bq	1,37E-06	0,00E+00	0,00E+00	0,00E+00	1,37E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Scandium	kg	5,32E-11	0,00E+00	0,00E+00	0,00E+00	5,17E-11	0,00E+00	1,37E-12	7,13E-14	0,00E+00	3,44E-14	0,00E+00
Selenium	kg	9,66E-09	0,00E+00	8,63E-11	2,07E-11	8,85E-09	8,63E-12	2,94E-10	2,65E-10	6,90E-12	9,30E-11	3,45E-11
Silicon	kg	6,55E-07	0,00E+00	0,00E+00	0,00E+00	6,28E-07	0,00E+00	1,61E-08	7,35E-09	0,00E+00	4,33E-09	0,00E+00
Silicon tetrafluoride	kg	1,00E-11	0,00E+00	0,00E+00	0,00E+00	9,36E-12	0,00E+00	5,13E-13	9,78E-14	0,00E+00	3,57E-14	0,00E+00
Silver	kg	6,15E-12	0,00E+00	0,00E+00	0,00E+00	5,81E-12	0,00E+00	1,76E-13	1,14E-13	0,00E+00	4,66E-14	0,00E+00
Silver-110	Bq	4,07E-09	0,00E+00	0,00E+00	0,00E+00	2,93E-09	0,00E+00	1,09E-09	3,41E-11	0,00E+00	1,43E-11	0,00E+00
Sodium	kg	1,45E-07	0,00E+00	0,00E+00	0,00E+00	1,25E-07	0,00E+00	5,86E-09	1,08E-08	0,00E+00	3,26E-09	0,00E+00
Sodium chlorate	kg	1,15E-10	0,00E+00	0,00E+00	0,00E+00	1,07E-10	0,00E+00	6,12E-12	1,33E-12	0,00E+00	4,96E-13	0,00E+00
Sodium dichromate	kg	1,70E-10	0,00E+00	0,00E+00	0,00E+00	1,31E-10	0,00E+00	1,95E-11	1,38E-11	0,00E+00	5,61E-12	0,00E+00
Sodium formate	kg	6,70E-12	0,00E+00	0,00E+00	0,00E+00	6,11E-12	0,00E+00	5,48E-13	2,72E-14	0,00E+00	1,47E-14	0,00E+00
Sodium hydroxide	kg	1,23E-09	0,00E+00	0,00E+00	0,00E+00	1,21E-09	0,00E+00	1,62E-11	2,22E-12	0,00E+00	1,32E-12	0,00E+00
Strontium	kg	1,35E-08	0,00E+00	0,00E+00	0,00E+00	1,31E-08	0,00E+00	2,41E-10	1,24E-10	0,00E+00	5,14E-11	0,00E+00
Strontium-89	Bq	4,10E-10	0,00E+00	0,00E+00	0,00E+00	4,10E-10	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Strontium-90	Bq	2,27E-07	0,00E+00	0,00E+00	0,00E+00	2,27E-07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Styrene	kg	4,00E-10	0,00E+00	0,00E+00	0,00E+00	3,86E-10	0,00E+00	1,26E-11	1,09E-12	0,00E+00	5,69E-13	0,00E+00
Sulfate	kg	4,43E-04	0,00E+00	0,00E+00	0,00E+00	4,42E-04	0,00E+00	1,08E-06	6,18E-09	0,00E+00	3,06E-09	0,00E+00
Sulfur dioxide	kg	1,69E-03	0,00E+00	0,00E+00	0,00E+00	1,66E-03	0,00E+00	1,48E-05	1,12E-05	0,00E+00	3,70E-06	0,00E+00
Sulfur hexafluoride	kg	6,40E-09	0,00E+00	0,00E+00	0,00E+00	6,06E-09	0,00E+00	1,63E-10	1,29E-10	0,00E+00	5,25E-11	0,00E+00
Sulfur oxides	kg	7,49E-05	0,00E+00	3,59E-05	8,63E-06	1,85E-06	3,59E-06	3,81E-06	1,92E-06	2,88E-06	1,92E-06	1,44E-05
Sulfuric acid	kg	2,57E-10	0,00E+00	0,00E+00	0,00E+00	2,53E-10	0,00E+00	3,38E-12	4,66E-13	0,00E+00	2,78E-13	0,00E+00
t-Butyl methyl ether	kg	1,43E-10	0,00E+00	0,00E+00	0,00E+00	8,82E-11	0,00E+00	5,45E-11	2,84E-13	0,00E+00	1,43E-13	0,00E+00
Technetium-99	Bq	9,60E-12	0,00E+00	0,00E+00	0,00E+00	9,60E-12	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Tellurium-123m	Bq	1,03E-09	0,00E+00	0,00E+00	0,00E+00	1,03E-09	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Terpenes	kg	8,70E-09	0,00E+00	0,00E+00	0,00E+00	8,67E-09	0,00E+00	3,13E-11	4,80E-13	0,00E+00	1,54E-13	0,00E+00
Thallium	kg	7,53E-11	0,00E+00	0,00E+00	0,00E+00	7,25E-11	0,00E+00	2,53E-12	2,18E-13	0,00E+00	1,28E-13	0,00E+00
Thorium	kg	7,69E-11	0,00E+00	0,00E+00	0,00E+00	7,50E-11	0,00E+00	1,80E-12	9,45E-14	0,00E+00	4,58E-14	0,00E+00
Thorium-228	Bq	9,11E-04	0,00E+00	0,00E+00	0,00E+00	8,93E-04	0,00E+00	9,27E-06	5,96E-06	0,00E+00	2,45E-06	0,00E+00
