UNIVERSITÀ DEGLI STUDI DI PADOVA

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DIPARTIMENTO DI INGEGNERIA INDUSTRIALE DII

CORSO DI LAUREA MAGISTRALE IN INGEGNERIA CHIMICA E DEI PROCESSI INDUSTRIALI

Tesi di Laurea Magistrale in
Ingegneria Chimica e dei Processi Industriali

A new model to address nitrogen related impacts in a life cycle perspective: the case of Sammontana S.p.A

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Anno Accademico 2022/2023

Ringraziamenti

Mi sento in dovere di dedicare questa pagina del presente elaborato alle persone che mi hanno supportato nella redazione dello stesso.

Innanzitutto, ringrazio il mio relatore Alessandro Manzardo e il mio correlatore Filippo Zuliani, sempre pronti a darmi le giuste indicazioni in ogni fase della realizzazione dell'elaborato. Grazie a voi ho accresciuto le mie conoscenze e le mie competenze.

Un ringraziamento speciale va al mio Tutor Gianluca Nocciolini che mi ha aiutato a condurre le ricerche, oggetto dell'elaborato, presso l'azienda Sammontana S.p.A.

Ringrazio tutto lo staff dell'azienda Sammontana S.p.A, in cui ho svolto un tirocinio formativo della durata di 9 mesi e complementare alla redazione della tesi, per l'ospitalità e per le skills acquisite sul campo.

Non posso non menzionare i miei genitori e i miei nonni che da sempre mi sostengono nella realizzazione dei miei progetti. Non finirò mai di ringraziarvi per avermi permesso di arrivare fin qui.

Grazie ai miei amici per essere stati sempre presenti anche durante questa ultima fase del mio percorso di studi.

Riassunto

Per millenni l'azoto reattivo (Nr), definito come tutte le specie contenenti azoto tranne il N_2, si è formato a seguito di fenomeni naturali (fulmini e fissazione biologica dell'azoto) a partire dall'N_2 disponibile. Tuttavia, dalla metà del ventesimo secolo, le attività umane hanno più che raddoppiato gli input di azoto negli ecosistemi attraverso processi artificiali di fissazione dell'azoto per produrre fertilizzanti per aumentare la produttività delle colture, la semina di piante azotofissatrici e la combustione di combustili fossili. Tutti questi fenomeni sono stati fondamentali per la crescita della popolazione umana, ma comportano un rilascio di Nr il quale, in eccesso, perturba il processo con cui la natura bilancia la disponibilità di azoto nell'aria, nell'acqua e nel suolo portando a conseguenze dannose come: acidificazione del suolo ed eutrofizzazione, perdita di biodiversità, cambiamenti climatici, formazione di ozono troposferico. Per valutare l'alterazione subita dal ciclo dell'azoto dovuta all'influenza delle attività umane generalmente si utilizza il concetto di "nitrogen footprint". Essa è definita come la quantità totale di azoto reattivo rilasciato nell'ambiente a causa del consumo di risorse, espresso in unità totali di azoto reattivo. Attualmente sono state definite diverse metodologie per quantificare la nitrogen footprint valutando come l'uso di risorse da parte dei consumatori, delle istituzioni, delle nazioni e di altre entità comporta perdite di Nr nell'ambiente. Lo scopo di questo lavoro è di applicare una metodologia innovativa sviluppata da all'interno di un gruppo di ricerca dell'Università di Padova, che, analizzando le debolezze degli strumenti esistenti, ha proposto una valutazione gli impatti ambientali legati al ciclo dell'azoto secondo gli standard internazionale della serie ISO 14040, utilizzando una struttura basata sulle procedure della valutazione dell'impatto del ciclo di vita (Life Cycle Assessment LCA).

Il caso studio proposto in questo lavoro riguarda i prodotti di Sammontana, un'importante azienda italiana che si occupa di produzione di gelati e pasticceria. Sammontana è una delle principali aziende nella produzione di gelati e pasticceria in Italia, con oltre 1000 dipendenti e diversi siti produttivi. Seguendo l'attenzione crescente che aziende come Sammontana stanno dedicando alle conseguenze ambientali delle loro attività, in questo lavoro viene effettuata una valutazione a livello di impatto delle emissioni legate alle sostanze contenenti azoto di quattro prodotti Sammontana durante il loro ciclo di vita. Attraverso il metodo proposto, è possibile ottenere informazioni valide sugli impatti legati all'azoto relativi al sistema produttivo di Sammontana, evidenziando anche in quale dei due settori (gelato o pasticceria) l'impatto è maggiore e in quale fase si hanno i maggiori contributi.

In particolare, i sistemi produttivi analizzati possono essere descritti come segue:

- "Barattolino Crema" commercializzato in singola confezione per la grande distribuzione organizzata (GDO) prodotta nello stabilimento di Empoli (FI);
- "Biscotto Amando Vaniglia e Frutti di Bosco" commercializzato sia in confezione da 4 pezzi per la GDO che in confezione da 18 pezzi per il canale Horeca. Sono prodotti nello stabilimento di Empoli (FI);
- "Croissant Vegano Albicocca" commercializzato in unità di vendita da 50 pezzi per il canale Horeca e prodotto nello stabilimento di Vinci (FI) (Figura 12);
- "Fagottino Crema" commercializzato in unità di vendita da 6 pezzi prodotta per la GDO nello stabilimento di Vinci (FI).

Il Capitolo 1 affronta brevemente quali sono le principali conseguenza legate ad un'alterazione del ciclo dell'azoto. Nel Capitolo 2 viene presentata una descrizione dettagliata del metodo applicato, affrontando tutti i passaggi che verranno effettuati nel caso studio. Infine, il Capitolo 3 contiene una prima presentazione dei sistemi produttivi studiati e successivamente valuta l'applicazione del metodo proposto a tali sistemi, insieme ai risultati e alle discussioni correlate.

L'applicazione del metodo comporta una serie di passaggi differenti, ognuno correlato ad un determinato output: quantificazione delle sostanze azotate in inventario, valutazione dell'indicatore dell'azoto reattivo, profilo di valutazione degli impatti e indicatore di impatto a punteggio singolo. Per quantificare le sostanze azotate in inventario, è stata effettuata una prima selezione dell'inventario complessivo e successivamente sono state considerate solo le sostanze azotate al suo interno. Successivamente, sviluppando l'indicatore dell'azoto reattivo, è stata effettuata una valutazione indicativa delle emissioni di sostanze contenenti azoto. È stato analizzato non solo il contributo di tutto il sistema produttivo per ogni prodotto, ma anche l'influenza delle diverse fasi di cui è composto (produzione delle materie prime, produzione degli imballaggi, processo produttivo, distribuzione, fase di utilizzo e fine vita). Da questa valutazione, i risultati mostrano come la fase di produzione delle materie prime, o in altre parole l'emissione di sostanze contenenti azoto causata dalla produzione e distribuzione di materie prime fino in stabilimento, contribuisca maggiormente al rilascio di azoto reattivo nell'ambiente.

Per ottenere il profilo di valutazione degli impatti, sono state scelte diverse categorie d'impatto che esprimono le alterazioni causate al ciclo dell'azoto. È stata quindi quantificata l'influenza che ogni sistema produttivo ha su queste categorie d'impatto e successivamente, al fine ottenere un valore che complessivamente rappresenti questi risultati sono stati calcolati gli indicatori di azoto a punteggio singolo per ogni processo produttivo. Per i prodotti del settore gelato, i risultati ottenuti mostrano un impatto maggiore legato al Barattolino Crema rispetto al Biscotto Amando. Per i prodotti del settore pasticceria, invece, i punteggi singoli possono essere considerati equivalenti.

In conclusione, questo lavoro confronta i risultati ottenuti in termini di Nitrogen Footprint per il Barattolino Crema e il Fagottino Crema con la valutazione già effettuata da Sammontana, analizzando i risultati dell'indicatore della Carbon Footprint. È infatti possibile utilizzare i risultati dell'indicatore dell'azoto reattivo come rappresentativi della Nitrogen Footprint per i prodotti in esame dato che presentano gli stessi risultati. Vale la pena notare che, sulla base del confronto citato sopra, la Carbon Footprint indica che la fase di produzione delle materie prime è la maggiore fonte di impatti come d'altronde ottenuto dai risultati dell'indicatore della Nitrogen Footprint. Tuttavia, a differenza dei risultati ottenuti dalla Nitrogen Footprint, nella Carbon Footprint un maggiore peso è dato da tutte le altre fasi, come la produzione degli imballaggi e la fase di distribuzione, che hanno una significativa influenza sull'indicatore. I prodotti di Sammontana, come si è osservato nel seguente lavoro, sono strettamente legati a processi agricoli, che presentano le maggiori emissioni di azoto reattivo e di conseguenza influenzano maggiormente gli impatti legati alla perturbazione del ciclo dell'azoto. Pertanto, i risultati presentati in questo studio guideranno le decisioni di Sammontana e miglioreranno la loro comprensione degli impatti dei loro prodotti. Questa tipologia di studi, in seguito al continuo aumento dell'azoto reattivo rilasciato attribuibile all'aumento della popolazione, si presume assumeranno una maggiore rilevanza in futuro, rendendo di conseguenza sempre più necessari strumenti, come quello qui descritto, per valutare dove concentrare gli sforzi per ridurre gli impatti legati all'alterazione del ciclo dell'azoto.

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Abstract

The disruption of the nitrogen cycle by anthropogenic sources has become an increasingly serious threat in recent years. Various methodologies have been developed to evaluate the impact of human activities on the natural balance of nitrogen substances exchanged within the environment. One such methodology is the concept of Nitrogen Footprint, which refers to the total amount of reactive nitrogen released to the environment due to resource consumption, expressed in total units of reactive nitrogen.

A research group at the University of Padova has developed a model that integrates the current definition of nitrogen footprint in the literature with an identification of the environmental impacts related to the nitrogen cycle for a product system following a Life Cycle Assessment (LCA) approach. The application of the method also allows the quantification of the contribution of different processes and activities in their life cycle.

The focus of this thesis work is on a case study in which the proposed method is applied. The method proposed assesses the impact of four products from Sammontana S.p.A., one of the leading firms in the Italian industry of ice cream and pastry products. The proposed method has been successfully tested in evaluating the impacts related to the nitrogen cycle alteration generated by the product systems in their life cycles, identifying critical issues, and assessing associated risks and opportunities. A comparison has also been carried out with results obtained from Sammontana's Carbon Footprint analysis developed on these products.

Introduction

For millennia reactive nitrogen (Nr), defined as all nitrogen-containing species except N_2, was formed by lighting and biological nitrogen fixation starting from the available N_2. Nr concentration was balanced by deep sedimentation and the conversion of Nr back to N_2 by environmental processes like ammonification and denitrification, leading to little accumulation of Nr in environmental reservoirs (Galloway et al., 2014). However, since the middle of the twentieth century, human activities have more than doubled nitrogen inputs to ecosystems through artificial nitrogen-fixing processes to produce fertilizers to increase crop productivity, planting of nitrogen-fixing plants and burning of fossil fuels. This increase has been fundamental for the human population growth but an excess of this substances disrupt the process with which nature balances nitrogen availability within air, water and soil leading to harmful consequences like: soil acidification and eutrophication, loss of biodiversity, climate change, tropospheric ozone formation… (McCourt & MacDonald, 2021).

To assess the alteration undergone by the nitrogen cycle due to the influence of human activities generally the concept of "nitrogen footprint" is used. It is defined as the total amount of reactive nitrogen released to the environment due to the resource consumption, expressed in total units of reactive nitrogen (Leach et al., 2012). Currently several approaches has been defined to quantify the nitrogen footprint (N-Calculator, N-Institution, N-Label …). These tools have been developed to demonstrate how resource use by consumers, institutions, nations, and other entities results in Nr losses to the environment, and to examine how policy can affect these losses. (Galloway et al., 2014).

The purpose of this work is to apply an innovative methodology developed by a research group at the University of Padova. The group analysed the weaknesses of existing tools and proposed an assessment for evaluating environmental impacts related to the nitrogen cycle, in accordance with the international standard of ISO 14040 series. The assessment uses a structure oriented toward life cycle impact assessment.

The case study proposed in this work regards Sammontana’s products. Sammontana is one of the leading firms regarding ice crem and pastry production in Italy with more than 1000 employees and 4 different production sites. Over the years, Sammontana has adopted a sustainable management approach starting from the analysis of the environmental performance of its products and has embarked on a path in line with the provisions of the Kyoto Protocol and international climate and energy standards.

Following the increasing attention that companies like Sammontana are paying to the environmental consequences of their operations, throughout this work, an assessment at impact level of the emissions related to nitrogen-containing substances of four Sammontana's product during their life cycle is observed. Through the method proposed valid information about nitrogen related impacts related to Sammontana's product system can be obtained highlighting also in which of the two sectors (ice cream or pastry) is more influent and also in which phase large contributes came from.

Specifically, the analysed product systems can be described as follows:

- "Barattolino Crema" commercialised in single bucket produced for the large-scale distribution (LSD) in Empoli (FI) plant;
- "Biscotto Amando Vaniglia e Frutti di Bosco" commercialised in both 4 pieces pack for the LSD and 18 pieces pack for Horeca channel. They are produced in Empoli (FI) plant;
- "Croissant Vegano Albicocca" commercialised in selling unit of 50 pieces for Horeca channel and produced in Vinci (FI) plant (Figure 12);
- "Fagottino Crema" commercialised in selling unit of 6 pieces produced for the LSD in Vinci (FI) plant.

Chapter 1 briefly analyses the problems that are currently associated with the nitrogen cycle and its disruption. This part is important in order to understand how serious nitrogen cycle disruption is becoming. Chapter 2 provides a detailed description of the method used, addressing all the steps taken in the case study. In Chapter 3, the product systems under study are presented, followed by the application of the proposed method to those product systems, along with related results and discussions

The Company: Sammontana S.p.A

The story of Sammontana began in 1946 in Empoli, in the province of Florence, where Renzo Bagnoli converted the family dairy into a bar-ice cream parlor, giving it the name of the nearby Sammontana farm from which the Bagnoli family supplied fresh milk. The transformation into an artisan workshop in 1948, which allowed the company to start distributing its products outside Empoli (thanks also to the start of the mechanized production), marks the fundamental and necessary step for Sammontana to be able to start obtaining results that today allow it to be among the leading Italian companies in the sector. In 2008 the consolidation process in the industrial ice cream market was confirmed with the acquisition of the GranMilano brand, which led Sammontana S.p.A. to also control the Sanson, Ringo and Togo brands.

Sammontana S.p.A. has always carried out its activities in respect and protection of the environment. Over the years, it has set itself a further objective to adopt a sustainable management approach starting from the analysis of the environmental performance of its products and has embarked on a path in line with the provisions of the Kyoto Protocol and international climate and energy standards. In order to give greater importance to its commitment to the environment, in July 2016 sign a voluntary agreement with the Ministry of the Environment, within the National Program for the assessment of the environmental footprint and renewed it in 2021 with the Ministry of Ecological Transition, with which undertakes a study of its emissions through Life Cycle Assessment.

This journey began with the analysis of the Carbon Footprint of the entire life cycle (LCA) of the iconic and most representative product of the company, Barattolino, to which were added the analyzes on Fruttiamo and Amando. The CO_2eq emissions identified by the Carbon Footprint analysis and not avoidable were neutralized through the purchase and withdrawal of verified Carbon Credits.

In 2019, the Agreement was renewed and expanded to include Sammontana's commitment to a circular economy model on which progress is constant. In 2021, the Agreement was renewed with the Ministry of Ecological Transition and expanded to the study of frozen pastry products.

Chapter One
The Nitrogen Cycle:
Changes and Consequences

This chapter will provide a brief explanation of the processes that characterize the nitrogen cycle, i.e. the system of reactions that allow its recirculation mainly between the atmosphere, the ground and living beings. In addition, the various effects generated by its alteration due mainly to human activities will also be listed.

1.1 The nitrogen cycle

Nitrogen is a common element that in fact compose 78% of the air we breathe, but it is in a form that plants and animals can't use. Dinitrogen molecules are formed by a triple bond between two nitrogen atom. This bond is one of the strongest in nature requiring 9.8 eV to be broken.

Naturally, two processes are able to break that bond. At first there are lighting, which break into two nitrogen atom the N_2 molecule. Then they quickly react to form nitrogen oxide (NO), that stay in atmosphere until water within clouds absorb them and rain bring them to the soil.

Secondly there are a few type of bacteria living in soil that breaking the N_2 bond, provide nitrogen for plants. They are able to fix NH_4^+ from dinitrogen. One example of nitrogen-fixing prokaryotes are Rhizobium, which live in symbiosis with leguminous plants such as peas, clover, soybeans, giving to plants the nitrogen required and, in exchange, prokaryotes obtain carbon and energy to grow. Both lighting and bacteria are main source of usable nitrogen and are examples of reactions that constitute the so called nitrogen cycle.

The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates among atmospheric, terrestrial, and marine ecosystems. The conversion of nitrogen can be carried out through both biological and physical processes.

Reactive nitrogen is the terms use to define all nitrogen forms apart from N_2 including oxidized nitrogen forms, as NO, N_2O, NO_2, NO_3^-, reduced forms of nitrogen, as NH_4^+, NH_3 , and organic nitrogen as proteins, amines, etc., with different states of oxidation.

In particular, the nitrogen cycle is made up of processes like fixation, ammonification, nitrification, and denitrification which will be clarified later.

In Figure 1, a simple representation of the connection between the nitrogen cycle processes above presented is done, showing also how the N is transformed from an inorganic compound to an organic one able to be used by the environment.