Thorium-230	Bq	2,88E-01	0,00E+00	0,00E+00	0,00E+00	2,87E-01	0,00E+00	1,03E-03	1,20E-05	0,00E+00	4,90E-06	0,00E+00
Thorium-232	Bq	3,66E-03	0,00E+00	0,00E+00	0,00E+00	3,63E-03	0,00E+00	2,03E-05	9,17E-06	0,00E+00	3,76E-06	0,00E+00
Thorium-234	Bq	1,81E-04	0,00E+00	0,00E+00	0,00E+00	1,68E-04	0,00E+00	8,66E-06	3,20E-06	0,00E+00	1,31E-06	0,00E+00
Tin	kg	6,28E-09	0,00E+00	0,00E+00	0,00E+00	5,92E-09	0,00E+00	3,11E-10	3,42E-11	0,00E+00	1,57E-11	0,00E+00
Titanium	kg	1,56E-08	0,00E+00	0,00E+00	0,00E+00	1,52E-08	0,00E+00	3,67E-10	1,88E-11	0,00E+00	9,17E-12	0,00E+00
Toluene	kg	4,37E-07	0,00E+00	5,71E-08	1,37E-08	2,90E-07	5,71E-09	2,64E-08	1,08E-08	4,57E-09	5,45E-09	2,28E-08
Uranium	kg	9,70E-11	0,00E+00	0,00E+00	0,00E+00	9,48E-11	0,00E+00	1,99E-12	1,05E-13	0,00E+00	5,12E-14	0,00E+00
Uranium-234	Bq	2,89E-01	0,00E+00	0,00E+00	0,00E+00	2,88E-01	0,00E+00	1,10E-03	3,74E-05	0,00E+00	1,53E-05	0,00E+00
Uranium-235	Bq	1,02E-04	0,00E+00	0,00E+00	0,00E+00	9,46E-05	0,00E+00	4,88E-06	1,81E-06	0,00E+00	7,39E-07	0,00E+00
Uranium-238	Bq	2,92E-01	0,00E+00	0,00E+00	0,00E+00	2,91E-01	0,00E+00	1,13E-03	5,99E-05	0,00E+00	2,45E-05	0,00E+00
Uranium alpha	Bq	9,82E-03	0,00E+00	0,00E+00	0,00E+00	9,11E-03	0,00E+00	4,70E-04	1,74E-04	0,00E+00	7,12E-05	0,00E+00
Vanadium	kg	2,57E-07	0,00E+00	0,00E+00	0,00E+00	1,97E-07	0,00E+00	1,35E-08	3,56E-08	0,00E+00	1,06E-08	0,00E+00
VOC, volatile organic compounds	kg	2,35E-05	0,00E+00	1,14E-05	2,73E-06	3,97E-07	1,14E-06	1,20E-06	6,07E-07	9,09E-07	6,07E-07	4,54E-06
water	kg	6,19E-06	0,00E+00	0,00E+00	0,00E+00	5,86E-06	0,00E+00	2,57E-07	5,16E-08	0,00E+00	2,33E-08	0,00E+00
Xenon-131m	Bq	5,72E-02	0,00E+00	0,00E+00	0,00E+00	4,67E-02	0,00E+00	9,44E-03	7,66E-04	0,00E+00	3,16E-04	0,00E+00
Xenon-133	Bq	1,90E+00	0,00E+00	0,00E+00	0,00E+00	1,52E+00	0,00E+00	3,42E-01	2,40E-02	0,00E+00	9,92E-03	0,00E+00
Xenon-133m	Bq	6,54E-03	0,00E+00	0,00E+00	0,00E+00	5,96E-03	0,00E+00	4,21E-04	1,12E-04	0,00E+00	4,60E-05	0,00E+00
Xenon-135	Bq	7,69E-01	0,00E+00	0,00E+00	0,00E+00	6,18E-01	0,00E+00	1,37E-01	9,86E-03	0,00E+00	4,08E-03	0,00E+00

Xenon-135m	Bq	4,60E-01	0,00E+00	0,00E+00	0,00E+00	3,65E-01	0,00E+00	8,60E-02	5,77E-03	0,00E+00	2,39E-03	0,00E+00
Xenon-137	Bq	1,03E-02	0,00E+00	0,00E+00	0,00E+00	7,53E-03	0,00E+00	2,64E-03	1,03E-04	0,00E+00	4,29E-05	0,00E+00
Xenon-138	Bq	8,60E-02	0,00E+00	0,00E+00	0,00E+00	6,48E-02	0,00E+00	1,98E-02	9,37E-04	0,00E+00	3,90E-04	0,00E+00
Xylene	kg	5,36E-07	0,00E+00	3,98E-08	9,55E-09	4,25E-07	3,98E-09	2,10E-08	1,17E-08	3,18E-09	5,58E-09	1,59E-08
Zinc	kg	2,68E-07	0,00E+00	0,00E+00	0,00E+00	2,46E-07	0,00E+00	2,01E-08	1,66E-09	0,00E+00	7,02E-10	0,00E+00
Zinc-65	Bq	7,51E-08	0,00E+00	0,00E+00	0,00E+00	5,31E-08	0,00E+00	2,11E-08	6,59E-10	0,00E+00	2,77E-10	0,00E+00
Zirconium	kg	8,08E-11	0,00E+00	0,00E+00	0,00E+00	7,42E-11	0,00E+00	6,17E-12	3,16E-13	0,00E+00	1,47E-13	0,00E+00
Zirconium-95	Bq	7,24E-08	0,00E+00	0,00E+00	0,00E+00	5,10E-08	0,00E+00	2,06E-08	6,45E-10	0,00E+00	2,71E-10	0,00E+00

Annex D – Case study 4 data inventory

SUBSTANCE	UNIT	TOTAL	Life Cycle Processes: All Processes from Breeding of chicks to eggs Preservation and consumption	Life Cycle Processes: End of Life
1-Butanol	kg	1,73E-10	1,73E-10	8,82E-16
1-Butene	kg	1,34E-12	1,34E-12	0,00E+00
1-Pentanol	kg	1,63E-10	1,63E-10	5,09E-16
1-Pentene	kg	1,46E-10	1,46E-10	1,06E-15
1-Propanol	kg	3,12E-08	3,12E-08	4,42E-12
1,3-Butadiyne	kg	1,34E-12	1,34E-12	0,00E+00
1,4-Butanediol	kg	3,51E-10	3,51E-10	9,09E-15
2-Aminopropanol	kg	5,08E-11	5,08E-11	3,34E-16
2-Butene	kg	1,34E-12	1,34E-12	0,00E+00
2-Butene, 2-methyl-	kg	2,04E-13	2,04E-13	1,92E-17
2-Methyl-1-propanol	kg	3,33E-10	3,33E-10	1,18E-15
2-Methyl-4-chlorophenoxyacetic acid	kg	4,07E-12	4,07E-12	4,20E-17
2-Nitrobenzoic acid	kg	1,01E-10	1,01E-10	5,72E-16
2-Pentene	kg	1,12E-12	1,12E-12	0,00E+00
2-Propanol	kg	2,71E-07	2,71E-07	9,39E-11
2-Propenal, 2-methyl-	kg	2,49E-09	2,49E-09	0,00E+00
2,4-D	kg	1,67E-08	1,67E-08	5,46E-14
2,4-D ester	kg	2,40E-11	2,40E-11	2,47E-16
2,4-D, dimethylamine salt	kg	2,05E-12	2,05E-12	2,12E-17
4-Methyl-2-pentanone	kg	4,79E-12	4,79E-12	3,42E-17
Acenaphthene	kg	1,61E-11	1,61E-11	1,85E-15
Acenaphthylene	kg	2,87E-12	2,87E-12	6,90E-16
Acephate	kg	1,77E-09	1,77E-09	5,80E-15
Acetaldehyde	kg	2,76E-06	2,75E-06	9,43E-09
Acetamide	kg	4,37E-10	4,37E-10	1,43E-15
Acetic acid	kg	5,89E-06	5,88E-06	1,68E-09
Acetone	kg	1,88E-06	1,88E-06	3,42E-10
Acetonitrile	kg	1,35E-07	1,35E-07	1,15E-12
Acidity, unspecified	kg	2,64E-12	2,64E-12	0,00E+00
Acifluorfen	kg	2,44E-10	2,44E-10	7,96E-16
Acrolein	kg	3,23E-07	3,23E-07	1,68E-11
Acrylic acid	kg	1,24E-10	1,24E-10	1,73E-13
Acrylonitrile	kg	7,39E-12	7,39E-12	0,00E+00
Actinides, radioactive, unspecified	Bq	4,57E-02	4,57E-02	3,85E-06
Aerosols, radioactive, unspecified	Bq	1,42E-03	1,41E-03	4,89E-06
Alachlor	kg	1,72E-09	1,72E-09	5,63E-15
Aldehydes, unspecified	kg	5,96E-08	5,96E-08	3,16E-11
Alkanes, C10	kg	6,45E-11	6,45E-11	0,00E+00
Alkenes, C7	kg	4,26E-12	4,26E-12	0,00E+00
Aluminium	kg	6,62E-05	6,62E-05	6,74E-08
Ammonia	kg	5,21E-03	5,21E-03	3,14E-07
Ammonium carbonate	kg	1,20E-09	1,20E-09	2,19E-12
Ammonium, ion	kg	1,79E-11	1,79E-11	0,00E+00
Aniline	kg	9,56E-10	9,56E-10	6,06E-15
Anthracene	kg	2,27E-13	2,27E-13	0,00E+00
Anthranilic acid	kg	7,83E-11	7,83E-11	4,43E-16
Antimony	kg	6,41E-06	6,41E-06	1,91E-10
Antimony-124	Bq	1,74E-07	1,73E-07	6,57E-10
Antimony-125	Bq	2,60E-06	2,59E-06	6,89E-09
AOX, Adsorbable Organic Halogen as Cl	kg	5,22E-14	5,22E-14	0,00E+00
Argon-40	kg	1,06E-05	1,06E-05	2,46E-09
Argon-41	Bq	4,50E-01	4,49E-01	1,22E-03
Arsenic	kg	3,76E-07	3,76E-07	4,22E-10
Arsenic trioxide	kg	6,04E-16	6,04E-16	0,00E+00
Arsine	kg	5,16E-14	5,16E-14	2,01E-18
Atrazine	kg	1,38E-09	1,38E-09	4,62E-15
Azoxystrobin	kg	8,06E-10	8,06E-10	2,63E-15
Barium	kg	2,87E-06	2,87E-06	2,84E-09
Barium-140	Bq	9,41E-05	9,36E-05	4,46E-07
Bentazone	kg	7,47E-10	7,47E-10	2,44E-15
Benzal chloride	kg	7,23E-14	7,23E-14	2,23E-18
Benzaldehyde	kg	2,71E-07	2,71E-07	1,18E-11
Benzene	kg	2,21E-05	2,20E-05	1,13E-07
Benzene, 1-methyl-2-nitro-	kg	8,70E-11	8,70E-11	4,94E-16
Benzene, 1,2-dichloro-	kg	8,41E-10	8,41E-10	4,25E-15
Benzene, 1,2,3-trimethyl-	kg	2,74E-09	2,74E-09	0,00E+00
Benzene, 1,2,4-trimethyl-	kg	9,48E-09	9,48E-09	0,00E+00

Benzene, 1,3,5-trimethyl-	kg	2,24E-09	2,24E-09	0,00E+00
Benzene, ethyl-	kg	1,55E-06	1,55E-06	1,69E-09
Benzene, hexachloro-	kg	2,85E-10	2,77E-10	7,76E-12
Benzene, pentachloro-	kg	8,09E-11	6,26E-11	1,83E-11
Benzo(a)anthracene	kg	1,70E-13	1,70E-13	1,33E-17