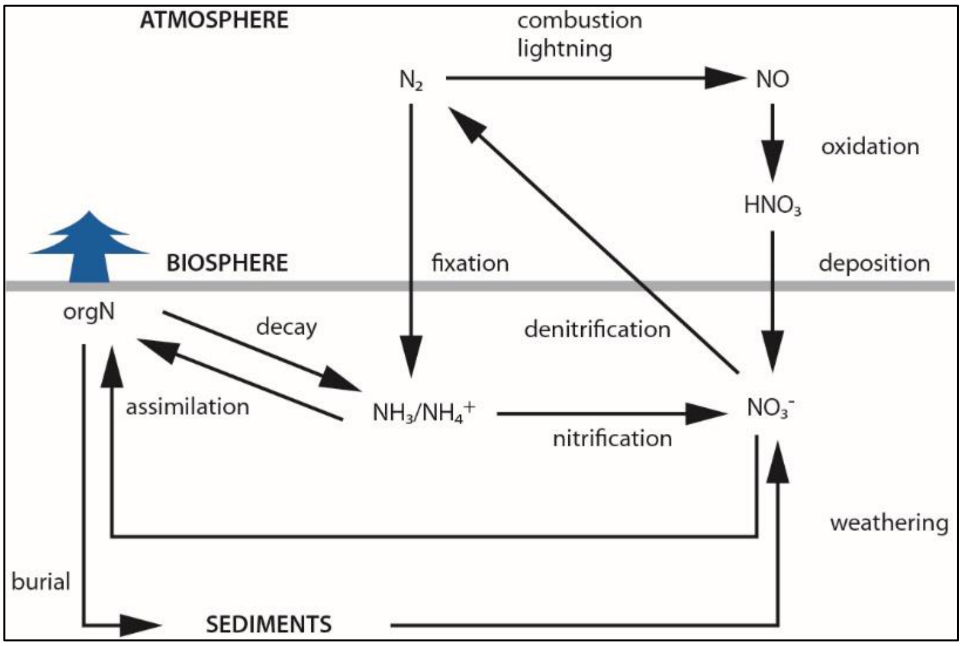


Figure 1: Nitrogen Cycle major processes. (OECD, 2018)

As in lighting, biological nitrogen fixation is the process able to convert the highly stable inert dinitrogen (N_2) molecule to a biologically available ("reactive") nitrogen, in soil or aquatic systems. This is done by specialized bacteria able to obtain reduced compound as NH_3 and NH_4^+ . (OECD, 2018)

NH_3 /NH_4^+ produced by bacteria can then be assimilated by plants as organic nitrogen (any organic compound that contain nitrogen such as amino acids, proteins, nucleotides…). Animals took them eating plants. When animals die or remove the nitrogen they take in, they return the initial nitrogen to the soil, which is mineralized by bacteria into NH_3 /NH_4^+ .

Another route to form organic nitrogen is nitrification, an aerobic process performed by bacteria in which NH_3 /NH_4^+ are used as a source of energy by oxidizing it to nitrite NO_2^- and nitrate NO_3^-. NO_3^- is then easily assimilated by plants and bacteria through soil.

When oxygen is depleted in water and soil (anaerobic conditions), bacteria may use NO_3^- as an alternative oxidant to convert organic carbon to carbon dioxide (CO_2). This process is called denitrification and converts NO_3^- into N_2 which is released in the atmosphere. Denitrification produces also some gaseous nitrous oxide (N_2O) and nitric oxide (NO).

To summarize, those biogeochemical processes control the amount and the form of the N available for the environment. Additionally, they can be divide into two main groups: processes which regulate input and outputs of N creating and destroying it and processes that instead transform N among its different forms and transport it, while neither creating nor destroying it and thus not altering the size of the fixed N reservoir. In the first group, fixation operations (lighting and bacteria) are present. In the second instead, all the phases that favor the recycling of N nutrient are considered (X. Zhang et al., 2020).

1.2 The nitrogen usage over the years

Nitrogen-rich manure has been used to fertilize crops for millennia. Then, in the 1800s, the role of nitrogen as a crop nutrient was explored scientifically developing a market for mineralized guano form South America and the South Pacific Islands (the latter was so important that brings South America nations to the War of Pacific in the 1879).

In the early 1900s, industrial processes for fixing nitrogen, especially the Haber-Bosch process, greatly expanded the availability of nitrogen-based fertilizers. Haber-Bosch process was so important that led Fritz Haber to the Nobel Prize in 1918 and helped population exponential growth in that century.

Subsequently, as highlighted in Figure 2, over the last 50 years the increased use of synthetic fertilizer, increased cultivation of nitrogen-fixing crops and increase emissions of NO_x all contribute to raise the overall amount of reactive nitrogen in the environment (Battye et al., 2017).

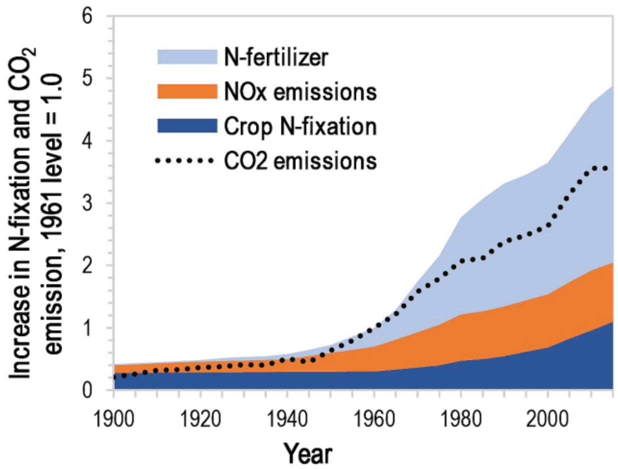


Figure 2: Trends in anthropogenic reactive nitrogen sources since 1900 compared with the trend in anthropogenic CO_2 emissions (Battye et al., 2017)

Regarding global NO_x emission, the trajectory has still grown even if U.S. and Europe have applied more stringent regulation in substantial emission reductions. However, emissions continue to increase in the developing world, especially China (Dentener et al., 2010).

Underling the increased use of synthetic fertilizer, estimates (Erisman et al., 2008) evaluate that around half of the nitrogen in the protein that humans eat today got into that food by way of artificial fertilizer.

1.3 Anthropogenic influence on the nitrogen cycle

Addressing now problems related to anthropogenic nitrogen usage, Figure 3 shows which are the main sources, assigning also a quantitative value at the total (black numbers) and anthropogenic (red numbers) contribution that can be used to extract a qualitative consideration. To be more specific, anthropogenic nitrogen pollution sources can be classified in two main groups: oxidized nitrogen and reduced nitrogen. Oxidized nitrogen comes predominantly from burning fossil fuels (vehicle exhaust, power generator,…). Reduced nitrogen, instead, comes from agriculture sources (fertilizer, volatilization of animal waste, biomass burning) (Fowler et al., 2013).

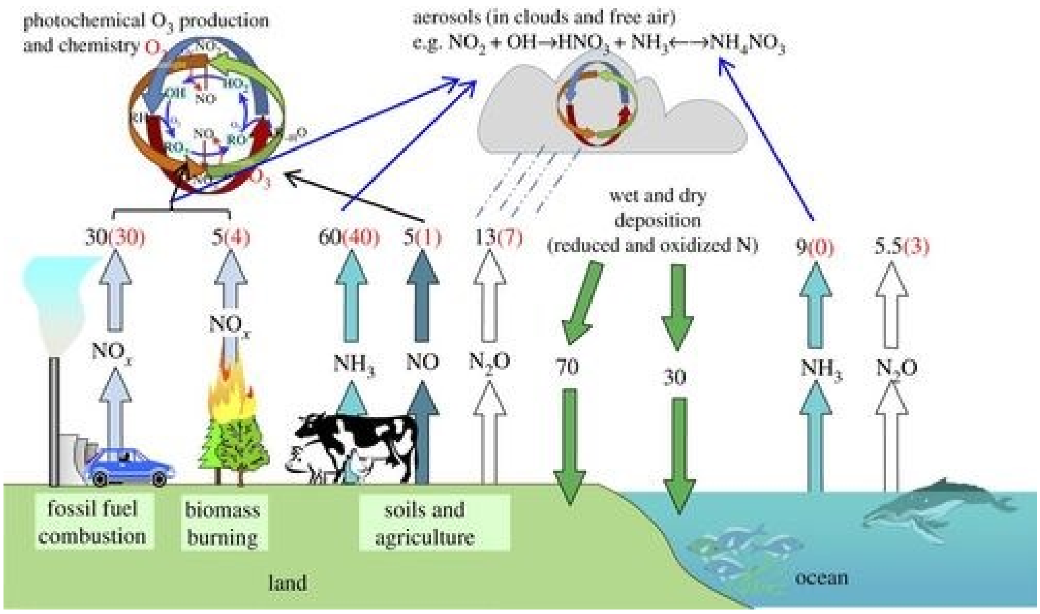


Figure 3: The global atmospheric processing of reactive nitrogen, illustrating the main sources, the main chemical pathways and products and the magnitudes of the fluxes (units Tg yr^{-1}). The emission values in black are the total fluxes while the red values indicate the anthropogenic contribution (Fowler et al., 2013)

So, based on literature (Fowler et al., 2013), qualitative considerations about anthropogenic sources of reactive nitrogen can be done. In fact, NO_x can be exclusively ascribed to human origin. Also other sources shows a large reactive nitrogen emission driven by anthropogenic sources like NH_3 from agricultural sources and, on the other hand, ocean reactive nitrogen compounds release are much more driven by natural sources.

Afterwards, the majority of anthropogenic reactive nitrogen components emitted can enter terrestrial and marine ecosystems via atmospheric N deposition. (Q. Zhang et al., 2021) This process happens via precipitation (wet deposition) or as gases and particles (dry deposition).

Nitrogen deposition is important for ecosystem health but an excessive atmospheric nitrogen concentration can sinks into nitrogen limited ecosystems, leading to unintentional fertilization and loss of biodiversity (OECD, 2018). Consequently, the health of the ecosystem start to decline generating environmental problems like soil acidification, eutrophication etc….

In fact, as with terrestrial ecosystems, many of coastal ecosystems are nitrogen-limited, such that abundance in nitrogen leads to algal blooms and a decline in the quality of aquatic ecosystems (OECD, 2018).

In terms of soil and agriculture areas, synthetic nitrogen fertilizer and the anthropogenic cultivation of nitrogen-fixing crops both increase the overall amount of biologically available nitrogen compounds. This nitrogen is supposed to remain within the farm system, but instead, a substantial portion of the reactive nitrogen (∼70%) escapes to the surrounding environment worsening problems already mentioned (Battye et al., 2017).

Another study (OECD, 2018). estimates that anthropogenic and natural fixed amount of N are quantitively similar. In fact, as shown in Figure 4, roughly 200 Tg yr^{-1} comes from both fixation processes.

Mechanism	Amount[1] (million tonnes N per year)
Terrestrial pre-industrial biological fixation	58
Marine biological fixation	140
Lightning fixation of nitrogen	5
Sub-total of "natural" fixation	203
Biological fixation by croplands	60
Combustion	30
Fertiliser and industrial feedstock	120
o/w fertiliser	*96*
o/w industrial feedstock[2]	*24*
Sub-total of "anthropogenic" fixation	210
Total fixation	413

Figure 4: Contribution to annual global fixation (2015) (OECD, 2018)

Recalling that with fixation processes it is intended all the phenomena able to transform N_2 into a usable nitrogen compound (reactive nitrogen compound).

However, estimates (Battye et al., 2017) indicate that global nitrification fixation is balanced by denitrification, although these budget calculations are subject to large uncertainties. Thus, the large increase in anthropogenic production may be balanced by increased denitrification. Nevertheless, if anthropogenic production continues to increase, denitrification processes may not be able to offset the increased production. And also, it is important to remember that denitrification is associated with a N_2O release, compound with a high GWP value.

To sum up all the effects related to a disruption of the nitrogen cycle by anthropogenic influence, planet boundaries concept can be used. Planet boundaries, in fact, express the risk related to anthropogenic perturbations of Earth System (Steffen et al., 2015).

The Planet Boundaries framework identifies levels of anthropogenic perturbations below which the risk of destabilization of the Earth System is likely to remain low while zone of uncertainty for each Planet Boundaries highlights the area of increasing risk.

The risk that human activities overcomes planet resilient capacity is visualized in Figure 5 using three different colors:

- Green: safe zone in which human activities are not destabilizing Earth's conditions
- Yellow: uncertainty area in which risk is increased
- Red: high risk area of irreversible destabilizations

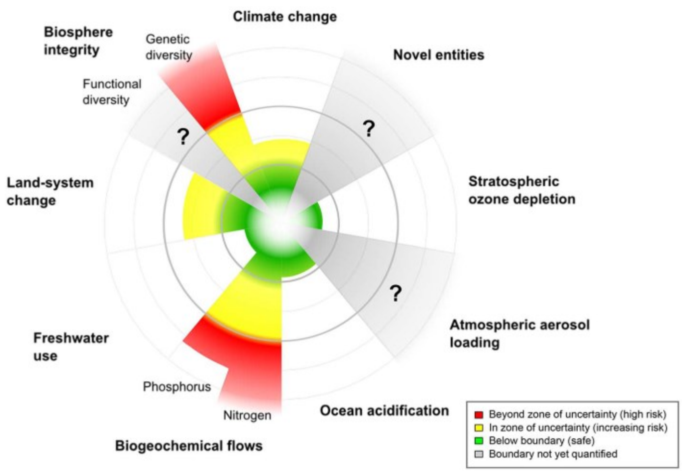


Figure 5: Current status of the control variables for seven of the planetary boundaries. The planet boundaries lies at the intersection of the green and yellow zones (Steffen et al., 2015).

From Figure 5, anthropogenic perturbation levels of four of the Earth System processes/features (climate change, biosphere integrity, biogeochemical flows, and land system change) exceed the Planet Boundaries. In particular, within the biogeochemical flows group, the study reports that we have changed the nitrogen cycle to such an extent that its potential to cause problem globally is really apparent. Considering in fact biogeochemical flows of nitrogen, planet boundaries address the risk associated as red highlighting how critical the situation is.

However, as shown in the Figure 6, a few agricultural regions of very high N application rates are the main contributors to the transgression of this boundaries.

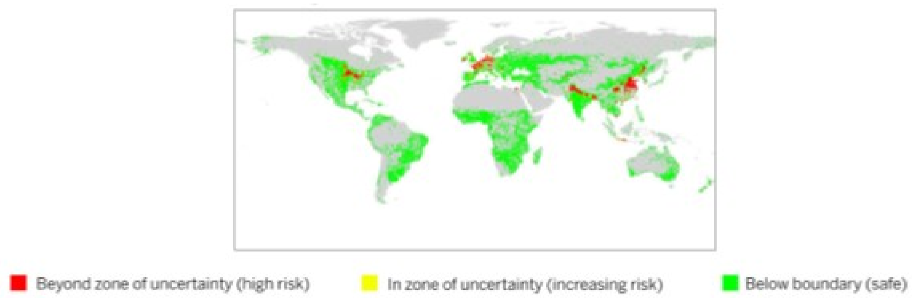


Figure 6: The subglobal distributions and current status of the control variables for biogeochemical flows of N (Steffen et al., 2015)

This suggests that a redistribution of N could simultaneously boost global crop production and reduce the transgression of the regional level boundaries.

1.4 Environmental issues influenced by a disruption on the nitrogen cycle

As briefly explained above, an excessive release of nitrogen into the environment can affect it in different ways. Environmental issues that are influenced by a disruption on the nitrogen cycle are related to: air quality, greenhouse balance and ozone layer, water quality, ecosystems and biodiversity and soil quality. OECD, 2018 classify them as in Figure 7.

Environmental issue	Adverse impact on health and the environment	Main form of nitrogen involved
Water	Nitrate contamination of ground- and drinking water	Nitrate (NO_3^-)
Air	Human health effects and effects on vegetation	Nitrogen oxides (NO_x), ammonia (NH_3), particulate matter (PM)[1], ground-level ozone (GLO)
	Effects on materials and monuments	Nitric acid (HNO_3), PM[1], GLO
Greenhouse balance and ozone layer	Global warming and ozone layer depletion	Nitrous oxide (N_2O)
Ecosystems and biodiversity	Eutrophication and acidification of terrestrial ecosystems	NO_3^-, ammonium (NH_4^+)
	Eutrophication of freshwater and marine ecosystems	NO_3^-, organic nitrogen[2]
Soil	Acidification	Organic nitrogen[2]

Figure 7: Key threats of excessive release of nitrogen into the environment. (OECD, 2018)

1.4.1 Air quality

Atmospheric emissions of reactive nitrogen can undergo rapids changes and create health hazards in the troposphere. In addition, their deposition in the earth's surface create a risk for the ecosystem (Nieder & Benbi, 2022).

There are many reactive nitrogen substances that affect air quality which can be summarized into two main categories: primary air pollutants, which are emitted from a single source and secondary air pollutants that results from primary pollutants interaction.

Some primary air pollutants are ammonia (NH_3), nitrogen oxides (NO_x) and dinitrogen oxide (N_2O). Instead some secondary air pollutants are particulate matter from NH_3 and NO_x or ozone formation due to the presence of NO_x.

- *Sources of* NO_x*:*

Atmospheric NO_x comes from denitrification processes like biogenic emissions from soil and also from direct anthropogenic emissions like combustions.

Denitrification is by definition microbial reduction of NO_3^- to N either at molecular N_2 or as an oxide of N, both performed in anaerobic condition. Catalyzed by an enzyme, the intermediate reactive nitrogen compounds that characterized the denitrification process are shows in reaction (1.1).

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (1.1)$$

The complete process can be expressed as a net balanced redox reaction, where nitrate (NO_3^-) gets fully reduced to dinitrogen (N_2) as in reaction (1.2).

$$2\,NO_3^- + 10\,e^- + 12\,H^+ \rightarrow N_2 + 6\,H_2O \quad (1.2)$$

Concerning anthropogenic source, the NO is formed by reaction between N_2 and O_2 in combustion air or by oxidation of organic nitrogen present in the fuel. Then NO forms NO_2 by oxidation.

Regarding human health, some differences are present between NO_2 and NO. This is because NO_2 is water-soluble and NO is not. Studies report NO_2 is several times more human toxic than NO. This behavior can be explained considering that NO_2, in water, reacts to produce nitric (HNO_3) and nitrous acid (HNO_2). Its hazard became relevant considering that NO_2 contribute to urban haze.

Its dangerous effects start when concentration becomes relevant (15 ppm) with symptoms like irritations into nose and eyes. Higher concentrations lead to more severe symptoms that affect especially lungs, thanks to the ability of NO_2 to penetrate deeply within human respiratory system. If nitric acids forms in the alveoli, it can destroy the protein structure of the membrane, leading to edema.

- *Source of* NO_3^-*:*

Ammonia (NH_3) as a primary air pollutant is emitted to the atmosphere mainly from agriculture, sector that is responsible of roughly 80% of the total global emissions.

Atmospheric ammonia is highly water-soluble causing wet tissues (mucosa, eyes, …) and skin irritation damages.

An increase in NH_3 emissions is also related to the animal population growth (Battye et al., 2017). Animals convert only a part of the nitrogen intake to protein in meat and milk. Much of the balanced is released to the environment and converted to mainly NH_3 emitted in the atmosphere. This is not related to a new addition of nitrogen because the nitrogen released comes from the one present in the plants but this is a serious problem for the environment that surround farms, influenced by the augmented concentration NH_3.