Benzo(a)pyrene	kg	8,17E-08	8,17E-08	2,48E-11
Benzo(b)fluoranthene	kg	6,56E-14	6,56E-14	1,58E-17
Benzo(g,h,i)perylene	kg	1,06E-13	1,06E-13	9,70E-19
Benzo(k)fluoranthene	kg	2,51E-13	2,51E-13	1,14E-17
Beryllium	kg	2,69E-09	2,68E-09	8,49E-12
Boric acid	kg	8,39E-14	8,39E-14	7,51E-18
Boron	kg	6,85E-06	6,80E-06	4,34E-08
Boron trifluoride	kg	5,62E-10	5,62E-10	5,03E-14
Bromide	kg	2,12E-12	2,12E-12	0,00E+00
Bromine	kg	1,24E-06	1,23E-06	9,97E-09
Bromoxynil	kg	2,26E-12	2,26E-12	2,34E-17
Butadiene	kg	4,03E-10	4,03E-10	2,90E-15
Butane	kg	4,15E-05	4,14E-05	7,55E-08
Butene	kg	6,77E-07	6,75E-07	1,69E-09
Butyric acid, 4-(2,4-dichlorophenoxy)-	kg	1,18E-11	1,18E-11	1,24E-16
Butyrolactone	kg	2,73E-11	2,73E-11	4,31E-15
Cadmium	kg	1,29E-07	1,29E-07	2,20E-10
Calcium	kg	1,85E-05	1,85E-05	2,05E-08
Caprolactam	kg	1,62E-14	1,62E-14	0,00E+00
Carbaryl	kg	2,04E-10	2,04E-10	6,73E-16
Carbon	kg	1,43E-09	1,43E-09	5,48E-14
Carbon-14	Bq	1,31E+01	1,31E+01	5,09E-02
Carbon dioxide	kg	1,15E-02	1,15E-02	3,68E-09
Carbon dioxide, biogenic	kg	3,38E-01	3,11E-01	2,69E-02
Carbon dioxide, fossil	kg	2,67E+00	2,65E+00	1,62E-02
Carbon dioxide, land transformation	kg	1,48E-02	1,48E-02	1,71E-07
Carbon disulfide	kg	6,28E-06	6,28E-06	5,12E-09
Carbon monoxide	kg	1,56E-05	1,56E-05	0,00E+00
Carbon monoxide, biogenic	kg	2,30E-04	2,28E-04	2,34E-06
Carbon monoxide, fossil	kg	3,69E-03	3,68E-03	1,05E-05
Carbon monoxide, land transformation	kg	7,40E-05	7,40E-05	3,04E-10
Carbonyl sulfide	kg	1,45E-07	1,45E-07	4,70E-11
Carfentrazone-ethyl	kg	2,24E-11	2,24E-11	7,31E-17
Cerium-141	Bq	2,28E-05	2,27E-05	1,08E-07
Cesium-134	Bq	1,05E-05	1,05E-05	5,17E-09
Cesium-137	Bq	3,90E-05	3,89E-05	9,17E-08
Chloramine	kg	7,46E-10	7,46E-10	3,27E-15
Chloride	kg	3,38E-09	3,38E-09	0,00E+00
Chlorimuron-ethyl	kg	4,07E-10	4,07E-10	1,33E-15
Chlorinated solvents, unspecified	kg	1,49E-08	1,49E-08	3,82E-14
Chlorine	kg	1,66E-06	1,66E-06	1,62E-09
Chloroacetic acid	kg	4,66E-09	4,66E-09	6,30E-14
Chloroform	kg	2,30E-08	2,30E-08	1,82E-12
Chlorosilane, trimethyl-	kg	1,61E-10	1,61E-10	1,41E-13
Chlorosulfonic acid	kg	1,77E-10	1,77E-10	1,07E-15
Chlorpyrifos	kg	8,11E-09	8,11E-09	2,65E-14
Chromium	kg	1,75E-06	1,75E-06	2,89E-09
Chromium-51	Bq	1,46E-06	1,45E-06	6,92E-09
Chromium III	kg	1,00E-12	1,00E-12	0,00E+00
Chromium IV	kg	2,50E-15	2,50E-15	9,58E-20
Chromium VI	kg	4,76E-08	4,75E-08	8,15E-11
Chrysene	kg	2,87E-13	2,87E-13	1,45E-18
Clethodim	kg	1,20E-09	1,20E-09	3,93E-15
Cloransulam-methyl	kg	2,12E-10	2,12E-10	6,93E-16
Cobalt	kg	1,26E-07	1,26E-07	1,06E-10
Cobalt-58	Bq	2,90E-06	2,89E-06	9,67E-09
Cobalt-60	Bq	2,32E-05	2,31E-05	8,53E-08
Copper	kg	6,06E-06	6,06E-06	2,69E-09
Crotonaldehyde	kg	5,23E-09	5,23E-09	0,00E+00
Cumene	kg	6,25E-07	6,25E-07	3,34E-10
Cyanide	kg	2,99E-06	2,96E-06	2,89E-08
Cyanoacetic acid	kg	1,45E-10	1,45E-10	8,41E-16
Cyclohexane	kg	9,61E-11	9,61E-11	3,76E-15
Cyfluthrin	kg	4,25E-11	4,25E-11	1,39E-16
Cyhalothrin, gamma-	kg	4,87E-10	4,87E-10	1,59E-15
Cypermethrin	kg	1,03E-10	1,03E-10	3,37E-16
Decane	kg	2,82E-08	2,82E-08	0,00E+00
Dibenz(a,h)anthracene	kg	9,44E-14	9,44E-14	7,40E-18
Dicamba	kg	1,77E-10	1,77E-10	8,69E-16
Dichlorprop	kg	2,94E-12	2,94E-12	3,03E-17
Diethyl ether	kg	3,33E-10	3,33E-10	4,37E-17
Diethylamine	kg	4,41E-10	4,41E-10	2,83E-15