- *Source of particulate matter:*

Particulate matter (PM), a secondary air pollutant, is a complex mixture of extremely small particles and liquid droplets. PM which are considered dangerous for human health are categorized as $PM_{2.5}$ and PM_{10}. The effect of $PM_{2.5}$ is 4–5 times as severe as PM_{10}.

NH_3 can form ammonium nitrate (NH_4NO_3) mainly in winter and ammonium sulfate ($(NH_4)_2SO_4$) in summer. NH_4NO_3 has been identified as an important contributor to $PM_{2.5}$ in many polluted regions.

Regarding health effects, the WHO estimated (Nieder & Benbi, 2022) that, globally, in 2016 ambient air pollution was responsible for 4.2 million premature deaths and approximately 3% of cardiopulmonary and 5% of lung cancer deaths were attributable to PM.

More recent works (OurWorldInData.org, 2019) assign to air pollution (indoor and outdoor particulate matter and ozone) a risk factor for many of the leading causes of death including heart disease, stroke, lower respiratory infections, lung cancer, diabetes and chronic obstructive pulmonary disease (COPD) (Figure 8) addressing to it 6,67 million of deaths.

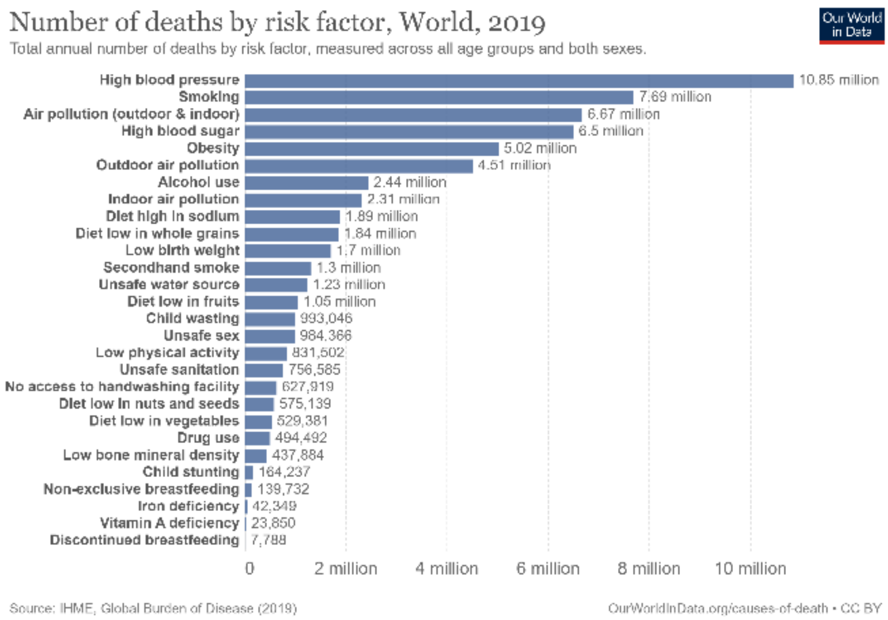


Figure 8: Total annual number of deaths by risk factor, measured across all age groups and both sexes (OurWorldInData.org, 2019)

- *Tropospheric O_3 formation:*

In addition to PM formation, NO_x also raise production of tropospheric ozone (O_3). In fact, NO_2 can react with O_2 in presence of VOCs and, thanks to solar radiation, produces O_3 in the troposphere (Nieder & Benbi, 2022). O_3 tropospheric formation has two important impacts: firstly it is a local air pollutant that has direct human health impacts and secondly it is also a strong greenhouse gas.

The process described above, also known as photochemical smog, can be summarize in reaction (1.3).

$$NO_x + VOCs \xrightarrow{UV} PANs + O_3 \tag{1.3}$$

PANs are peroxyacetyl nitrate, an important secondary pollutant and component of photochemical smog which causes eyes irritation and more importantly enables the long range transport of nitrogen oxides once reaching the free troposphere, which is why its formation in polluted regions is highly important and not only of local concern (Xu et al., 2021).

An important role in photochemical smog is played by NO_x which formation can be derived from many sources but from one main principle, high temperature processes (or, in other words, combustions).

A significant event happened in 1952, remembered as the Great Smog of London, that can be used to highlight risks related to photochemical smog. In fact, due to the extensive coal burning, a bronze haze creates above London and thanks to particular meteorological conditions the smog remains for days killing thousands of people (EPA, 2004).

1.4.2 Greenhouse balance and ozone layer:

Nitrous oxide (N_2O) is the product of nitrification and denitrification processes. It is relatively inert in the atmosphere allowing it to reach the stratosphere and also to spread all over the word like CO_2 and CH_4 (Nieder & Benbi, 2022).

N_2O has two main impacts: it has a global warming effect in the troposphere and contribute to the O_3 depletion in the stratosphere.

Almost 60 % of the total N_2O produced comes from natural sources. Instead the other 40 % is from anthropogenic sources. Within the latter the main origins are agriculture activities in which N_2O originates from livestock manure and fertilize leaching. Other anthropogenic sources are fuel combustion and industrial processes like the production of nitric acid. (OECD, 2018)

The N_2O stratospheric influence on the O_3 layer can be summarized as in reaction (1.4).

$$
\begin{aligned}
N_2O + O^* &\rightarrow 2\,NO \\
NO + O_3 &\rightarrow NO_2 + O_2
\end{aligned}
\tag{1.4}
$$

Regarding O_3 stratospheric disruption, Montreal protocol banned only CFCs and nowadays N_2O is the dominant O_3 depleting substances (Nieder & Benbi, 2022).

For what has been said N_2O health impacts are indirect, because related to the consequences of climate change and O_3 layer depletion.

1.4.3 Water quality

For freshwater ecosystems nitrogen substances have different pathways that influence concentration of nitrogen substances within water. From the atmosphere, after fixation and denitrification processes, wet and dry deposition brings nitrogen substances within freshwater.

Regarding anthropogenic sources, industries and waste water treatment plants directly discharge nitrogen into freshwater. An important role is played by agriculture which directly increase N substance concentration within surface water, or add NO_3^- to ground water through excess fertilization. (OECD, 2018)

Nitrogen pathways in marine water include nitrogen imports by river discharge, precipitation and bacteria activity. Furthermore oceanic current has an impact on the exchange of nitrogen within the sea and the resuspension of sediment nitrogen.

Eutrophication happens when high concentrations of nutrients (i.e. NO_3^- and phosphorus) in fresh and marine waters result in phytoplankton (microscopic algae) growth. High density of phytoplankton also have an impact, because reduce water transparency limiting the penetration reached by sunlight and so the dept at which macrophytes and sea grasses can grow. Consequently, low oxygen or oxygen free zones in deep water are formed and higher organism are unable to survive ("dead zones").

1.4.4 Ecosystems and biodiversity

Nutrient precipitation (wet deposition) or as gases and particles (dry deposition) onto land-based and aquatic ecosystems is a phenomena that influence strongly biodiversity loss.

In fact, studies (OECD, 2018) reports that NH_4^+ and NO_3^- deposition on terrestrial ecosystems favors some species over than others. Also acid rains is a serious problem for non-alkaline soils, as the acid-neutralizing capacity of soils gets depleted, and so ecosystems become increasingly sensitive to additional acid inputs. In contrast, acid rain falling over the oceans is rapidly neutralized by the large supply of carbonate ions.

An excess of reactive nitrogen compounds can affects vegetation biodiversity through direct foliar damage, eutrophication and acidification. The accumulation of extra nutrients, as well as reduction in soil pH, is negatively affecting natural and semi-natural habitats whose important biodiversity developed in direct response to low nutrient levels.

1.4.5 Soil quality

The major nitrogen-containing substance that represent a threats on soil quality for both agricultural and natural land are related to changes in soil acidity and loss of soil diversity.

Soil acidification is strictly related to an imbalance of electrical charge between soil and plants. This imbalance results as a H^+ net charge within the soil. For what concern the N cycle, there are two processes related to generation of H^+ ions: plant induced and soil induced processes. (Bolan et al., 1991)

Plant induced processes related to the N cycle are the ones that takes up anions (NO_3^-), cations (NH_4^+) or neutral (N_2) form of nitrogen in other to produce essential components like amino acids.

Depending on the chemical species plants take in, the electrical balance within roots must be always ensured and so an H^+ or an OH^- is released to the soil. As an example, an uptake of NO_3^-, releases a OH^- to the soil.

Within the roots, deprotonation of ammonium (NH_4^+) into NH_3 releases an H^+. In the roots to maintain the pH balanced H^+ can be exchanged with a cation taken from the soil. Cations are needed by the plant and, in order to maintain an electrical balance within the roots, a H^+ is released to the soil and a cation (es. Calcium, magnesium, potassium …) is taken into the plant. Considering instead N_2, it can be assimilated by the plant and transformed in proteins without charge imbalance. For what concern NO_3^- intake, it is then transformed into NH_3 with a OH^- release. All the above processes are summarized in Figure 9.

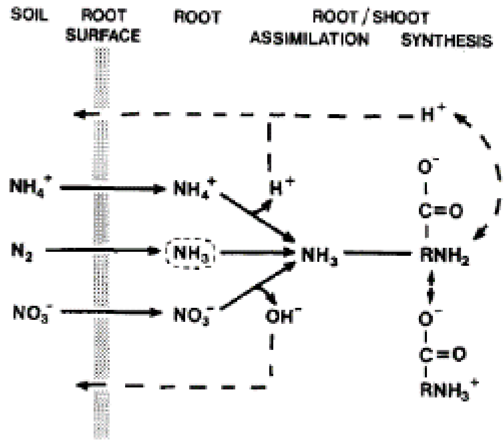


Figure 9: Proton (H+) and hydroxyl ion (OH-) generation during the uptake and assimilation of different forms of N (Bolan et al., 1991)

So, independently on the nitrogen substances from which plants start, the final product in the roots is NH_3 that will be used to produce mainly amino acids with a H^+ release.

Considering also the environment that surrounds the plant, soil induced processes take count of reactions performed by microbial organism that starting from amino acids produce N_2, then released into the atmosphere. Those processes are the already mentioned ammonification, nitrification and denitrification:

- Ammonification
  Enzymatic catalytic microbial processes whereby organic N compounds (es. amino acids) are hydrolyzed to obtain NH_4^+ ions

$$R - CH - NH2 + 3H^+ + 2e^- \rightarrow R - CH_2 + NH_4^+ \quad (1.5)$$

- Nitrification
  Process in which NH_4^+ is oxidized to yield NO_3^- expressed in the overall reaction

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \quad (1.6)$$

- Denitrification
  Microbial reduction of NO_3^- to gaseous N either at molecular N_2 or as an oxide of N. This happen under anaerobic conditions

$$2NO_3^- + 12H^+ + 10e^- \rightarrow N_2 + 6\,H_2O \quad (1.7)$$

Considering all the above reaction together the net results is a perfect charge balance.

Soil induced and plant induced processes act simultaneously and without perturbation the electrical charge is balanced within the rhizosphere. However, there are many variables that can influence the electrical charge within the soil. Ammonium-based fertilizers are the major contributors to soil acidification, especially if the nitrogen is leached rather than taken up by plants (Gazey & Davies, 2009). In fact, only if the nitrogen is returned to the soil again when the plant dies there is no acidification.

Figure 10 shows how ammonium from fertilizer or soil organic matter is readily converted to nitrate and hydrogen ions by bacteria in the soil.

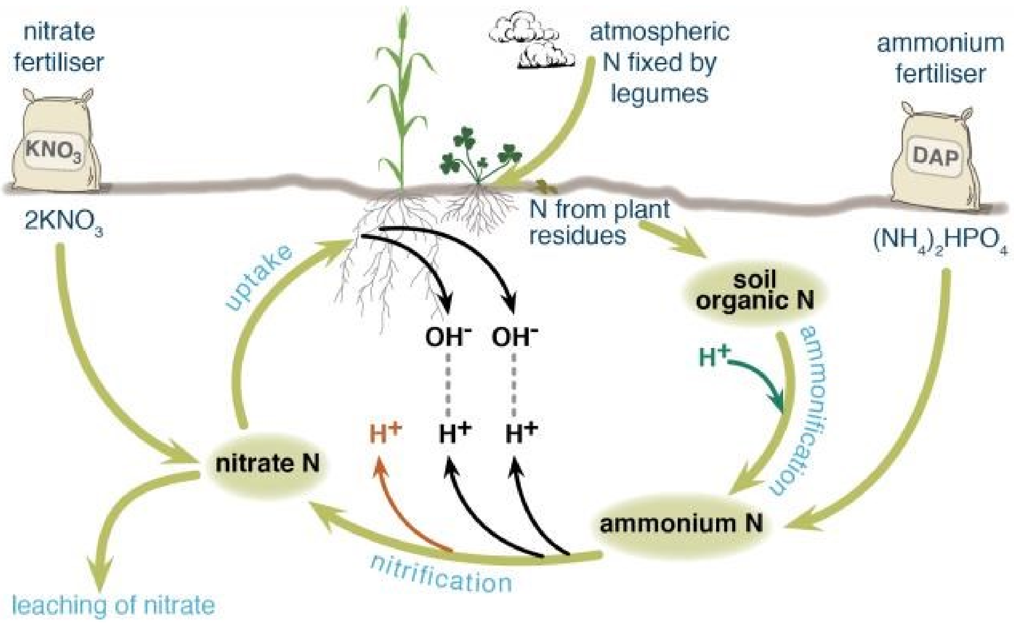


Figure 10: Different nitrogen fertilisers follow different pathways in the nitrogen cycle and different numbers of hydrogen ions are released (Gazey & Davies, 2009)

When nitrate, which is negatively charged, is taken up by plants, a hydroxide ion, also negatively charged, is released from the plant to maintain electrical balance. This hydroxide ion combines with a hydrogen ion in the soil to form water (the hydrogen ion is no longer contributing to soil acidity). Depending on the fertilizer, all hydrogen ions released by nitrification may be neutralized or there may be a net increase in hydrogen ions in the soil.

If nitrate is not taken up by plants, it can leach away from the root zone, meaning that no hydroxide ion is released from the plant to bind with a hydrogen ion and so a positively charge remain contributing to soil acidity.

To summarize, in general, plants absorb more cations than anions, which means that most plant material is slightly alkaline. In a natural system, when plants die they are decomposed and returned to the soil, balancing the acidity caused by hydrogen ions. However in agriculture, if plant material is removed by grazing or harvest rather than being returned to the soil, there is a net export of alkalinity and residual hydrogen ions remain in the soil. If this process is repeated over time the soil becomes acidic.

Chapter Two
Method Description: Assessment of Impacts Related to Nitrogen Cycle

In this chapter the method developed in Zuliani (2018) with aim of calculating of environmental impacts related to the nitrogen cycle will be presented. A first part is dedicated to the purpose of the method and its difference respects the current state of the art and then the method is presented describing in detail all its phases and steps and the underlying conceptual and mathematical models.

2.1 Description and purpose of the method applied

Nowadays, footprint indicators are considered a guide for companies, public sector and also consumers, indicating pressure on the environment of human activities, and so helping them to make decision in a more sustainable way. Each footprint focuses on a particular environmental concern, and measures either resource appropriation or pollution/waste generation, or both (Vanham et al., 2019). In particular, the nitrogen footprint was developed to measure the contribution of people products, organisations, and countries to reactive nitrogen levels in the environment (Lewis & Cohen, 2022). In fact, the nitrogen footprint is defined as the amount of reactive nitrogen released into the environment because of human activities (Leach et al., 2012).

A range of nitrogen footprint tools have been developed over the years (Nitrogen calculator, Nitrogen institution, Nitrogen loss indicator, Nitrogen label …) with different targets and scopes. However, in this thesis work no analysis have been done regarding the assessment of the right tool to evaluate the nitrogen footprint. In fact, this study focuses on the implementation of the method proposed by (Zuliani, 2018) onto a real case and discusses results in a critical way.

This method was developed in order to support the use of database and software for LCA applications and to formulate an assessment method to identify and account environmental impacts related to the nitrogen cycle for a product system.

This need comes from the fact that, based on the definition of nitrogen footprint, common tools so far proposed perform only an evaluation of the reactive nitrogen at inventory level, so accounting incoming and outcoming flows from the system under study. In other words the proposed method wants to implement a nitrogen footprint assessment providing information at an impact level as it is normally the case for the LCA studies.

The approach proposed will be tested, in the next chapter devoted to the application of the method, onto four products of an ice cream and pastry industry Italian company: “Sammontana”.

2.2 Method

The methodology proposed by Zuliani and the research group of University of Padova, has been designed with the aim of providing a framework for comprehensive assessment of nitrogen-related impacts, applying a life cycle approach and adapting schemes, tools and methods typically used in the LCA applications. LCA approach was chosen because is the most widely used and scientifically recognized methodology for the assessment of environmental impacts for a product system.

Life cycle assessment is a methodology for the identification and assessment of the environmental impacts of a product system over its life cycle. As standardized by ISO 14040 and ISO 14044, the LCA methodology for the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle requires 4 phases, as follows:

- Goal and scope definition: is the initial step in which the goal and scope of an LCA shall be clearly defined and shall be consistent with the intended application.
- Inventory analysis: is the initial step in which the goal and scope of an LCA shall be clearly defined and shall be consistent with the intended application.
- Impact assessment: is the step in which the assessment of potential environmental impacts is performed, starting from the results coming from inventory phase:
- Interpretation: this phase consists in the correlation of results obtained from the inventory analysis and environmental impact assessment.

Using the LCA structure, a framework for the nitrogen footprint assessment has been proposed by Zuliani (2018). In particular, a section called “nitrogen inventory study” starts from the goal and scope definition – with characteristics and requirements similar to those of the corresponding phase of the LCA methodology – and includes the “nitrogen inventory analysis” aimed at describing the flows that affect the product system with reference to the substances relevant for nitrogen cycle alterations.

In the presented method a further section, defined as "nitrogen footprint assessment", which starts from the outputs of the previous section, includes the phase of assessment of impacts generated by the product system considering only the impact categories which have a direct influence on nitrogen cycle perturbation.

Lastly, the "interpretation stage" regroup the findings from the nitrogen inventory analysis and the nitrogen footprint assessment. The aim is to deliver results that are consistent with the defined goal and scope of the application, to reach conclusions, explain limitations and provide recommendations.

A schematic representation of the methodology's steps is presented in Figure 11.

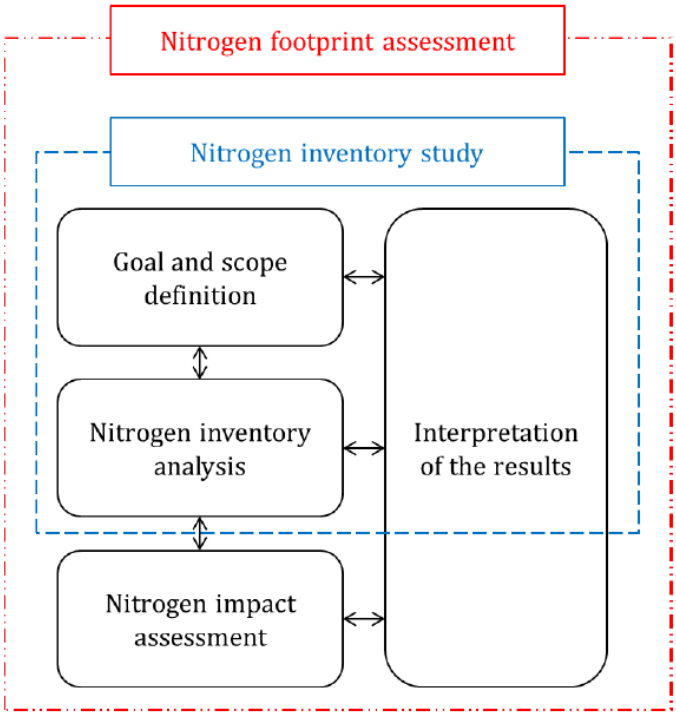


Figure 11: Schematic representation of the proposed methodology's steps for nitrogen footprint assessment, comprising the sections of nitrogen inventory study and nitrogen impact assessment. (Zuliani, 2018)

The proposed methodology will be applied to four different product systems. Product system is a concept taken from LCA studies. It is defined as a system of consecutive and interlinked unit processes, which models a product life cycle (UNEP, 2011).

The method applied consists of the following phases:

- goal and scope definition,
- inventory analysis,
- assessment at inventory level,
- impact assessment (characterization),
- impact assessment (normalization and weighting),
- interpretation of the results.

As in LCA studies goal and scope definition and interpretation of results are mandatory steps and represent the conceptual part of the study meant to define objectives and evaluate results obtained. The other four steps listed above are methodological operation which, starting from the inventory analysis, wants to collect and check data available. Then, following assessment phases use data previously collected and treat them at an inventory level and then at an impact level in the impact assessment phases.

2.2.1 Supporting tools for the development of the methodology

Before proceeding to the detailed description of the method used, a preliminary description of tools needed for the model implementation is needed. The supporting tools suggested by Zuliani (2018) are typical support tools used for LCA applications.

- <u>Databases:</u>
  During inventory analysis, process units defined within the studied product system must be described in the most detailed manner, analysing the inputs and outputs of materials, energy, products, and releases to environment. Information gathered can be divided into three main categories:
  - Primary data: data determined by direct measurement, estimation or calculation from the original source (interviews, on site measurements, etc…)
  - Secondary data: data assembled by means of statistics, or literature review
  - Tertiary data: data obtained though estimates and calculations

  Data collected will be combined with data from existing databases to complete the inventory of the assessment.
- <u>Characterization models:</u>
  In the impact assessment phase the purpose is to interpret the life cycle emissions and resource consumption inventory in terms of indicators evaluating the environmental impact. In LCA studies this phase is defined as Life Cycle Impact Assessment (LCIA)

and is composed of mandatory and other are optional. Characterization is a mandatory step in which, through a characterization model, potential impacts related to inventory emissions into environment are modelled quantitatively.

For each substance that constitutes an elementary flow, characterization model evaluates a characterization factor which express its potential impact in terms of common unit of category indicator. In this way elementary flows' ability to contribute to an impact category indicator can be compared through their characterization factors.

Impact category indicators can be chosen anywhere along the impact pathway and depending on that characterization can be distinguished into two main levels. This two levels are called midpoint and endpoint level. Characterization at midpoint level models the impact using an indicator located somewhere along (but before the end of) the mechanism. Instead, characterization at endpoint level requires modelling all the way to the impact on the entities described by the areas of protection.

The characterization model choice is a crucial point for the method proposed by Zuliani (2018) for nitrogen footprint accounting, in particular in the impact assessment phase. In fact, their validity influenced largely the results of the assessment at impact level. Further details on chosen characterization model and impact categories will be given in the specific section.

- Normalization and weighting

  Once the characterization models are applied an impact assessment profile can be obtained showing the environmental impacts in several impact categories. As it is valid in LCA studies, based on ISO standards, category indicator results is the last mandatory step because the impact profile obtained is a useful result for the assessment of the impacts related to the nitrogen cycle. In the case of an impact assessment profile composed of different criteria and different units of measure a comparison can be difficult. In fact, from Zuliani (2018) work a multi criteria approach is expected with different characterization models needed to describe all the different environmental impacts related to nitrogen-containing substances.

  Thus, a single score as a results of the assessment becomes important for comparing different alternatives and product systems. So, applying normalization and weighting can be necessary tools for comparative assessment.

  As defined by the ISO standards (ISO 14044), normalization is the calculation of the magnitude of the category indicator results relative to some reference information. The aim of the normalization is to understand better the relative magnitude for each indicator result of the product system under study. In fact, normalization provides a reference situation for the environmental pressures of all the impact categories, meaning that, through normalization, absolute impact scores are converted into relative contributions of the analysed product or system to a reference situation.

Again according to ISO standards (ISO 14044), weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choices. Weighting, furthermore, allows for impacts to be aggregated into a single score for easier evaluation. However, weighting sets are inherently subjective and can vary depending on culture, political views, gender, demographics, and professional opinion of stakeholders. In LCA literature, five groups of approaches to develop weighting factors have been identified (Sala et al., 2018):

- Single Item: physical properties or equivalents are used to characterize/weight the inventory (e.g. Cumulative Energy Demand, carbon footprint);
- Distance-to-Target: where characterization results are related to target levels, either policy based or carrying capacity-based (e.g. planetary boundaries);
- Panel-based (value based or preference based): the relative importance of damages/impact categories/interventions is derived from a group of people (experts and/or stakeholders) through surveys and elicitation techniques;
- Monetary valuation: monetary estimation involved in evaluation (willingness to pay, etc);
- Meta-models: impacts are weighted by applying multiple weighting factors, resulting from the combination of other weighting sets.

- Software:

A usual LCA application requires accounting data about several processes and their input and output flows, managing the connections between processes, balance calculating, impact assessing, normalizing and weighting. The management of data and calculations related to the inventory, impact assessment and interpretation phase would be not possible without the support of an appropriate software. For LCA applicators software is the tool that, in synthesis, converts data into a model, providing results to be used, generally, in decision support.

Among the different features that the software offer, is worth mentioning the availability of several specific databases, different characterization, normalization and weighting methodologies and uncertainty calculation tools,

Within this work has been used the SimaPro software in the version 9.1 released by Pré Consultants (PRé Sustainability B. V., 2020).

2.2.2 Goal and scope definition

In this step, the plan of the assessment is defined as clearly as possible, dealing with topics as the intended application, the reason for carrying out the assessment, the intended audience, the willingness to use the results for comparative assertions, etc. The scope definition also provides the setting of the product system, including the function and the functional unit. Due to the iterative nature of the proposed methodology, the scope may have to be refined during the application.

2.2.3 Nitrogen inventory analysis

Based on the defined goal and scope an inventory is planned. As structured in a LCA study, an inventory analysis consists of a series of operations:

- Data collection: for each unit process that is included within the system boundary qualitative and quantitative data shall be collected.
- Data validation: during the process of data collection a check on data validity shall be conducted in order to confirm that the data quality requirements for the intended application have been fulfilled.
- Relating data to unit process and functional unit: for each unit process an appropriate flow shall be determined. Then, in relation to this flow, quantitative input and output data shall be calculated for the unit process. Based on the flow chart and the flows between unit processes, the flows of all unit processes are related to the reference flow. For all system input and output data calculation should result in being referenced to the functional unit.
- Data aggregation: care should be taken when aggregating the inputs and outputs in the product system. The level of aggregation shall be consistent with the goal of the study.

During the data collection stage, allocation operations may be needed in order to partition 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.

Even if the objective of this methodology is to focus only onto nitrogen cycle, all the operations presented should be performed as in a normal LCA study, obtaining a complete inventory of incoming and outgoing flows. Completed the inventory analysis, a selection of the data related to the nitrogen impact analysis is needed. This step consists in the identification of only the incoming and outcoming nitrogen containing substances within the product system analysed.

Starting from a previous analysis of the main commercial database done by Zuliani (2018), which select only nitrogen-containing substances and compounds for which it is more probable to detect incoming and outgoing flows from the product systems, an upgrade has been done in this work studying Ecoinvent 3 (Wernet, 2016), Word Food LCA (van Paassen M, 2019) and Agrifootprint 5 (van Paassen M, 2019) databases.

The results of the inventory analysis carried out within this work, allowed to identify a set of more than 300 nitrogen-containing substances and compounds.

2.2.4 Reactive nitrogen indicator accounting

The first step towards assessment of environmental impacts related to nitrogen cycle, as stated the proposed method is the reactive nitrogen quantification for the product system.

The reactive nitrogen quantification is done starting from inventory results that have already been obtained according to the LCA approach in the previous phase and it is based on the current definition of nitrogen footprint.

However the above mentioned databases, in accordance with the requirements for inventory analysis, are designed to provide quantification of incoming and outgoing streams from a product systems and no direct data about reactive nitrogen is contained within them. So, considering the definition of nitrogen footprint as "the total amount of reactive nitrogen released to the environment as a result of an entity's resource consumption, expressed in total units of Nr" (Leach et al., 2012) in the method proposed a specific approach to have that information. This approach consists on firstly the calculation of a nitrogen coefficient (Nc) for each nitrogen containing substances that results as an output from the product system analysed according to the following:

$$Nitrogen\ Coefficient\ (Nc_i) = \frac{molar\ mass\ of\ N\ contained\ in\ the\ substance/compound\ i}{molar\ mass\ of\ the\ substance/compound\ i} \quad (2.1)$$

In some specific cases highlighted below (for example for emissions of particulate matter), the (2.1) could not be used and some assumptions had to be made to calculate their nitrogen coefficient. Those assumptions are listed in the Appendix A.

Starting from the coefficients thus obtained, the reactive nitrogen indicator is then defined as the total reactive nitrogen released by the product system, according to the following:

$$Total\ Reactive\ Nitrogen\ (N_r) = \sum_{i=1}^{n} \sum_{j=1}^{m} s_{i,j} * f_{i,j} * Nc_{i,j}\ [\frac{kg}{functional\ unit}] \quad (2.2)$$

where:

- *N_r is the reactive nitrogen indicator calculated for the whole product system;*

- *$s_{i,j}$ is the emitted amount of the i substance in the j compartment as resulting from inventory analysis [emission unit/functional unit];*

- *$f_{i,j}$ is the conversion factor for the homogenization of the results depending on the unit of measure used for the amount of the emitted substance [kg/emission unit of measure]: it will be considered implicit in the next equations;*

- $Nc_{i,j}$ is the nitrogen coefficient for the substance/compound i in the j compartment (the nitrogen coefficient Nc_i of the i substance is the same for all j compartments, except for nitrogen emissions; $Nc_{i,j}$ = 0 for nitrogen-non containing substances);

- i is the identification index of the specific substance/compound;

- j is the identification index of the substance compartment of emission;

- n is the total number of nitrogen-containing substance and compound for the product system;

- m is the total number of the compartments of emission (for this study m=3; the considered compartments are: air, water, soil).

Total reactive nitrogen and *nitrogen coefficient* are used to aggregate inventory results into a single indicator. In fact, it is important to highlight that, due to the fact that they has been evaluate at inventory level, they are not related to an impact indicator results for a defined impact category.

In Table 1 the evaluation of the nitrogen coefficient is presented for more than 300 substances obtained as outputs from the product systems evaluated within this work using Ecoinvent 3.6, Word Food LCA and Agrifootprint 5 databases.

For each selected compound or substance that is reported in Table 1, together with their nitrogen coefficient evaluated with equation (2.1) it is also represented: the compartment in which the substance is released, its molar mass, the number of nitrogen atoms present in its chemical formula and the related mass of nitrogen contained. For the determination of the composition of substances and of the molar mass, the PubChem open database (Kim et al., 2023) and the NIST Chemistry WebBook (Acree & Chickos, 1998) were used.

Table 1: Nitrogen coefficient (Nc) calculated for more than 300 nitrogen containing substances and compounds obtained as output from the inventory analysis carried out within the present work using databases Ecoinvent 3.6, Agri-footprint 5 and Word Food LCA.

Substance/Compound	**Compartment**	**Molar mass [g/mol]**	**Nitrogen atoms**	**Nitrogen content [g/mol]**	**Nc - Nitrogen coefficient**
1-Amino-2-propanol	Air, Water, Soil	75,1	1	14,01	0,186
2-Aminopropanol	Air, Water	75,1	1	14,01	0,186
2-Nitrobenzoic acid	Air	167,1	1	14,01	0,084
8-Quinolinol	Air, Water, Soil	145,2	1	14,00	0,096
Acephate	Air, Water, Soil	183,2	1	14,01	0,076
Acetamide	Air, Water, Soil	59,1	1	14,01	0,237
Acetochlor	Air, Water, Soil	269,8	1	14,01	0,052
Acetonitrile	Air, Water, Soil	41,1	1	14,01	0,341
Acifluorfen	Air, Water, Soil	361,7	1	14,01	0,039
Aclonifen	Air, Water, Soil	264,7	2	28,01	0,106
Acrylonitrile	Air, Water, Soil	53,1	1	14,01	0,264
Alachlor	Air, Water, Soil	269,8	1	14,01	0,052

Substance/Compound	Compartment	Molar mass [g/mol]	Nitrogen atoms	Nitrogen content [g/mol]	Nc - Nitrogen coefficient
Alanycarb	Soil	399,5	3	42,00	0,105
Aldicarb	Air, Water, Soil	190,3	2	28,01	0,147
Amidosulfuron	Air, Water, Soil	369,4	5	70,03	0,190
Amine oxide	Air	30,0	1	14,00	0,467
Ammonia	Air, Water, Soil	17,0	1	14,01	0,822
Ammonia, as N	Water	14,0	1	14,01	1,000
Ammonium carbonate	Air	96,1	2	28,01	0,292
Ammonium chloride	Air	53,5	1	14,00	0,262
Ammonium, ion	Air, Water, Soil	18,0	1	14,01	0,776
Aniline	Air, Water, Soil	93,1	1	14,01	0,150
Anthranilic acid	Air	137,1	1	14,01	0,102
Antimycin A	Air, Water, Soil	548,6	2	28,01	0,051
Asulam	Air, Water, Soil	230,2	2	28,01	0,122
Atrazine	Air, Water, Soil	215,7	5	70,03	0,325
Azaconazol	Soil	300,1	3	42,00	0,140
Azinphos-methyl	Air, Water, Soil	317,3	3	42,02	0,132
Aziprotryne	Soil	225,3	7	98,00	0,435
Azoxystrobin	Air, Water, Soil	403,4	3	42,02	0,104
Benalaxyl-M	Air, Water, Soil	325,4	1	14,00	0,043
Benfluralin	Air, Water, Soil	335,3	3	42,02	0,125
Benomyl	Air, Water, Soil	290,3	4	56,03	0,193
Bensulfuron methyl ester	Air, Water, Soil	410,4	4	56,03	0,137
Bentazone	Air, Water, Soil	240,3	2	28,01	0,117
Benzene, 1-methyl-2-nitro-	Air, Water, Soil	137,1	1	14,01	0,102
Benzene, pentachloronitro-	Air, Water, Soil	295,3	1	14,01	0,047
Benzidine	Air, Water, Soil	184,2	2	28,01	0,152
Benzthiazuron	Soil	207,3	3	42,00	0,203
Beta-cypermethrin isomer	Air, Water, Soil	416,3	1	14,01	0,034
Bifenox	Air, Water, Soil	342,1	1	14,01	0,041
Bitertanol	Air, Water, Soil	337,4	3	42,02	0,125
Bromacil	Soil	261,1	2	28,00	0,107
Bromofenoxim	Soil	461,0	3	42,00	0,091
Bromoxynil	Air, Water, Soil	276,9	1	14,01	0,051
Bromuconazole	Air, Water, Soil	377,1	3	42,02	0,111
Bupirimate	Soil	316,4	4	56,00	0,177
Butachlor	Air, Water, Soil	311,8	1	14,00	0,045
Butoxycarboxim	Soil	222,3	2	28,00	0,126
Butralin	Soil	295,3	3	42,00	0,142
Caprolactam	Air	113,2	1	14,00	0,124
Captan	Air, Water, Soil	300,6	1	14,01	0,047
Carbamic acid, (3,4-diethoxyphenyl)-, 1-methylet	Air, Water, Soil	267,3	1	14,00	0,052
Carbaryl	Air, Water, Soil	201,2	1	14,01	0,070
Carbendazim	Air, Water, Soil	191,2	3	42,02	0,220
Carbetamide	Air, Water, Soil	236,3	2	28,01	0,119