Diethylene glycol	kg	6,03E-12	6,03E-12	5,40E-16
Diflubenzuron	kg	2,24E-11	2,24E-11	7,31E-17

Dimethenamid	kg	2,51E-12	2,51E-12	2,65E-17
Dimethyl malonate	kg	1,81E-10	1,81E-10	1,05E-15
Dimethylamine	kg	6,41E-12	6,41E-12	1,71E-16
Dinitrogen monoxide	kg	4,61E-04	4,61E-04	7,43E-07
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	kg	9,78E-13	9,20E-13	5,75E-14
Dipropylamine	kg	2,53E-10	2,53E-10	1,62E-15
Esfenvalerate	kg	2,54E-10	2,54E-10	8,30E-16
Ethane	kg	9,01E-05	9,01E-05	3,53E-08
Ethane thiol	kg	2,13E-14	2,13E-14	0,00E+00
Ethane, 1,1-difluoro-, HFC-152a	kg	9,47E-08	9,47E-08	4,76E-12
Ethane, 1,1,1-trichloro-, HCFC-140	kg	4,41E-10	4,41E-10	3,71E-14
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	kg	1,89E-06	1,89E-06	1,04E-09
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	kg	1,85E-08	1,85E-08	1,56E-13
Ethane, 1,2-dichloro-	kg	4,17E-07	4,17E-07	9,80E-11
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	kg	2,46E-08	2,46E-08	2,13E-11
Ethane, 2-chloro-1,1,1,2-tetrafluoro-, HCFC-124	kg	1,78E-08	1,78E-08	1,29E-13
Ethane, hexafluoro-, HFC-116	kg	2,20E-08	2,20E-08	1,33E-11
Ethanol	kg	1,06E-06	1,06E-06	2,55E-10
Ethene	kg	1,20E-05	1,20E-05	5,07E-09
Ethene, chloro-	kg	2,03E-07	2,03E-07	5,88E-11
Ethene, tetrachloro-	kg	2,92E-09	2,92E-09	1,68E-13
Ethephon	kg	1,09E-16	1,09E-16	1,28E-21
Ethyl acetate	kg	2,26E-06	2,26E-06	4,39E-10
Ethyl cellulose	kg	1,78E-09	1,78E-09	8,85E-13
Ethylamine	kg	1,77E-08	1,77E-08	5,50E-15
Ethylene diamine	kg	1,64E-08	1,64E-08	1,32E-14
Ethylene oxide	kg	2,43E-08	2,43E-08	3,75E-12
Ethyne	kg	1,43E-06	1,43E-06	1,28E-10
Fenoxaprop	kg	3,32E-10	3,32E-10	1,09E-15
Fluazifop-p-butyl	kg	4,77E-10	4,77E-10	1,56E-15
Flufenacet	kg	1,79E-10	1,79E-10	5,85E-16
Flumetsulam	kg	4,18E-11	4,18E-11	1,37E-16
Flumiclorac-pentyl	kg	7,16E-11	7,16E-11	2,34E-16
Flumioxazin	kg	7,24E-10	7,24E-10	2,37E-15
Fluoranthene	kg	1,25E-12	1,25E-12	1,21E-16
Fluorene	kg	2,81E-12	2,81E-12	1,10E-16
Fluoride	kg	2,47E-09	2,47E-09	0,00E+00
Fluorine	kg	3,14E-07	3,12E-07	1,11E-09
Fluosilicic acid	kg	7,49E-08	7,49E-08	1,84E-11
Fomesafen	kg	2,69E-09	2,69E-09	8,80E-15
Formaldehyde	kg	1,22E-05	1,22E-05	1,80E-08
Formamide	kg	2,99E-10	2,99E-10	9,32E-16
Formic acid	kg	8,31E-07	8,31E-07	7,95E-12
Furan	kg	3,43E-06	3,43E-06	1,52E-11
Glyphosate	kg	5,38E-07	5,38E-07	1,76E-12
Heat, waste	MJ	1,17E+01	1,13E+01	3,11E-01
Helium	kg	1,77E-06	1,77E-06	5,75E-09
Heptane	kg	3,17E-05	3,17E-05	1,69E-08
Hexadecane	kg	4,99E-10	4,99E-10	0,00E+00
Hexamethylene diamine	kg	1,80E-15	1,80E-15	0,00E+00
Hexane	kg	5,44E-05	5,44E-05	3,72E-08
Hydrocarbons, aliphatic, alkanes, cyclic	kg	1,29E-04	1,29E-04	3,51E-11
Hydrocarbons, aliphatic, alkanes, unspecified	kg	1,97E-05	1,96E-05	1,10E-08
Hydrocarbons, aliphatic, unsaturated	kg	4,67E-06	4,67E-06	1,02E-09
Hydrocarbons, aromatic	kg	1,24E-05	1,24E-05	5,91E-09
Hydrocarbons, chlorinated	kg	4,02E-07	4,02E-07	4,08E-11
Hydrocarbons, unspecified	kg	6,96E-07	6,96E-07	2,26E-12
Hydrogen	kg	2,06E-05	2,06E-05	1,33E-08
Hydrogen-3, Tritium	Bq	4,15E+01	4,14E+01	1,65E-01
Hydrogen bromide	kg	1,93E-11	1,93E-11	0,00E+00
Hydrogen chloride	kg	1,35E-04	1,32E-04	3,98E-06
Hydrogen cyanide	kg	2,10E-12	2,10E-12	0,00E+00
Hydrogen fluoride	kg	2,56E-05	2,51E-05	5,61E-07