Substance/Compound	Compartment	Molar mass [g/mol]	Nitrogen atoms	Nitrogen content [g/mol]	Nc - Nitrogen coefficient
Carbofuran	Air, Water, Soil	221,3	1	14,01	0,063
Carfentrazone-ethyl	Air, Water, Soil	412,2	3	42,02	0,102
Cellulose, nitrate	Air, Water, Soil	999,4	11	154,07	0,154
Chloramben, ammonium salt	Air, Water, Soil	223,1	2	28,01	0,126
Chloramben, methyl ester	Air, Water, Soil	220,0	1	14,01	0,064
Chloramine	Air, Water, Soil	51,5	1	14,01	0,272
Chloramine-b	Air, Water, Soil	213,6	1	14,01	0,066
Chloridazon	Air, Water, Soil	221,6	3	42,02	0,190
Chlorimuron-ethyl	Air, Water, Soil	414,8	4	56,03	0,135
Chlormequat	Air, Water, Soil	122,6	1	14,01	0,114
Chlormequat chloride	Air, Water, Soil	158,1	1	14,00	0,089
Chlorothalonil	Air, Water, Soil	265,9	2	28,01	0,105
Chlorpropham	Air, Water, Soil	213,7	1	14,00	0,066
Chlorpyrifos	Air, Water, Soil	350,6	1	14,01	0,040
Chlorsulfuron	Air, Water, Soil	357,8	5	70,03	0,196
Chlortoluron	Air, Water, Soil	212,7	2	28,01	0,132
Chlozolinate	Soil	332,1	1	14,00	0,042
Choline chloride	Air, Water, Soil	139,6	1	14,01	0,100
Cinidon-ethyl	Soil	394,2	1	14,01	0,036
cis-4-[3-(p-tert-butylphenyl)-2-methylpropyl]-2,6-dimethylmorpholine	Air, Water, Soil	304,5	1	14,00	0,046
Clethodim	Air, Water, Soil	359,9	1	14,01	0,039
Clodinafop-propargyl	Air, Water, Soil	349,7	1	14,01	0,040
Clofentezine	Soil	303,1	4	56,00	0,185
Clomazone	Air, Water, Soil	239,7	1	14,01	0,058
Clopyralid	Air, Water, Soil	192,0	1	14,01	0,073
Cloquintocet-mexyl	Air, Water, Soil	335,8	1	14,01	0,042
Cloransulam-methyl	Air, Water, Soil	429,8	5	70,03	0,163
Cyanazine	Air, Water, Soil	240,7	6	84,00	0,349
Cyanide	Air, Water	26,0	1	14,01	0,538
Cyanoacetic acid	Air	85,1	1	14,01	0,165
Cycloxydim	Air, Water, Soil	325,5	1	14,00	0,043
Cycloxydim	Air, Water, Soil	325,5	1	14,01	0,043
Cyfluthrin	Air, Water, Soil	434,3	1	14,01	0,032
Cyhalothrin	Air, Water, Soil	449,9	1	14,01	0,031
Cyhalothrin, gamma-	Air, Water, Soil	449,9	1	14,01	0,031
Cymoxanil	Air, Water, Soil	198,2	4	56,03	0,283
Cypermethrin	Air, Water, Soil	416,3	1	14,01	0,034
Cyproconazole	Air, Water, Soil	291,8	3	42,02	0,144
Cyprodinil	Air, Water, Soil	225,3	3	42,02	0,187
Cyromazine	Soil	166,2	6	84,00	0,505
Dazomet	Soil	162,3	2	28,00	0,173
Deltamethrin	Air, Water, Soil	505,2	1	14,01	0,028
Desmedipham	Air, Water, Soil	300,3	2	28,01	0,093

Substance/Compound	Compartment	Molar mass [g/mol]	Nitrogen atoms	Nitrogen content [g/mol]	Nc - Nitrogen coefficient
Dialifor	Soil	393,8	1	14,00	0,036
Diazinon	Air, Water, Soil	304,3	2	28,01	0,092
Dichlobenil	Soil	172,0	1	14,00	0,081
Dicrotophos	Air, Water, Soil	237,2	1	14,01	0,059
Diethylamine	Air, Water, Soil	73,1	1	14,01	0,192
Difenoconazole	Air, Water, Soil	406,3	3	42,02	0,103
Diflubenzuron	Air, Water, Soil	310,7	2	28,01	0,090
Diflufenican	Air, Water, Soil	394,3	2	28,01	0,071
Diflufenzopyr-sodium	Air, Water, Soil	356,3	4	56,03	0,157
Dimethachlor	Air, Water, Soil	255,7	1	14,01	0,055
Dimethenamid	Air, Water, Soil	275,8	1	14,01	0,051
Dimethenamid-P	Soil	275,8	1	14,00	0,051
Dimethoate	Air, Water, Soil	229,2	1	14,01	0,061
Dimethomorph	Air, Water, Soil	387,9	1	14,01	0,036
Dimethoxon	Air, Water, Soil	213,2	1	14,00	0,066
Dimethylamine	Air, Water, Soil	45,1	1	14,01	0,311
Dinitrogen monoxide	Air, Water, Soil	44,0	2	28,01	0,636
Dinitrosohomopiperazine	Air, Water, Soil	158,2	4	56,03	0,354
Dinoseb	Soil	240,2	2	28,00	0,117
Dipropylamine	Air, Water, Soil	101,2	1	14,01	0,138
Diquat	Air, Water, Soil	184,2	2	28,01	0,152
Diquat dibromide	Air, Water, Soil	344,1	2	28,01	0,081
Dithianone	Air, Water, Soil	296,3	2	28,01	0,095
Diuron	Air, Water, Soil	233,1	2	28,01	0,120
DNOC	Air, Water, Soil	198,1	2	28,00	0,141
Dodemorph	Soil	281,5	1	14,00	0,050
EDTA	Water	292,2	2	28,00	0,096
Epoxiconazole	Air, Water, Soil	329,8	3	42,02	0,127
Esfenvalerate	Air, Water, Soil	419,9	1	14,01	0,033
Ethalfluralin	Air, Water, Soil	333,3	3	42,02	0,126
Ethane, Z-ethyl-O,N,N-azoxy-	Air, Water, Soil	102,1	2	28,01	0,274
Ethiofencarb	Air, Water, Soil	225,3	1	14,00	0,062
Ethylamine	Air, Water, Soil	45,1	1	14,01	0,311
Ethylene diamine	Air, Water, Soil	60,1	2	28,01	0,466
Etoxazole	Soil	359,4	1	14,00	0,039
Fenamiphos	Soil	303,4	1	14,00	0,046
Fenazaquin	Soil	306,4	2	28,00	0,091
Fenbuconazole	Air, Water, Soil	336,8	4	56,03	0,166
Fenitrothion	Air, Water, Soil	277,2	1	14,00	0,050
Fenoxaprop	Air, Water, Soil	333,7	1	14,01	0,042
Fenoxaprop-P ethyl ester	Air, Water, Soil	361,8	1	14,01	0,039
Fenpiclonil	Air, Water, Soil	237,1	2	28,01	0,118
Fenpropathrin	Air, Water, Soil	349,4	1	14,01	0,040
Fenpropidin	Air, Water, Soil	273,5	1	14,01	0,051

Substance/Compound	Compartment	Molar mass [g/mol]	Nitrogen atoms	Nitrogen content [g/mol]	Nc - Nitrogen coefficient
Fenpropimorph	Air, Water, Soil	303,5	1	14,01	0,046
Fenpyroximate	Soil	421,5	3	42,00	0,100
Fipronil	Air, Water, Soil	437,1	4	56,03	0,128
Florasulam	Soil	359,3	5	70,03	0,195
Fluazifop	Soil	327,3	1	14,00	0,043
Fluazifop-P-butyl	Air, Water, Soil	383,4	1	14,01	0,037
Fluazinam	Air, Water, Soil	465,1	4	56,00	0,120
Flucarbazone sodium salt	Soil	418,3	4	56,03	0,134
Fludioxonil	Air, Water, Soil	248,2	2	28,01	0,113
Flufenacet	Air, Water, Soil	363,3	3	42,02	0,116
Flumetsulam	Air, Water, Soil	325,3	5	70,03	0,215
Flumiclorac-pentyl	Air, Water, Soil	423,9	1	14,01	0,033
Flumioxazin	Air, Water, Soil	354,3	2	28,01	0,079
Fluorodifen	Air, Water, Soil	328,2	2	28,00	0,085
Fluoroglycofen	Soil	419,7	1	14,00	0,033
Fluroxypyr	Air, Water, Soil	255,0	2	28,01	0,110
Flurtamone	Soil	333,3	1	14,01	0,042
Flusilazole	Air, Water, Soil	315,4	3	42,02	0,133
Fluvalinate	Air, Water, Soil	502,9	2	28,00	0,056
Folpet	Air, Water, Soil	296,5	1	14,01	0,047
Fomesafen	Air, Water, Soil	438,8	2	28,01	0,064
Foramsulfuron	Air, Water, Soil	452,4	6	84,04	0,186
Formamide	Air, Water, Soil	45,0	1	14,01	0,311
Furathiocarb	Soil	382,5	2	28,00	0,073
Glufosinate ammonium	Air, Water, Soil	198,2	2	28,00	0,141
Glyphosate	Air, Water, Soil	169,1	1	14,01	0,083
Haloxyfop	Soil	361,7	1	14,00	0,039
Hexaconazole	Air, Water, Soil	314,2	3	42,00	0,134
Hexamethylene diamine	Air	116,2	2	28,00	0,241
Hexazinone	Air, Water, Soil	252,3	4	56,00	0,222
Hexythiazox	Soil	352,9	2	28,00	0,079
Hydramethylnon	Air, Water, Soil	494,5	4	56,03	0,113
Hydrazine	Water	32,0	2	28,00	0,874
Hydrazine, methyl-	Air	46,1	2	28,00	0,608
Hydrogen cyanide	Air,Water	27,0	1	14,00	0,518
Hymexazol	Soil	99,1	1	14,00	0,141
Imazalil	Soil	297,2	2	28,00	0,094
Imazamethabenz (isomer mix)	Air, Water, Soil	288,3	2	28,00	0,097
Imazamox	Air, Water, Soil	305,3	3	42,02	0,138
Imazapyr	Air, Water, Soil	261,3	3	42,02	0,161
Imazaquin	Air, Water, Soil	311,3	3	42,02	0,135
Imazethapyr	Air, Water, Soil	289,3	3	42,02	0,145
Imidacloprid	Air, Water, Soil	255,7	5	70,03	0,274
Indoxacarb	Air, Water, Soil	527,8	3	42,02	0,080

Substance/Compound	Compartment	Molar mass [g/mol]	Nitrogen atoms	Nitrogen content [g/mol]	Nc - Nitrogen coefficient
Ioxynil	Air, Water, Soil	370,9	1	14,01	0,038
Iprodione	Air, Water, Soil	330,2	3	42,02	0,127
Isocyanic acid	Air	43,0	1	14,01	0,326
Isoprocarb	Air, Water, Soil	193,2	1	14,00	0,072
Isopropylamine	Air, Water, Soil	59,1	1	14,01	0,237
Isoproturon	Air, Water, Soil	206,3	2	28,01	0,136
Isoxaben	Air, Water, Soil	332,4	2	28,00	0,084
Isoxaflutole	Air, Water, Soil	359,3	1	14,01	0,039
Kresoxim-methyl	Air, Water, Soil	313,4	1	14,01	0,045
Lactofen	Air, Water, Soil	461,8	1	14,01	0,030
Lambda-cyhalothrin	Air, Water, Soil	449,9	1	14,01	0,031
Linuron	Air, Water, Soil	249,1	2	28,01	0,112
Mancozeb	Air, Water, Soil	541,0	4	56,03	0,104
Mefenpyr	Soil	317,1	2	28,01	0,088
Mefenpyr-diethyl	Soil	373,2	2	28,01	0,075
Mepiquat chloride	Air, Water, Soil	149,7	1	14,01	0,094
Mesotrione	Air, Water, Soil	339,3	1	14,01	0,041
Metalaxyl-M	Soil	279,3	1	14,00	0,050
Metamitron	Air, Water, Soil	202,2	4	56,03	0,277
Metazachlor	Air, Water, Soil	277,8	3	42,02	0,151
Methabenzthiazuron	Air, Water, Soil	221,3	3	42,00	0,190
Methidathion	Air, Water, Soil	302,3	2	28,00	0,093
Methiocarb	Air, Water, Soil	225,3	1	14,00	0,062
Methomyl	Air, Water, Soil	162,2	2	28,01	0,173
Methoxyfenozide	Soil	368,5	2	28,00	0,076
Methyl carbamate	Air, Water, Soil	75,1	1	14,00	0,186
Methylamine	Air, Water, Soil	31,1	1	14,01	0,451
Metobromuron	Air, Water, Soil	259,1	2	28,00	0,108
Metolachlor	Air, Water, Soil	283,8	1	14,01	0,049
Metolachlor, (S)	Soil	283,8	1	14,00	0,049
Metoxuron	Air, Water, Soil	228,7	2	28,00	0,122
Metribuzin	Air, Water, Soil	214,3	4	56,03	0,261
Monocrotophos	Air, Water, Soil	223,2	1	14,01	0,063
Monoethanolamine	Air, Water, Soil	61,1	1	14,01	0,229
Monolinuron	Air, Water, Soil	214,7	2	28,00	0,130
Morpholine	Water	87,1	1	14,00	0,161
Napropamide	Air, Water, Soil	271,4	1	14,01	0,052
Nitrate	Air, Water, Soil	62,0	1	14,01	0,226
Nitrate compounds	Water	62,0	2	28,00	0,452
Nitric oxide	Air	30,0	1	14,01	0,467
Nitrite	Air, Water	46,0	1	14,01	0,304
Nitrobenzene	Air, Water, Soil	123,1	1	14,01	0,114
Nitrogen	Water,Soil	0,0	0	0,00	0,000
Nitrogen	Air	14,0	1	14,01	0,000
Nitrogen	Water, Soil	14,0	1	14,01	1,000

Substance/Compound	**Compartment**	**Molar mass [g/mol]**	**Nitrogen atoms**	**Nitrogen content [g/mol]**	**Nc - Nitrogen coefficient**
Nitrogen	raw material	14,0	1	14,01	0,000
Nitrogen dioxide	Air, Water, Soil	46,0	1	14,01	0,304
Nitrogen fluoride	Air	71,0	1	14,01	0,197
Nitrogen oxides	Air, Water, Soil	46,0	1	14,01	0,304
Nitrogen, organic bound	Water	n.a.	n.a	n.a	0,160
Nitrogen, total	Water	0,0	0	0,00	0,000
Nitrogen, total	Air, Water, Soil	14,0	1	14,01	1,000
Nitrogenous Matter (unspecified, as N)	Water	n.a.	n.a	n.a	0,000
Nitrosamine-methyl-phenylethyl-	Air, Water, Soil	164,2	2	28,01	0,171
Nitrosoheptamethyleneimine	Air, Water, Soil	142,2	2	28,01	0,197
Nitrosomethylethylamine, N-	Air, Water, Soil	88,1	2	28,01	0,318
N-methyl o-sec-butyl phenyl carbamate	Air, Water, Soil	207,3	1	14,00	0,068
N-Nitrosodiethylamine	Air, Water, Soil	102,1	2	28,01	0,274
Norflurazon	Soil	303,7	3	42,00	0,138
Orbencarb	Air, Water, Soil	257,8	1	14,01	0,054
Oryzalin	Soil	346,4	4	56,00	0,162
Oxadixyl	Air, Water, Soil	278,3	2	28,00	0,101
Oxasulfuron	Soil	406,4	4	56,00	0,138
Oxydiazon	Air, Water, Soil	345,2	2	28,00	0,081
Paclobutrazol	Air, Water, Soil	293,8	3	42,00	0,143
Paraquat dichloride	Air, Water, Soil	257,2	2	28,01	0,109
Parathion	Air, Water, Soil	291,3	1	14,01	0,048
Particulates, < 10 um	Air,Water	n.a	n.a	n.a	0,054
Particulates, < 10 µm	Air, Water	n.a	n.a	n.a	0,054
Particulates, < 2.5 µm	Air	n.a	n.a	n.a	0,081
Particulates, > 2.5 µm, and < 10 µm	Air	n.a	n.a	n.a	0,028
Particulates, unspecified	Air	n.a	n.a	n.a	0,062
Penconazole	Air, Water, Soil	284,2	3	42,00	0,148
Pencycuron	Air, Water, Soil	328,8	2	28,00	0,085
Pendimethalin	Air, Water, Soil	281,3	3	42,02	0,149
Pethoxamid	Soil	295,8	1	14,00	0,047
Phenmedipham	Air, Water, Soil	300,3	2	28,01	0,093
Phosalone	Soil	367,8	1	14,00	0,038
Phosphamidon	Air, Water, Soil	299,7	1	14,00	0,047
Pirimiphos methyl	Soil	305,3	3	42,00	0,138
Primisulfuron-methyl	Air, Water, Soil	468,3	4	56,00	0,120
Prometryn	Soil	241,4	5	70,00	0,290
Pronamide	Air, Water, Soil	256,1	1	14,01	0,055
Propachlor	Air, Water, Soil	211,7	1	14,00	0,066
Propamocarb	Air, Water, Soil	188,3	2	28,00	0,149
Propanil	Air, Water, Soil	218,1	1	14,01	0,064
Propaquizafop	Air, Water, Soil	443,9	3	42,00	0,095

Substance/Compound	Compartment	Molar mass [g/mol]	Nitrogen atoms	Nitrogen content [g/mol]	Nc - Nitrogen coefficient
Propiconazole	Air, Water, Soil	342,2	3	42,02	0,123
Propineb	Air, Water, Soil	226,4	2	28,00	0,124
Propoxur	Air, Water, Soil	209,2	1	14,00	0,067
Propylamine	Air, Water, Soil	59,1	1	14,01	0,237
Proquinazid	Soil	372,2	2	28,00	0,075
Prosulfocarb	Air, Water, Soil	251,4	1	14,00	0,056
Pyrazophos	Soil	373,4	3	42,00	0,112
Pyridate	Air, Water, Soil	378,9	2	28,01	0,074
Pyridine	Air, Water, Soil	79,1	1	14,00	0,177
Pyrifenox	Soil	295,2	2	28,00	0,095
Pyrimethanil	Air, Water, Soil	199,3	3	42,00	0,211
Pyriproxyfen	Air, Water, Soil	321,4	1	14,00	0,044
Pyrithiobac sodium salt	Soil	348,7	2	28,00	0,080
Quinalphos	Air, Water, Soil	298,3	2	28,00	0,094
Salicylanilide	Air, Water, Soil	213,2	1	14,00	0,066
Simazine	Air, Water, Soil	201,7	5	70,03	0,347
Starane	Air, Water, Soil	367,2	2	28,00	0,076
Sulfentrazone	Air, Water, Soil	387,2	4	56,03	0,145
t-Butylamine	Air, Water, Soil	73,1	1	14,01	0,192
Tebufenpyrad	Soil	333,9	3	42,00	0,126
Tebupirimphos	Air, Water, Soil	318,4	2	28,01	0,088
Tebutam	Soil	233,4	1	14,01	0,060
Terbacil	Soil	216,7	2	28,00	0,129
Terbuthylazin	Air, Water, Soil	229,7	5	70,03	0,305
Terbutryn	Soil	241,4	5	70,00	0,290
Thiabendazole	Soil	201,3	3	42,00	0,209
Thiacloprid	Soil	252,7	4	56,00	0,222
Thidiazuron	Soil	220,3	4	56,00	0,254
Toluene, 2,4-dinitro-	Air	182,1	2	28,00	0,154
Tralkoxydim	Air, Water, Soil	329,4	1	14,01	0,043
Triadimefon	Air, Water, Soil	293,8	3	42,00	0,143
Triazamate	Soil	314,4	4	56,00	0,178
Tridemorph	Soil	297,5	1	14,00	0,047
Trifloxystrobin	Air, Water, Soil	408,4	2	28,01	0,069
Triflumizole	Soil	345,8	3	42,00	0,121
Trifluralin	Air, Water, Soil	335,3	3	42,02	0,125
Triflusulfuron-methyl	Air, Water, Soil	492,4	6	84,00	0,171
Triforine	Soil	435,0	4	56,00	0,129
Trimethylamine	Air, Water, Soil	59,1	1	14,01	0,237
Triticonazole	Soil	317,8	3	42,00	0,132
Urea	Air, Water, Soil	60,1	2	28,01	0,466
Used Air	Air	n.a.	n.a.	n.a.	0,000
Vamidothion	Soil	287,3	1	14,00	0,049
Vernolate	Air, Water, Soil	203,4	1	14,00	0,069
Yellow ob	Air, Water, Soil	261,3	3	42,02	0,161

Substance/Compound	Compartment	Molar mass [g/mol]	Nitrogen atoms	Nitrogen content [g/mol]	Nc - Nitrogen coefficient
Zineb	Air, Water, Soil	275,7	2	28,01	0,102
Ziram	Air, Water, Soil	305,8	2	28,01	0,092

The results of the application of this step of the method to product systems analysed in this work are presented in the next chapter devoted to the application of the methodology.