Hydrogen iodide	kg	2,12E-14	2,12E-14	0,00E+00
Hydrogen peroxide	kg	2,43E-09	2,43E-09	6,55E-13
Hydrogen sulfide	kg	1,54E-05	1,54E-05	3,40E-09
Imazamox	kg	1,07E-10	1,07E-10	3,50E-16
Imazaquin	kg	3,42E-10	3,42E-10	1,12E-15
Imazethapyr	kg	7,07E-10	7,07E-10	2,31E-15
Indeno(1,2,3-cd)pyrene	kg	8,80E-14	8,80E-14	2,91E-18
Iodide	kg	6,76E-13	6,76E-13	0,00E+00
Iodine	kg	6,20E-07	6,20E-07	2,01E-10
Iodine-129	Bq	3,95E-03	3,92E-03	2,82E-05
Iodine-131	Bq	1,01E-01	1,01E-01	3,96E-04
Iodine-133	Bq	2,04E-04	2,04E-04	5,92E-07
Iodine-135	Bq	4,44E-06	4,32E-06	1,22E-07
Iron	kg	2,39E-05	2,39E-05	2,21E-08
Isobutane	kg	2,49E-10	2,49E-10	0,00E+00
Isocyanic acid	kg	2,63E-06	2,63E-06	2,53E-11

Isopentane	kg	1,75E-09	1,75E-09	0,00E+00
Isoprene	kg	1,20E-08	1,20E-08	1,02E-13
Isopropylamine	kg	6,25E-09	6,25E-09	1,96E-15
Ketones, unspecified	kg	1,67E-08	1,67E-08	0,00E+00
Krypton-85	Bq	1,27E+03	1,27E+03	4,12E-03
Krypton-85m	Bq	1,85E+00	1,85E+00	6,47E-03
Krypton-87	Bq	3,10E-01	3,09E-01	1,46E-03
Krypton-88	Bq	4,06E-01	4,04E-01	1,91E-03
Krypton-89	Bq	1,70E-01	1,69E-01	8,05E-04
Lactic acid	kg	1,98E-10	1,98E-10	1,27E-15
Lactofen	kg	3,44E-10	3,44E-10	1,12E-15
Lambda-cyhalothrin	kg	3,46E-18	3,45E-18	4,05E-23
Lanthanum-140	Bq	8,04E-06	8,00E-06	3,81E-08
Lead	kg	1,91E-06	1,91E-06	1,27E-09
Lead-210	Bq	2,69E-01	2,69E-01	9,20E-05
Lead dioxide	kg	4,93E-15	4,93E-15	0,00E+00
Lithium	kg	2,44E-13	2,44E-13	9,36E-18
m-Xylene	kg	2,56E-07	2,56E-07	2,32E-11
Magnesium	kg	5,32E-06	5,30E-06	1,76E-08
Manganese	kg	6,49E-07	6,48E-07	9,74E-10
Manganese-54	Bq	7,48E-07	7,45E-07	3,54E-09
MCPB	kg	4,04E-12	4,04E-12	4,17E-17
Mercury	kg	6,96E-08	6,93E-08	2,90E-10
Methane	kg	2,11E-05	2,11E-05	1,87E-13
Methane, biogenic	kg	5,46E-03	2,07E-03	3,39E-03
Methane, bromo-, Halon 1001	kg	1,65E-14	1,65E-14	5,09E-19
Methane, bromochlorodifluoro-, Halon 1211	kg	1,00E-08	9,99E-09	3,45E-12
Methane, bromotrifluoro-, Halon 1301	kg	2,35E-08	2,35E-08	5,70E-11
Methane, chlorodifluoro-, HCFC-22	kg	1,20E-07	1,20E-07	2,09E-11
Methane, chlorotrifluoro-, CFC-13	kg	2,82E-11	2,82E-11	0,00E+00
Methane, dichloro-, HCC-30	kg	8,35E-09	8,35E-09	7,53E-13
Methane, dichlorodifluoro-, CFC-12	kg	9,93E-09	9,93E-09	3,88E-13
Methane, dichlorofluoro-, HCFC-21	kg	1,18E-11	1,18E-11	4,73E-16
Methane, fossil	kg	6,88E-03	6,78E-03	1,06E-04
Methane, land transformation	kg	5,82E-06	5,82E-06	3,14E-11
Methane, monochloro-, R-40	kg	1,17E-08	1,17E-08	9,90E-13
Methane, tetrachloro-, CFC-10	kg	5,90E-09	5,89E-09	1,36E-11
Methane, tetrafluoro-, CFC-14	kg	2,42E-07	2,42E-07	1,19E-10
Methane, trichlorofluoro-, CFC-11	kg	2,28E-10	2,28E-10	7,36E-16
Methane, trifluoro-, HFC-23	kg	3,76E-09	3,76E-09	1,51E-13
Methanesulfonic acid	kg	1,46E-10	1,46E-10	8,50E-16
Methanol	kg	4,67E-06	4,67E-06	1,23E-09
Methomyl	kg	3,73E-16	3,73E-16	4,38E-21
Methyl acetate	kg	2,33E-11	2,33E-11	1,33E-16
Methyl acrylate	kg	1,41E-10	1,40E-10	1,96E-13
Methyl borate	kg	1,22E-10	1,22E-10	3,89E-16
Methyl ethyl ketone	kg	2,26E-06	2,26E-06	4,39E-10
Methyl formate	kg	1,02E-10	1,02E-10	1,53E-15
Methyl lactate	kg	2,18E-10	2,18E-10	1,39E-15
Methyl methacrylate	kg	9,96E-16	9,96E-16	0,00E+00
Methylamine	kg	1,41E-10	1,41E-10	2,34E-15
Metolachlor	kg	5,64E-09	5,64E-09	1,85E-14
Metribuzin	kg	2,23E-09	2,23E-09	7,29E-15
Molybdenum	kg	6,81E-07	6,81E-07	7,29E-11
Monoethanolamine	kg	2,17E-06	2,17E-06	2,33E-11
N-octane	kg	5,23E-09	5,23E-09	0,00E+00
Naphthalene	kg	2,39E-11	2,39E-11	0,00E+00
Nickel	kg	1,59E-06	1,59E-06	1,25E-09
Niobium-95	Bq	7,47E-01	7,47E-01	1,13E-05
Nitrate	kg	3,22E-07	3,22E-07	2,10E-10
Nitric oxide	kg	2,63E-13	2,63E-13	0,00E+00
Nitrobenzene	kg	1,37E-09	1,37E-09	8,71E-15
Nitrogen dioxide	kg	1,48E-05	1,48E-05	0,00E+00
Nitrogen fluoride	kg	1,64E-12	1,64E-12	1,47E-16
Nitrogen oxides	kg	8,69E-03	8,66E-03	2,99E-05
Nitrogen, atmospheric	kg	3,30E-06	3,30E-06	1,02E-10
NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1,67E-03	1,66E-03	8,93E-06
Noble gases, radioactive, unspecified	Bq	3,73E+04	3,70E+04	2,71E+02
Nonane	kg	1,25E-08	1,25E-08	0,00E+00
o-Xylene	kg	7,44E-08	7,44E-08	2,80E-12
Octadecane	kg	4,99E-10	4,99E-10	0,00E+00
Organic carbon	kg	3,55E-09	3,55E-09	1,36E-13
Oxygen	kg	5,11E-06	5,11E-06	0,00E+00
Ozone	kg	1,01E-05	1,01E-05	8,70E-09
p-Xylene	kg	1,57E-12	1,57E-12	0,00E+00
PAH, polycyclic aromatic hydrocarbons	kg	4,15E-07	4,14E-07	7,02E-10
Palladium	kg	1,81E-17	1,81E-17	0,00E+00
Paraffins	kg	8,75E-09	8,75E-09	3,19E-13

Paraquat	kg	1,43E-09	1,43E-09	4,69E-15
Parathion, methyl	kg	2,75E-10	2,75E-10	9,00E-16
Particulates, < 10 um	kg	6,34E-04	6,34E-04	0,00E+00
Particulates, < 2.5 um	kg	1,37E-03	1,37E-03	2,55E-06
Particulates, > 10 um	kg	1,87E-03	1,87E-03	1,07E-06
Particulates, > 2.5 um, and < 10um	kg	6,76E-04	6,75E-04	5,49E-07
Pendimethalin	kg	1,51E-08	1,51E-08	4,96E-14
Pentane	kg	4,96E-05	4,95E-05	9,53E-08
Pentane, 3-methyl-	kg	1,55E-09	1,55E-09	5,65E-14
Permethrin	kg	2,25E-10	2,25E-10	7,34E-16
Phenanthrene	kg	1,46E-11	1,46E-11	1,70E-15
Phenol	kg	5,55E-07	5,55E-07	9,74E-11
Phenol, 2,4-dichloro-	kg	4,74E-10	4,74E-10	2,28E-15
Phenol, pentachloro-	kg	3,31E-08	3,31E-08	9,51E-12
Phosphate	kg	1,40E-12	1,40E-12	0,00E+00
Phosphine	kg	3,84E-09	3,84E-09	3,43E-13
Phosphoric acid	kg	2,97E-12	2,97E-12	2,66E-16
Phosphorus	kg	3,43E-07	3,42E-07	9,09E-10
Phosphorus trichloride	kg	1,46E-09	1,46E-09	1,53E-13
Platinum	kg	5,31E-14	5,26E-14	4,73E-16
Plutonium-238	Bq	5,29E-10	5,25E-10	3,85E-12
Plutonium-alpha	Bq	3,81E-09	3,80E-09	8,82E-12
Polonium-210	Bq	4,78E-01	4,78E-01	1,55E-04
Polychlorinated biphenyls	kg	5,36E-10	5,35E-10	8,24E-13
Potassium	kg	1,84E-05	1,84E-05	1,67E-08
Potassium-40	Bq	9,23E-02	9,23E-02	1,59E-05
Propanal	kg	2,02E-08	2,02E-08	2,06E-12
Propane	kg	5,75E-05	5,74E-05	7,76E-08
Propene	kg	3,76E-06	3,76E-06	3,81E-09
Propiconazole	kg	2,64E-10	2,64E-10	8,62E-16
Propionic acid	kg	1,59E-07	1,59E-07	3,92E-11
Propylamine	kg	1,02E-10	1,02E-10	4,17E-16
Propylene oxide	kg	1,67E-07	1,67E-07	8,69E-11
Propyne	kg	2,00E-09	2,00E-09	0,00E+00
Protactinium-234	Bq	4,32E-03	4,31E-03	5,43E-06
Prothioconazol	kg	9,53E-18	9,53E-18	1,12E-22
Pyraclostrobin (prop)	kg	6,21E-10	6,21E-10	2,03E-15
Pyrene	kg	3,69E-13	3,69E-13	8,86E-17
Quizalofop ethyl ester	kg	8,34E-11	8,34E-11	2,73E-16
Radioactive species, other beta emitters	Bq	7,11E+01	7,11E+01	3,19E-03
Radium-226	Bq	1,93E-01	1,93E-01	1,91E-04
Radium-228	Bq	7,09E-02	7,09E-02	1,64E-05
Radon-220	Bq	1,97E+00	1,97E+00	5,19E-04
Radon-222	Bq	1,43E+05	1,42E+05	6,86E+02
Rhodium	kg	1,75E-17	1,75E-17	0,00E+00