2.2.5 Nitrogen impact assessment

In this step of the method aim is to obtain an impact assessment profile of the product system starting from the results of the nitrogen inventory, from which nitrogen-containing substances flows were defined. Starting from those flows, impacts will be obtained considering only impact categories in which characterization factor of nitrogen-containing flows are present. In detail, following steps are included within this phase:

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

As studied in Zuliani (2018) characterization methods proposed by JRC (Joint Research Centre, 2011), denoted as "ILCD 2011 Midpoint +", are chosen thanks to their reliability in the scientific community. In the mentioned characterization models only the midpoint one were taken into account because more suitable for the purposes of the proposed methodology, as well as more scientifically recognized.

In conclusion, nine impact categories at midpoint level were selected to be used in this work based on considerations done in Zuliani (2018). In Table 2 the characterization models chosen for each impact category needed are reported with related category indicators and classification by JRC expressed in three levels of recommendation. A multi-criteria approach has been chosen because many environmental impacts are related to nitrogen cycle and therefore different impact categories are associated with elementary flows of nitrogen containing substances, as seen in Chapter 1.

Table 2: Characterization models at midpoint recommended under the ILCD. The classification levels are the following: I – recommended and satisfactory; II – recommended but in need of some improvements; III – recommended, but to be applied with caution. (Joint Research Centre, 2011)

Impact category	**Best among existing characterization models**	**Indicator**	**Classification**
Climate change	Baseline model of 100 years of the IPCC (Forster et al., 2007)	Radiative forcing as global warming potential (GWP_{100})	I
Human toxicity, cancer effects	USEtox model (Rosenbaum et al., 2008)	Comparative toxic unit for humans (CTU_h)	II/III
Human toxicity, non-cancer effects	USEtox model (Rosenbaum et al., 2008)	Comparative toxic unit for humans (CTU_h)	II/III
Particulate matter - respiratory inorganics	Compilation in Humbert (2009) based on Rabl and Spadaro (2004) and Greco et al. (2007)	Intake fraction for fine particles (kg $PM_{2.5}$-eq/kg)	I/II
Photochemical ozone formation	LOTOS-EUROS as applied in ReCiPe (van Zelm et al., 2008)	Tropospheric ozone concentration increase	II
Acidification	Accumulated exceedance (Seppälä et al., 2006; Posch et al., 2008)	Accumulated exceedance (AE)	II
Eutrophication, terrestrial	Accumulated exceedance (Seppälä et al., 2006; Posch et al., 2008)	Accumulated exceedance (AE)	II
Eutrophication, aquatic	EUTREND model as implemented in ReCiPe (Struijs et al., 2009 in Goedkoop et al., 2009)	Residence time of nutrients in freshwater (P) or marine end compartment (N)	II
Ecotoxcity (freshwater)	USEtox model (Rosenbaum et al., 2008)	Comparative Toxic Unit for ecosystems (CTU_e)	II/III

Following, the next phase is the assignment of nitrogen inventory results to the selected impact categories. This can be done comparing the results of nitrogen inventory with the input streams considered by the different impact categories, exhaustively assigning the corresponding streams. From the chosen methods, after the classification, characterization factors are selected and the category indicator result can be obtained by:

$$category\ indicator\ result\ (I_k) = \sum_{i=1}^{n}\sum_{j=1}^{m} s_{i,j,k} * cf_{i,j,k}\ \left[\frac{category\ indicator\ results}{functional\ unit}\right] \tag{2.3}$$

where:

- *I_k is the indicator result for the k impact category;*

- *k is the identification index of the nitrogen-related impact category;*

- *$s_{i,j,k}$ is the amount of the i nitrogen-containing substance in the j compartment assigned to the k nitrogen-related impact category [emission unit/functional unit];*

- *$cf_{i,j,k}$ is the characterization factor for the i substance in the j compartment defined for the k nitrogen-related impact category [category indicator unit/emission unit]: $cf_{i,j,k}$=0 if the substance is not assigned to the k impact category after the classification;*

- *i is the identification index of the specific substance/compound;*

- *j is the identification index of the substance compartment of emission;*

- n is the total number of nitrogen-containing substance and compound for the product system;

- m is the total number of the compartments of emission.

In summary, equation (2.3) shows how inventory results are converted to a common unit that then is aggregated to form the category indicator results. In this work category indicators are specifically used to quantify environmental impacts related to nitrogen-containing substances that come out from the product system.

Characterization factors' value used within work referred to products systems analysed and they are presented in the next chapter. Specifically, the factors are derived from the above presented "ILCD 2011 Midpoint +" characterization methodology (Joint Research Centre, 2011) with the exception of the characterization factors for the category "Climate Change" which are updated to the result presented in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker et al., 2014), according to the method known as "IPCC 2013 GWP 100a".

Analysing the characterization factors provided by "ILCD 2011 Midpoint +" can be seen as some impact categories address specifically impact related to the nitrogen cycle. In fact terrestrial and marine eutrophication are influenced essentially by nitrogen containing substances. Acidification and freshwater ecotoxicity are also strongly influenced by those compounds.

After evaluating the category indicator results for all the impact categories selected, the nitrogen impact assessment profile can be formulated according to the following:

$$nitrogen\ impact\ assessment\ profile = \bigcup_{k=1}^{z} I_k \tag{2.4}$$

where:

- Ik is the indicator result for the k impact category as defined in (2.3);

- k is the identification index of the nitrogen-related impact category;

- z is the number of the selected impact categories (for the application presented in this work z=9).

The wide use in LCA studies of the characterization model proposed within this work and also their reliability recognized by the scientific community ensure that the presented midpoint characterization factors are a reliable way, from a scientific point of view, to quantify the link between substance and energy flows of a product system and the caused environmental impact.

It is important to highlight, that from impact profile results, information regarding impact related to the nitrogen cycle can be obtained. This differ respect what is obtained with the analysis performed with the "*total reactive nitrogen indicator*", which only presents general indications of the potential overall impact of the analysed system.

Following the ISO standard associated with life cycle impact assessment (LCIA) the characterization phase is the last mandatory step. After characterization other optional step can be assessed: normalization and weighting. Both of these phases are generally applied in practice for different reasons, such as identifying "important" impact categories, understanding the meaning of results by comparing with more familiar references or solving trade-offs between results.

2.2.6 Single score nitrogen impact indicator calculating

Starting from nitrogen impact assessment profile results, from the method proposed subsequent operations can be carried out to calculate a result for the assessment of impacts related to the nitrogen cycle, expressed as a single score indicator. Thise final steps are normalization and weighting. Even if, through those operations results will be more understandable and usable, it is introduce some subjectivity to the analysis that reduces its scientific value.

- *Normalization*

Normalization's aim is to provide and communicate information on the relative significance of the indicator results, and prepare for additional procedures, such as grouping and weighting. This process calculate category indicator's magnitude results relatively to a reference system (European Commission, 2021), in order to understand better the relative contribution of the studied system to the reference system for each indicator result, and which impact categories are more critical for the product system under study.

The normalization factors' source used in this work is the one suggested within product category rules developed with the Italian Ministry of Ecological Transition (Sammontana Spa, 2022) used by Sammontana in other to label some of its product with the brand "Made Green Italy". Thus, the normalization factors set used is taken from "*Understanding Product Environmental Footprint and Organisation Environmental Footprint methods*" (European Commission, 2021). It was developed considering an extensive collection of data on emissions and resources extracted at a global scale in 2010, gathering different sources and comparing them. Further details are available in Crenna (2019). Normalization factors selected, are presented in Table 3.

Table 3: Global normalisation factors based on European Commission (2021). Inventory coverage completeness, i.e. the extent to which the inventory data cover the list of flows available. Inventory robustness, i.e. the quality of data, assessed by considering both the combination of different sources and the adoption of extrapolation strategies. The attributed score is from I-highest to III-lowest.

Impact category	Udm	Normalization factors (PEF)	Inventory coverage completeness	Inventory robustness
Climate change	kg CO2 eq./person	8,10E+03	II	I
Marine eutrophication	kg N eq./person	1,95E+01	II	II/III
Freshwater ecotoxicity	CTUe/person	4,27E+04	III	III
Terrestrial eutrophication	mol N eq./person	1,77E+02	II	I/II
Acidification	mol H+ eq./person	5,56E+01	II	I/II
Photochemical ozone formation	kg NMVOC eq./person	4,06E+01	III	I/II
Particulate matter	kg PM2.5 eq/person	1,34E+01	I/II	I/II
Human toxicity, cancer effects	CTUh/person	1,69E-05	III	III
Human toxicity, non-cancer effects	CTUh/person	2,30E-04	III	III

Starting from the indicator results for the selected impact categories and applying the normalization factors presented in Table 3, the corresponding normalized indicator results are calculated as follows:

$$normalized\ indicator\ result\ (norm\ I_k) = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} s_{i,j,k} * cf_{i,j,k}}{nf_k} \left[\frac{equivalent\ person}{functional\ unit}\right] \quad (2.5)$$

where:

- norm I_k is the normalized indicator result for the k impact category;

- k is the identification index of the nitrogen-related impact category;

- $s_{i,j,k}$ is the amount of the i nitrogen-containing substance in the j compartment assigned to the k nitrogen-related impact category [emission unit/functional unit];

- $cf_{i,j,k}$ is the characterization factor for the i substance in the j compartment defined for the k nitrogen-related impact category [category indicator unit/emission unit];

- nf_k is the normalization factor defined for the k impact category: for this study the JRC normalization factors per person are used;

- i is the identification index of the specific substance/compound;

- j is the identification index of the compartment of emission of the nitrogen-containing substance;

- n is the total number of nitrogen-containing substance and compound for the product system;

- m is the total number of the compartments of emission (for this study m=3; the considered compartments are: air, water, soil).

The normalization factors proposed by within "*Understanding Product Environmental Footprint and Organisation Environmental Footprint methods"* (European Commission, 2021) are expressed as unit of measure of impact categories/person, so the normalized indicator results will be express as "equivalent person" related to the functional unit defined for the product system.

To summarize, after the normalization, the indicator results represent the magnitude of the impacts compared to the estimated reference impact per person, so they are all expressed in a common unit of measure and can be compared. Different condition respect the one reached after the characterization phase in which each indicator is expressed with its own unit of measure.

As in characterization phase, also in in this section normalized results can be expressed as a normalized nitrogen impact assessment profile defined as follow:

$$normalized\ nitrogen\ impact\ assessment\ profile = \bigcup_{k=1}^{z} norm\ I_k \qquad (2.6)$$

where:

- norm I_k is the normalized indicator result for the k impact category calculated as in (2.5);

- k is the identification index of the nitrogen-related impact category;

- z is the number of the nitrogen related selected impact categories.

Even though normalized results can be compared one another, because they have the same unit of measure, the operations that has been done introduce a degree of subjectivity in the assessment, deviating the results from the scientific nature that belongs to the characterization results.

- *Weighting and single score indicator calculating*

It may be appropriate, once obtained normalized results of the nitrogen impact assessment profile, to perform a weighting operation onto them. From ISO requirements in LCA studies (ISO 14044), weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choices. Weighting may help to:

- identify the most relevant impact categories;
- guide decision makers towards the most effective solutions for reducing environmental impacts;

- present results in an aggregated manner (up to a single score) for better decision support and for communication purposes.

As seen in normalization procedure, weighting introduces further elements of subjectivity because weighting factors differ depending on the party and their interest, influencing the final result.

Within this work, two types of weighting factors sets will be used. Firstly, weighting factors obtained through a standard weighting approach defined in "*Development of a weighting approach for the Environmental Footprint*" (Sala & Cerutti, 2018) has been used. To obtain those weighting factor not only a panel based approach has been used by the author's working group, but also an evidence based procedure together with expert's judgement influenced the final results. This set has been selected because suggested by the product category rules (Sammontana Spa, 2022) developed with the Italian Ministry of Ecological Transition for the ice cream industrial sector.

Secondly, a weighting method designed by Zuliani (2018) will be used. This procedure instead evaluates weighting factor based on data directly derived from the analysed system. In fact, weighting factors will be proportional to the amount of reactive nitrogen associated to each specific impact category. It means that, a greater weight is given to the impact categories to which are assigned the nitrogen-containing substances causing higher emissions in terms of reactive nitrogen.

In order to evaluate this type of weighting factors, firstly is needed to calculate reactive nitrogen for each impact category, summing the contributions of the different product systems in the case of a comparative analysis. So, category reactive nitrogen is evaluated according to the following:

$$category\ reactive\ nitrogen\ (CNr_k) = \sum_{x=1}^{p}\sum_{i=1}^{w}\sum_{j=1}^{m} s_{i,j,x,k} * Nc_{i,j}\ \left[\frac{mass\ unit\ of\ measure}{functional\ unit}\right] \quad (2.8)$$

where:

- *CNr_k is the reactive nitrogen calculated for the k impact category;*

- *$s_{i,j,x,k}$ is the amount of the i nitrogen-containing substance in the j compartment accounted for the x product system and assigned to the k nitrogen-related impact category [emission unit/functional unit];*

- *$Nc_{i,j}$ is the nitrogen coefficient for the i substance in the j compartment, calculated as in (2.1);*

- *i is the identification index of the specific substance/compound;*

- *j is the identification index of the compartment of emission of the nitrogen-containing substance;*

- *x is the identification index of the analysed system;*

- *k is the identification index of the nitrogen-related impact category;*

- p is the total number of analysed product systems: p=1 for single product system analysis, p>1 for comparative analysis of different product systems;

- w is the number of nitrogen-containing substance assigned to the k impact category after the classification (with w ≤ n, where n is the total number of nitrogen-containing substance for the whole product system);

- m is the total number of the compartments of emission (for this study m=3; the considered compartments are: air, water, soil).

Thus, weighting factors for each impact category are calculated through:

$$category\ weighting\ factor\ (wf_k) = \frac{CNr_k}{\sum_{k=1}^{z} CNr_k} \tag{2.8}$$

where:

- wfk is the weighting factor calculated for the k impact category;

- CNr_k is the reactive nitrogen calculated for the k impact category as in (2.8);

- k is the identification index of the nitrogen-related impact category;

- z is the number of the selected impact categories (for the application presented in this work z=9).

In conclusion, some peculiar characteristics can be highlighted for the weighting procedure above presented:

- lower degree of subjectivity respect panel-based approaches;
- weighting factors are evaluated every time;
- there is an amplification of that impact categories which present higher reactive nitrogen emissions;
- more expensive in terms of calculation efforts respect traditional weighting procedure;
- there are no value choices that influences weighting factors' value.

Once chosen the set of weighting factors, starting from normalized indicator results calculated in (2.5), the weighting nitrogen indicator result can be evaluated as follow:

$$weighted\ indicator\ (wtI_k) = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} s_{i,j,k}cf_{i,j,k}}{nf_k} * wf_k \tag{2.9}$$

where:

- wt I_k is the weighted (after normalization) indicator result for the k impact category;

- wf_k is the weighting factor calculated for the k impact category as in (2.8);

- other parameters and indices are defined with the same meaning and used in the same way as in the previous equations.

Then, the weighted nitrogen impact assessment that consist in the union of the weighted indicator results calculated for each select impact category, is evaluated by:

$$weighted\ nitrogen\ impact\ assessment\ profile = \bigcup_{k=1}^{z} wt\ I_k \qquad (2.10)$$

where:

- *wt I_k is the weighted indicator result for the k impact category defined as in (2.9);*

- *other parameters and indices are defined with the same meaning and used in the same way as in the previous equations.*

And finally, the single score nitrogen impact indicator for the analysed product system can be defined as follows:

$$single\ score\ nitrgoen\ impact\ indicator = \sum_{k=1}^{z} wt\ I_k \qquad (2.11)$$

where:

- *wt I_k is the weighted indicator result for the k impact category defined as in (2.10);*

- *k is the identification index of the nitrogen-related impact category;*

- *z is the number of the selected impact categories.*

To summarize, this indicator represents an assessment of environmental impacts of a product system related to the nitrogen cycle, expressed as a single stand-alone indicator.

It is important to remember that the weighting process introduces a further degree of subjectivity in the assessment, compared to the results of the nitrogen impact profile obtained after the characterization step. In particular the degree of subjectivity increases when the weighting set is selected on the basis of value-choices or panel weighting methods.

2.2.7 Interpretation of the results

The final phase of the proposed methodology, interpretation of the results, is aimed at consider the findings from all the operative steps (inventory, and assessment) to deliver results that are consistent with the defined goal and scope and reach conclusions, explaining limitations and providing recommendations.

Chapter Three
Method Application: Sammontana Case Study

Within this chapter the application of the methodology presented in Chapter 2 is done. In this work the case study is an Italian ice cream and pastry company called Sammontana S.p.a.

Bearing in mind the objectives that Sammontana has set for itself in terms of sustainability and the environment, and considering the trend that sees at an international level a progressive interest of the main stakeholders in other issues besides climate change, the company has decided to evaluate, with this preliminary work, which are the impacts of its products also in terms of influence in to the nitrogen cycle studying reference products for both ice cream and pastry production line for which it has the most accurate primary data.

3.1 Goal and scope definition

Four product systems of the Italian company Sammonta S.p.a are analysed in order to assess the impacts related to the nitrogen cycle of two ice cream products and two pastry products for a total of four product systems.

The objective of this case study are to:

- provide a description of impacts related to the nitrogen cycle arising from emissions derived by all the processes involved in the life cycle of the analysed products;
- apply the method previously described improving and amplifying information owned by Sammontana S.p.a about its products' impacts and nitrogen-containing substances emissions.

Specifically, the analysed product systems can be described as follows:

- "Barattolino Crema" commercialised in single bucket produced for the large-scale distribution (LSD) in Empoli (FI) plant (Figure 13);
- "Biscotto Amando Vaniglia e Frutti di Bosco" commercialised in both 4 pieces pack for the LSD and 18 pieces pack for Horeca channel. They are produced in Empoli (FI) plant (Figure 13);
- "Croissant Vegano Albicocca" commercialised in selling unit of 50 pieces for Horeca channel and produced in Vinci (FI) plant (Figure 12):

- "Fagottino Crema" commercialised in selling unit of 6 pieces produced for the LSD in Vinci (FI) plant (Figure 12).

Figure 13: Barattolino Crema (on the left) and Biscotto Amando Vaniglia e Frutti di Bosco (on the right)

Figure 12: Croissant Vegano Albicocca (on the left) and Fagottino Crema (on the right)

The function of the system can be identified as the development of the operation needed to make finished products edibles and marketable.

The functional units of the analysed systems can be described as in

- Barattolino Crema:

  1 kg of a "Barattolino Crema" (0.5 kg/pz), every piece has a cap and a bucket made of coated paper as a primary packaging and it is distributed on the national market and consumed by the end user.

- Biscotto Amando Vaniglia e Frutti di Bosco:

  1 kg of a "Biscotto Amando Vaniglia e Frutti di Bosco" (0.0559 kg/pz), every piece is wrapped with polypropylene as a primary packaging. Then, they are distributed on the national market with different secondary packaging depending on their final destination (Large-scale distribution or Horeca) and eventually consumed by the end user.

- Croissant Vegano Albicocca:

  1 kg of a “Croissant Vegano Albicocca” (0.0823 kg/pz) sold within plastic bags of 50 pieces as a primary packaging, distributed, through the channel Horeca, on the national market and consumed by the end user

- Fagottino alla Crema

  1 kg of “Fagottino alla Crema” (0,0817 kg/pz) sold within plastic bags of 50 pieces as a primary packaging, distributed, through the channel Horeca, on the national market and consumed by the end user

System boundaries have been defined by including all attributable processes to each product analysed in its life cycle taking into account data referring to the year of production 2021. All incoming and outgoing material and energy flows were therefore counted, considering all the phases of the life cycle of each product, as well as waste and emissions into the air (for example those generated by methane combustion processes), as shown in Figure 14 where a simplified scheme of the processes considered throughout the entire life cycle of the products is presented using a general structure valid for the different product systems. Following, the main processes and related input and output considered are briefly described:

- Production of raw materials and pre-treatments: starting from the extraction of primary resources, also considering the various intermediate treatment processes and transport;
- Production of packaging components: primary, secondary and tertiary packaging production processes;
- Production of the food under study: internal processes at the Sammontana plants in Empoli (FI) and Vinci (FI) aimed at the production of each reference, considering all the flows of matter and energy entering and leaving the analysed system, such as electricity and thermal energy, processing waste, by-products, auxiliary materials, etc.;
- Distribution of finished products: refrigerated transport of products to intermediate and final distribution centres, disposal of waste originating from the unpackaging of products;
- Phase of use of products: processes related to the consumption of the finished product, and energy consumption generated by the points of sale/ costumer house;
- End of life of products: processes related to the final disposal of the packaging that makes up each product.

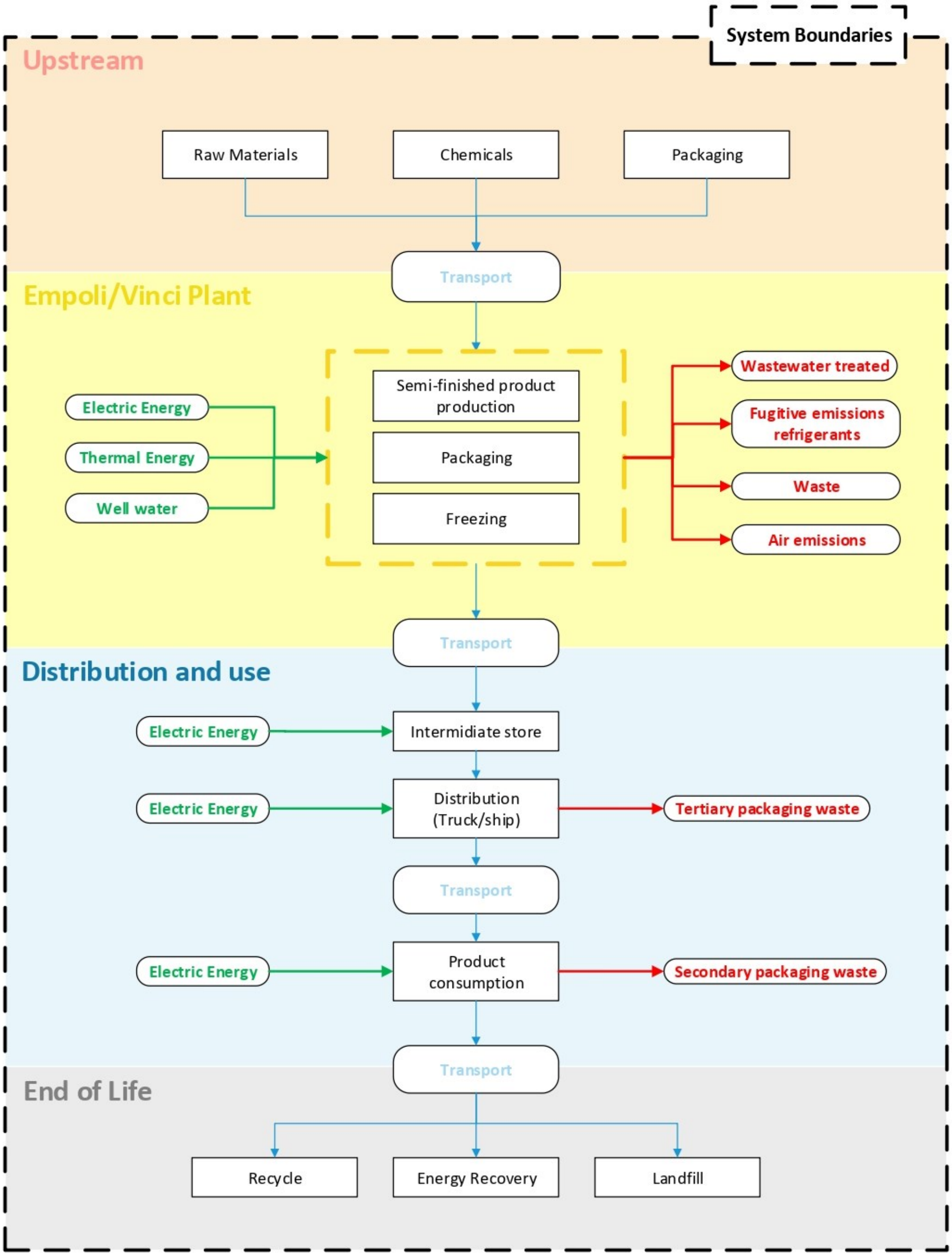


Figure 14: System boundaries general scheme for the analysed product systems

A mass-based cut-off was used, neglecting the set of material flows that together represent less than 1% of the incoming compressive flow. This 1% includes material flows for which it is impossible to collect data or which have a negligible mass compared to the process considered.

However, all processes for which data are available have been taken into account, even if their contribution is less than 1%. This choice is confirmed by similar LCA studies reported in the literature (Humbert et al., 2009).

Moreover, with reference to the modelling of waste, and specifically to those destined for recycling operations, the Circular Footprint Formula has been used, as described in “Suggestions for updating the Product Environmental Footprint (PEF) method” (Zampori & Pant, 2019).

The allocation consists in the distribution of the input and output flows of a unitary process or a product system between the product system subject to study and one or several other product systems (ISO 14044). This is necessary when a process has more than one output and is accomplished by dividing the overall environmental impact of the processes between the different output products. In accordance with the provisions of ISO 14040, allocation should be avoided through a division or expansion of system boundaries. Where allocation cannot be avoided, it is preferable to adopt the principle of allocation on the basis of physical quantities such as mass rather than economic quantities.

In this study allocation was performed on some fluxes within both Empoli and Vinci plant. Consumption of chemicals, refilling of refrigerant leaked, electrical and thermal energy consumption and waste were allocated to volumes/mass produced by the ice cream and pastry products covered by the analysis. Allocation was used because consumption were provided in aggregate form for all the production plant.

In the present study a model products’ life cycle was done through the commercial software SimaPro v.9.1 Analyst. In other to perform the product life cycle analysis, a set of databases recognized at international level were used: Ecoinvent v3.6, Agri-footprint version 5, and World Food LCA Database 3.5.

3.2 Description of the product systems

Representativeness and importance over the life cycle are main aspects that have guided the approach used in collecting data of the analysed products. Primary data referred to the year 2021 were collected for production, packaging and distribution processes, as these aspects were directly managed by the producer Sammontana S.p.A.

Moreover, concerning secondary data choice, critical considerations were done using six quality indicators: technological, geographical, temporal representativeness and completeness, precision and coherence. This analysis is based on information provided by *Understanding Product Environmental Footprint and Organisation Environmental Footprint methods* (European Commission, 2021).

Each indicator was scored from 1 to 5, corresponding to “excellent”, “very good”, “good”, “fair”, and “poor” quality level. Then, the average value determines the overall data quality.

Based on these criteria, data quality used for the study is very good because: data have been considered for all relevant processes, the primary data have been carefully collected by the company and the secondary data come from internationally recognized and validated datasets.

As mention briefly in the first part of this chapter ice cream and pastry products systems can be divided into phases: production of raw materials and pre-treatments, production of packaging components, production of the food under study, distribution of finished products, use phase and end of life.

Due to the fact the production phase and the use phase are modelled with some differences between ice cream and pastry product, their production system description will be separated. A different consideration respects what is done in Figure 14, where the illustration presented is appropriate for both types of food production.

3.2.1 Product system for Ice Cream products

Hence, related to the processes above described, a summary of the data considered for the analysis in relation to the different process units of ice cream product systems is presented:

- Production of raw materials and pre-treatment:

  This phase concerns the extraction and processing processes of raw materials that are used in the production process of the products under study.

  For most of the ingredients it was possible to use specific databases, taking into account the set of all the processes interconnected to their realization, such as the cultivation phase and related operations (e.g. irrigation, use of fertilizers, etc.), the transformation of the raw material and the related transport to the production plant located in Empoli (FI). Where specific databases were not available, literature data were used. For some minority ingredients, namely flavourings, thickeners and colourants, generic databases have been used. In the packaging process of the products under consideration, all primary, secondary and tertiary packaging were considered, taking into account the production and transport processes from the various producers to the plant in Empoli (FI) where the packaging of the products under study takes place, adopting a "from cradle to industry gate" approach.

- Production of packaging components:

  This phase concerns the extraction and processing processes of packaging materials that are used in the production process of the products under study.

In the packaging process of the products under consideration, all primary, secondary and tertiary packaging were considered, taking into account the production and transport processes from the various producers to the Empoli (FI) plant where the products under study are packaged, adopting a "from cradle to industry gate" approach.

- Ice cream production

The ice cream production process is mainly divided into 3 phases: the preparation phase of semi-finished products, the production phase and the hardening phase of the ice cream itself.

During the production phase of semi-finished products, depending on the ice cream recipe, the different raw materials are dosed and undergo pre-treatments preparatory to the production of the ice cream mixture. The powdered ingredients undergo the dissolution process, the liquid ingredients are stirred and mixed, finally, the usual ingredients such as butter are dissolved. Once the different ingredients have been mixed according to the recipe, the mass obtained is pasteurized reaching a temperature of 87°C for a few seconds and then cooling takes place. Once pasteurized, the mixture leaves the pasteurization plant at a temperature between +4°C and +8°C and is stored for 24/48 hours in special maturation vats placed under slow stirring.

After the specific maturation time, the ice cream mixture (liquid) is ready to be transferred from the vats to the production lines and, specifically, to the machines called "freezer" where the mixture undergoes a quick freezing, which varies between -4 ° C / -6 ° C, at the same time as the air blow which thus causes an increase in volume, passing from liquid to semi-solid, and assuming the usual characteristics of ice cream. The positioning phases of the primary packaging (for example, containers or wrappers etc.) on the appropriate conveyor belts are then verified; the passage of the containers under the dispensers of ice cream mixture, and possibly of gaskets, and the automatic closing phase of the package.

The product then enters the freezing tunnel, where it encounters a forced ventilation of cold air at -40 ° C and stays in this environment for about 35/45 minutes. Thanks to the tunnel, the product undergoes a first partial hardening. Then the product comes out of the tunnel and is ready to be packaged with secondary packaging (box) and at the end of the line with tertiary packaging (stretch film and pallet). The packaged product is then stored at the cell of the headquarters of each plant or at the Montelupo cell, where the freezing process is carried out keeping the temperature at about -28 ° C / -33 ° C.

- Product Distribution

  The distribution phase was modelled considering the different types of destination of the finished products leaving the Empoli plant. For the products in question, it was observed that the destinations all fall within the Italian national market. In this phase, account was taken of emissions from the movement of refrigerated road vehicles and consumption of energy and refrigerants due to the permanence in the logistics platforms of the large-scale distribution.

- Phase of use of the products

  The use phase for the products distributed in the GDO channel includes storage at household units through emissions deriving from energy consumption for product cooling. Emissions from the transport of the product purchased by the consumer to the point of sale and transported to the point of consumption are also included.

  With regard to the phase of use of the products distributed in the Horeca channel, since the finished product is consumed at the point of sale, no further impact contributions deriving from any transport of the product and its maintenance in the cold have been assumed.

- End of life of products

  In the end-of-life phase, all the elements constituting the primary packaging of each product analysed are considered. Depending on the type of material disposed of, landfilling, incineration and recycling processes were considered. Emissions from the transport of waste from the collection point to the site where final disposal takes place are also included. On the other hand, the end of life of each food, linked to the process of human digestion and the purification of the related biological fluids, has not been considered, as it is difficult to estimate these emissions.

Afterwards, a detailed description of databases used to model mass and energy fluxes as an input and output of processes in Empoli (FI) plant to produce “Barattolino Crema” and “Biscotto Amando” is presented. The following list is based on Sammontana product’s life cycle phases here analysed.

- Raw Materials:
  Products under study are made using recipes in which quantity and raw materials typology are written. Below almond paste, biscuit cereals and fruit, butter, carob seed flour, citric acid, cream, defatted almond flour, dextrose monohydrate, glycose syrup,

inulin, juice of various fruits, mono and diglycerides, pectin, refined coconut oil, skimmed milk powder, sugared egg yolk, sugar, tapioca starch, water and other additives are described. In other to distinguish between "Barattolino Crema" and "Biscotto Amando"'s raw materials letter B is indicate for the first and letter A is associated to the second product.

Almond paste (A): the ingredients used are almonds and water. For this raw materials primary data are present for the electricity and heat used during almond grinding and water for irrigation. Starting from an World Food LCA Database primary data has been added. In that database emissions for the establishment and the productive phase of the almond tree were included: tree nursery, soil cultivation, planting trees, sowing grass, installation of trellis system, irrigation, fertiliser and pesticide usage and harvesting.

Biscuit cereals and fruit (A): the set of ingredient considered is oat flakes, rice flour, corn starch, coconut oil, beet and cane sugar, caramel E150A, apple preparation (apple juice, sugar, pectin, citric acid, water), pectin, dehydrated blueberries (blueberries, sugar and sunflower oil), salt and aromas. For the modelling of oat flakes, World Food LCA Database 3.5 has been used in which the processes of sowing, pesticide application, harvesting and grain drying is included. For the rice flour, starting from white rice modelled with Agri-footprint 4.1 a process of dry milling has been used which consists of several processing steps including receiving of rice, and multiple grinding and sieving steps.

Butter (B): modelled using production database presents in Ecoinvent 3. Butter is a dairy product made by churning fresh or fermented cream or milk. This activity covers main flows related to butter production from cream. From primary data obtained by the supplier raw material and energy in input has been selected properly based on the origin country of the supplier.

Carob seed flour (A,B): without any available database for this raw material, the agricultural production process of soybean has been used as an approximation to account its emissions. Soybean production is modelled through an Ecoinvent database within which all machine operations like soil cultivation, sowing, fertilisation, weed control, combine-harvest, transport from field to processing centre and drying of beans are included.

Citric acid (A): an Econinvent is used to describe that citric acid is produced by a submerged fermentation process which employs a strain of the micro-organism Aspergillus niger to convert sugar into citric acid.

Cream (B): modelled using an Ecoinvent dataset which assess the cream production as a coproduct of the milk production.

Defatted almond flour (A): for the almond, as in almond paste, the reference databased used is Ecoinvent. Instead, for the production of the flour datasets chosen are the one of wheat flour which include inputs of wheat from various countries, transport inputs, water, heat from combustion of natural gas and electricity and an output of waste water to waste water treatment. Reference for flour production are from Agri-Footprint databases.

Dextrose monohydrate (A): obtained from corn starch. It is modelled with a World Food LCA Database which take count of all the production phases as described for the Glucose syrup.

Glucose syrup (A,B): modelled through the World Food LCA Database. Produced from corn, steps included within the dataset are: steeping to soften the hard corn kernel, wet milling and physical separation. Then through enzymes the glucose molecules structure is decomposed leaving the syrup.

Inulin (A): without any available database for this raw material, an assumption has been done modelling inulin with an Ecoinvent dataset that describe the production of fatty acids from vegetables oils.

Juice of various fruits (A): this raw material comprehend different concentrated juice made from apple, elderberry, red currants and lampoon. All of this concentrated juices has been modelled through secondary data following the work of Beccali et al. (2010) because no dataset are available to model those products. Through this approach cultivation, pasteurization, concentration, cooling and packaging with all the energy consumption are taken in account. For the starting fruits and consumption Ecoinvent has been used.