Ruthenium-103	Bq	1,95E-08	1,94E-08	9,24E-11
Scandium	kg	1,41E-08	1,41E-08	6,31E-11
Selenium	kg	1,53E-07	1,53E-07	8,30E-11
Sethoxydim	kg	1,79E-10	1,79E-10	5,87E-16
Silicon	kg	4,28E-05	4,28E-05	5,59E-08
Silicon tetrachloride	kg	1,79E-10	1,79E-10	3,10E-14
Silicon tetrafluoride	kg	3,84E-10	3,84E-10	1,14E-13
Silver	kg	1,82E-08	1,82E-08	2,75E-12
Silver-110	Bq	3,48E-07	3,47E-07	9,21E-10
Sodium	kg	4,02E-06	3,93E-06	9,08E-08
Sodium chlorate	kg	7,81E-09	7,81E-09	1,53E-12
Sodium dichromate	kg	9,45E-09	9,44E-09	1,50E-11
Sodium formate	kg	6,38E-10	6,38E-10	8,14E-14
Sodium hydroxide	kg	6,83E-09	6,82E-09	2,44E-12
Sodium tetrahydroborate	kg	1,09E-09	1,09E-09	9,76E-14
Strontium	kg	4,60E-07	4,59E-07	2,10E-10
Styrene	kg	1,65E-06	1,65E-06	9,63E-12
Sulfate	kg	1,94E-05	1,94E-05	2,87E-08
Sulfentrazone	kg	1,72E-09	1,72E-09	5,61E-15
Sulfur dioxide	kg	6,52E-03	6,51E-03	9,32E-06
Sulfur hexafluoride	kg	2,58E-07	2,58E-07	9,03E-11
Sulfur oxides	kg	7,90E-05	7,90E-05	2,20E-11
Sulfur trioxide	kg	1,03E-08	1,03E-08	1,34E-13
Sulfuric acid	kg	1,29E-07	1,29E-07	4,09E-12
t-Butyl methyl ether	kg	2,91E-08	2,91E-08	5,71E-12
t-Butylamine	kg	6,22E-09	6,22E-09	2,39E-15
Tar	kg	5,58E-16	5,58E-16	0,00E+00
Tebuconazole	kg	2,54E-17	2,54E-17	2,98E-22
Tefluthrin	kg	6,44E-13	6,44E-13	6,79E-18
Tellurium	kg	4,19E-14	4,19E-14	0,00E+00
Terpenes	kg	1,13E-07	1,13E-07	9,60E-13
Tetramethyl ammonium hydroxide	kg	3,94E-08	3,94E-08	3,53E-12
Thallium	kg	1,48E-09	1,48E-09	3,16E-12
Thifensulfuron	kg	2,45E-11	2,45E-11	8,00E-17

Thiodicarb	kg	8,72E-11	8,72E-11	2,85E-16
Thorium	kg	1,99E-09	1,99E-09	4,11E-13
Thorium-228	Bq	1,72E-02	1,72E-02	3,48E-06
Thorium-230	Bq	8,17E-03	8,15E-03	1,96E-05
Thorium-232	Bq	2,09E-02	2,09E-02	4,45E-06
Thorium-234	Bq	4,32E-03	4,31E-03	5,43E-06
Tin	kg	5,15E-07	5,15E-07	1,72E-10
Tin oxide	kg	4,29E-16	4,29E-16	0,00E+00
Titanium	kg	8,64E-07	8,58E-07	5,84E-09
Toluene	kg	1,21E-05	1,20E-05	6,00E-08
Toluene, 2-chloro-	kg	5,09E-10	5,09E-10	3,21E-15
Toluene, 2-ethyl-	kg	2,74E-09	2,74E-09	0,00E+00
Toluene, 3-ethyl-	kg	6,48E-09	6,48E-09	0,00E+00
Toluene, 4-ethyl-	kg	2,99E-09	2,99E-09	0,00E+00
Trifloxystrobin	kg	1,57E-11	1,57E-11	5,12E-17
Trifluralin	kg	2,47E-08	2,47E-08	8,08E-14
Trimethylamine	kg	4,88E-11	4,88E-11	2,75E-16
Tungsten	kg	1,48E-09	1,47E-09	7,10E-12
Uranium	kg	2,83E-09	2,83E-09	4,93E-13
Uranium-234	Bq	1,99E-02	1,98E-02	6,10E-05
Uranium-235	Bq	9,43E-04	9,40E-04	2,93E-06
Uranium-238	Bq	7,36E-02	7,35E-02	7,27E-05
Uranium alpha	Bq	7,07E-02	7,04E-02	2,83E-04
Used air	kg	3,60E-02	3,60E-02	0,00E+00
Vanadium	kg	2,31E-06	2,31E-06	1,82E-09
VOC, volatile organic compounds	kg	3,48E-08	3,48E-08	0,00E+00
Water	kg	1,79E-02	1,79E-02	3,99E-08
Water/m3	m3	1,68E-02	1,68E-02	1,12E-06
Xenon-131m	Bq	1,63E+00	1,62E+00	7,63E-03
Xenon-133	Bq	8,93E+01	8,90E+01	2,80E-01
Xenon-133m	Bq	6,44E-02	6,41E-02	2,89E-04
Xenon-135	Bq	3,19E+01	3,18E+01	1,12E-01
Xenon-135m	Bq	1,49E+01	1,48E+01	7,02E-02
Xenon-137	Bq	4,65E-01	4,63E-01	2,20E-03
Xenon-138	Bq	3,48E+00	3,47E+00	1,65E-02
Xylene	kg	1,03E-05	1,02E-05	4,93E-08
Zinc	kg	4,78E-06	4,77E-06	7,19E-09
Zinc-65	Bq	3,74E-06	3,72E-06	1,77E-08
Zinc oxide	kg	8,58E-16	8,58E-16	0,00E+00
Zirconium	kg	2,32E-10	2,31E-10	8,17E-13
Zirconium-95	Bq	6,50E-06	6,49E-06	1,74E-08