Mono and diglycerides (A,B): modelled using Ecoinvent database which asses the production of fatty acids from palm oil.

Pectin (A): without any available database for this raw material, pectin has been modelled using Ecoinvent dataset that express the production of a general fatty acid material

Refined coconut oil (A): modelling of this raw material was carried out by adopting as a starting point the Agri-footprint database, modifying all input datasets with Ecoinvent 3.6 databases. The use of this dataset as a starting point was dictated by the fact of being able to consider all the contributions related to the refining process of raw coconut oil which, during processing, also generates the soap co-product.

Skimmed milk powder (B): the modelling was carried out by considering information relating to several databases. For the fresh skimmed milk from which skimmed milk powder is obtained, the Ecoinvent was used. In addition, the evaporation process, necessary for the first removal of milk water content, was taken into account and modelled by Ecoinvent dataset, and further spray treatment, modelled using an

Ecoinvent dataset again. The mass balance was ensured taking into account the information included in the datasets used, which leads to a total demand of 11.68 kg of fresh skimmed milk for the final production of 1 kg of skimmed milk powder. Each dataset, where possible, has been modified on the basis of each different country of origin of the various producers.

Sugared egg yolk (B): these raw materials were modelled using the Agri-footprint database as a starting point, modifying all input datasets with Ecoinvent 3.6 databases. The use of this dataset as a starting point allowed to consider all the material flows and processes involved in egg production, including emissions due to enteric fermentation and manure management related to the agricultural phase. In addition, to consider the contributions deriving from the production of sweetened egg yolk, sugar was taken into account through the Ecoinvent dataset suitably modified according to the different country of origin of each producer, and the contributions of thermal and electrical energy based on literature information (Pelletier, 2017). In shaping these raw materials, account was taken of the fact that during the production of the yolk, the co-produced egg white and the waste represented by the shell are also obtained.

Sugar (A,B): modelled through Ecoinvent dataset which asses the production of sugar and of the co-product molasses and beet pulp that remain after treating sugar beet's roots.

Tapioca starch (A): a Agri-footprint dataset is able to describe the production of this raw material which assess its extraction from cassava plant.

Water (A,B): water needed during the production process in Empoli plant has been modelled starting from Ecoinvent dataset in which water flows has been regionalized.

Annatto (B), Aroma (A;B), Elderberry extract (A), K-carragenina (A),Sodium alginate (B), Vanilla beans (A): since no primary or secondary data is available for these types of raw materials and considering the negligible percentages for these subjects it was decided to take the Ecoinvent dataset "Chemical, organic {GLO}| production | Alloc Rec,U".

For all the described raw materials it has been considered, as transport process from the producer to the supplier, and then from each supplier to Empoli production plant, a general Ecoinvent dataset. That has been done because primary information weren't available for the right vehicle type. Furthermore, raw materials that needs a transport at lower degrees a specific dataset taken from Ecoinvent has been selected.

- Packaging:

As used in raw materials description, packaging will be divided between “Barattolino Crema” and “Biscotto Amando” with the symbol B for the first product and A for the second one.

- Primary packaging:

Can and cap (B): both can and cap for the “Barattolino Crema “ are built with poly-coated paper, so with an internal layer of polyethylene in contact with the product and an external layer made of paper. Both the material are modelled with an Ecoinvent dataset. For the polyethylene the dataset asses the production starting from the reaction at high temperature, its thermal control through a heat sink that take the heat generated by the exothermic reaction to recover it and finally extrusion and palletisation. In this phase also the ink used to print on it labels is taken into account modelling it with an Ecoinvent dataset which includes all the materials needed and the energy consumed.
Peelable film (B): used upon the cap of Barattolino product in other to isolate it from the external environment. Composed of a layer made of polyethylene terephthalate and a layer of polyethylene attached to each other by glue. All of these elements were modelled through Ecoinvent databases which asses their production impacts from the raw material until the delivery to the supplier.
Wrapping (A): used as a primary packaging for Biscotto Amando. Made of polypropylene and described with an Ecoinvent dataset in which operation included are: starting with monomers and comonomers entering the polymerisation plant and energy supply is included in terms of heat production inside the battery limits of the plant.

- Secondary packaging

Glue (A,B): modelled using an Ecoinvent dataset which describe the production of an urea formaldehyde resin with glue properties. The manufacturing process is considered with consumption of raw materials, energy, infrastructure and land use, as well as the generation of emissions to air.
Cardboard Box (A,B): modelled using two Ecoinvent datasets that assess impacts related to the production of the cardboard and the kraftliner part. The dataset includes pulp preparation, paper production and converting into sheets, packaging energy consumption, energy production on-site (natural gas, heavy fuel oil and biogas combustion), internal waste water treatment. The process for the production of Kraftliner starts with the reception of wood and wood chips at the mill gate. Processes include chipping, screening of chips, cooking to pulp for (kraft cooking process). The pulp produced is defiberized in refiners, screened and washed before being sent to the

paper mill. Then the stock passes through one or two head boxes onto the paper machine.
Cardboard Case (A): modelled as the cardboard box

- Tertiary packaging

Extensible film (A,B): used to wrap the material placed on pallets. Made of polyethylene and model with two Ecoinvent datasets: one that asses the production of PE as describe for wrapping material and the other models the extrusion process needed to produce the film.
Pallet (A,B): for this material, made of wood in the EU standard format, a reuse factor of 20 times has been assumed. Within the modelled pallet materials and production processes were included through Ecoinvent datasets.

- Production:

The energy components used during the production cycle are mainly two: electricity and methane for the production of thermal energy in the form of steam and hot water. In 2021, to meet the energy needs of the Empoli plant, part of medium-voltage and thermal electricity was purchased (around 44%) and the other part was generated by the company's cogeneration unit (around 56%). In addition, part of the low-voltage energy was generated by the photovoltaic system.

The emissions deriving from the consumption of natural gas boilers have been modelled using a World Food LCA database with some modification in other to consider energy Italian market mix. Considering the emission analysis performed during the year, primary data were also added in other to asses reactive nitrogen emissions associated with boiler combustion processes. For the electric energy consumption different Ecoinvent datasets were used depending on the voltage considered: medium and low voltage. For the production and self-consumption of photovoltaic energy produced in the Empoli plant another Ecoinvent dataset has been used. Empoli plant presents also a cogeneration unit able to produce thermal and electric energy by combustion of methane.

Those dataset are modified using the emission factor for electrical energy Italian residual mix as proposed by AIB – Association of issuing bodies in the report (Treyer & Bauer, 2016). A more detailed description on how the italian residual mix is applied can be found in the Appendix B.

Also for the cogeneration unit, air emissions analysis are available and used to assess the reactive nitrogen air emissions. The reactive nitrogen emissions associated to the methane combustion in the cogeneration unit were redistributed to the thermal and electrical energy generated based on the kWh of thermal and electrical energy obtained by the total amount of methane burned in 2021.

A simple scheme that sum up all the sources of energy above described for Empoli's plant is present in Figure 15.

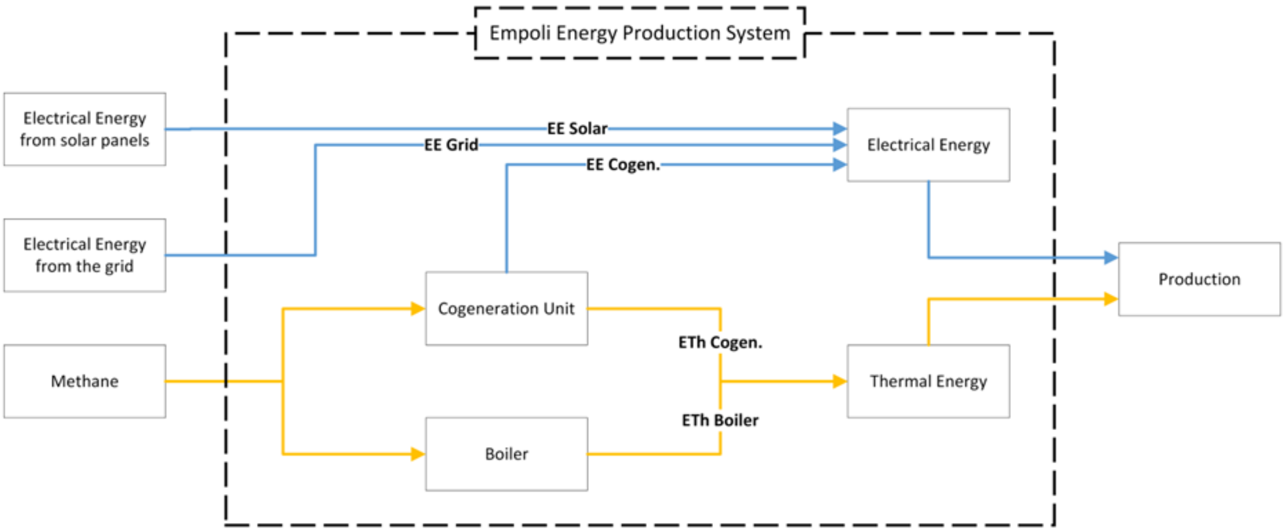


Figure 15: Empoli energy sources scheme. Blue line addresses electrical current flows and yellow lines present a thermal energy flow

For the transformation of electrical energy, purchased in high voltage and used on medium, the model referred to losses as predicted by Ecoinvent manuals.

For what concern chemical compounds used during production phases in Empoli's plant, they were modelled using primary information directly from Sammontana and instead generic dataset were used for compound for which no specific dataset is available. For every compound considered, its production process and transportation from supplier were modelled.

As regards refrigerants, all quantities used during refrigerant refilling operations were taken into account, corresponding to mixtures R507 and R404, two mixture of hydrofluorocarbons. If there was no compound in the databases, the dataset "Refrigerant R134a {GLO} was used| market for | Cut-off, U". Also ammonia is used for refrigeration purposes and its refilling operation were considered. The amount lost is considered emitted in the atmosphere.

Finally, waste streams are generated from the production process resulting from the entry of secondary packaging used to transport the primary packaging, also used in the packaging process, as well as the production waste generated in the packaging phases. To account for the emissions of the waste disposal processes, the end-of-life processes of the different CER ("Catalogo Europeo dei Rifiuti" or EWC, European Waste Catalogue) codes considered were modelled, using primary information from the Sammontana company. Table 4 shows the percentages used in the various end-of-life scenarios of the main types of waste for the Empoli plant.

Table 4: Waste treatment scenario for different Empoli's materials

Waste type	**Recovery**	**Incineration**	**Landfill**	**Biological treatment**
Unusable waste for consumption or transformation	0%	0%	0%	100%
Sludge from wastewater treatment	0%	0%	0%	100%
Paper/Cardboard	100%	0%	0%	0%
Plastic	100%	0%	0%	0%
Mixed packaging	100%	0%	0%	0%
Mixed packaging with dangerous substances	98%	0%	2%	0%
Iron	100%	0%	0%	0%

Waste water generated in the production process are not sent for treatment of material recovery but are directly disposed of in specific disposal facilities present in the plant. Primary data which consider the reactive nitrogen emission on the water compartment after the cited facilities were considered for the Empoli plant.

- Product Distribution:

The distribution of all the products in question takes place in the Italian market. The primary distribution, or between plant and wholesaler is characterized by weighted average distances obtained on the basis of primary information provided directly by the company logistics hub. To assess the distribution Ecoinvent dataset has been used. For "Barattolino Crema" primary distribution consist of 285 km by car and 4 km by ship on average for every product. For "Biscotto Amando" primary distribution consist of 850 km by car and 10 km by ship on average for every product.
Due to the lack of data in relation to secondary distribution, for which Sammontana S.p.A. does not hold operational or financial control, a distance travelled of 293 km by car and 5,9 km by ship has been assumed for each product. Secondary distribution consider the transport between wholesaler and the point of sale.
In conclusion, for large-scale distribution (LSD) products, the distribution from the point of sale to the final consumer has been modelled on the basis of the indications given in "*Suggestions for updating the Product Environmental Footprint (PEF) method*" (Zampori & Pant, 2019) which assumes an average distance of 5 km covered for 62% by cars, for 5% by vans while the remaining 33% is not attributed any

impact. However, even if the description of the last transport is done in this phase its impact is associated to the use phase.

Within the distribution phase, impact related to secondary and tertiary packaging disposal has been assessed. Following Zampori & Pant (2019) work, percentages used to assess the disposal scenario for above mention material are Table 5.

Table 5: Disposal scenario for waste considered in distribution phase (Zampori & Pant, 2019)(Zampori & Pant, 2019)

National waste disposal scenarios			
Material	**% Recycled**	**% Incineration**	**% Landfill**
Plastic	28%	25.2%	46.8%
Poly-coupled	73%	9.4%	7.6%
Paper/cardboard	73%	9.4%	17.6%
Wood	39%	21.4%	39.6%

During production, some scraps are created. It is assumed that during distribution a 5% of scraps is formed and also a 2% as well during use phase, analysed in the next paragraph. Following Zampori & Pant (2019) work, their disposal is managed by:

- Anaerobic digestion (25%): Biowaste {CH}| treatment of biowaste by anaerobic digestion | Cut-off, U;
- Landfill (32,5%): Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U;
- Incineration (17,5%): Biowaste {GLO}| treatment of biowaste, municipal incineration | Cut-off, U;
- Composting (25%): Biowaste {CH}| treatment of biowaste, industrial composting | Cut-off, U.

During the distribution phase, most of the finished product is stationed at the cold warehouse of the Sammontana logistics base (Montelupo) of the company. Its consumption of electricity and refrigerants is taken in to account within this phase. The product preservation processes along the entire distribution chain from the GDO platform to the hypermarket cell to the refrigerated counter were also considered.

Also for Horeca products the energy consumption associate to the refrigeration within the bar is accounted in this phase.

- Use Phase:

  Ice cream products analysed in this work presents both a GDO and a Horeca distribution type. For the GDO distribution procedure, the product reach the retailer and then, after being bought, arrive to consumer house where it is consumed. So within this phase, it is considered impacts related to:

- transport of the purchased product to the consumer's home.
- electricity consumed by the domestic refrigeration unit for cooling the product.

Based on Point et al. (2012) work it was assumed that distance travelled by consumer to bring the product at home is 5 km. Then an Ecoinvent dataset has been used to describe the consumer’s vehicle.

The electricity consumed by the domestic refrigeration unit for the maintenance of the product was evaluated considering a period one week within a freezer, an annual energy consumption of 180 kWh and a freezing cell capacity of 20 l. Energy consumption was therefore estimated depending on the volume occupied by each product in the freezer.

For products associated with the Horeca channel, due to the fact that products are consumed directly in the point of sale no other impact are associated in this phase because energy consumption to keep cold the product has been assessed in the previous phase.

- End of life products:

  The last modelled process corresponds to the last phase of the life cycle of each product studied, i.e. the end of life, which has been modelled considering the multi-component nature of each product. The end-of-life phase of each of the primary packaging has been modelled by distinguishing for each element three different types of disposal: recycling, incineration and disposal in landfills. The percentages of destination to the individual disposal processes for products destined for the Italian market are the same shown in Table 5. To transport all the primary packaging material towards their treatment location, 30 km were assumed as the distance travelled.

  Finally, the impacts related to the human digestion process of ice cream and the related purification treatment of biological fluids were not considered as they were difficult to model and presumably of very modest impact.

  The end-of-life packaging disposal/treatment scenarios were then modelled using the Circular Footprint Formula implemented with the parameters needed taken from *Suggestions for updating the Product Environmental Footprint (PEF) method*" (Zampori & Pant, 2019).

3.2.2 Product system for Pastry products

Hence, related to the processes above described, a summary of the data considered for the analysis in relation to the different process units of pastry product systems is presented:

- Production of raw materials and pre-treatment:
  This phase concerns the extraction and processing processes of raw materials and packaging components that are used in the production process of the products under study.
  For most of the ingredients it was possible to use specific databases, taking into account the set of all the processes interconnected to their realization, such as the cultivation phase and related operations (e.g. irrigation, use of fertilizers, etc.), the transformation of the raw material and the related transport to the production plant located in Vinci (FI). Where specific databases were not available, literature data were used. For some minority ingredients, namely flavourings, thickeners, emulsifiers and colourants, generic databases have been used.
  In the packaging process of the products under consideration, all primary, secondary and tertiary packaging were considered, taking into account the production and transport processes from the various producers to the plant in Vinci (FI) where the packaging of the products under study takes place, adopting a "from cradle to industry gate" approach.

- Frozen pastry production:
  Production process of pastry product is made of different phases:
  - Raw material first check:
    A first control is done onto the raw materials arrived from the supplier. Their code is checked with the one stored in Sammontana’s logistic system. Then, if the first control is passed, the raw materials is stored in suitable environment, in relation to the specific instructions on the packaging and based on the internal instructions.
  - Dough preparation:
    Following a scheduled production program, raw materials needed are brought to the dough mixer machine. Employees put the right amount of material needed and, when all ingredients are within the tank, they turn on the mixer.
    Recipes are used to add the right amount of ingredients.
    When the dough is ready, it will be sent to the production line.
  - Dough and margarine coupling:
    The dough is brought to an elevator which raise it and where it starts to be extruded and laminated. When the right thickness and shape is reached on the

centre of the laminated dough a layer of margarine/butter is disposed. Margarine/butter layer is then covered with the remaining dough creating an alternate system of dough and fat.

- Dough resting/ dough lamintaion:

  Subsequently, the carpet of dough formed passed through a multi-roller and bending machine, before entering the refrigerated tunnel for rest.

  At the exit of the tunnel, the belt passes through a second multi-roller and a second bending machine before undergoing the last lamination and being sent for calibration, which makes it suitable to be cut and formed according to the different types of product.
- Forming/ Filling/ Folding:

  The right height and thickness is reach within the calibration phase. The dough thus prepared passes to the forming machine where it is cut and folded into the desired shape. Depending on the type of product, there is also a filling machine on the line that inserts the filling inside. At the end, the forming machine deposits the products on the trays to be sent to the next production phases.
- Leavening:

  If the product need to leaven it is send to the leavening tunnel. After some hour and a strict control of the temperature and humidity, the product has the right dimension and characteristic for the next phase
- Gilding:

  A liquid product is sprayed on the product surface in order to obtain a amber colour during cooking. After gilding, if needed, the product goes under a machine which cover it with sugar.
- Freezing

  The product, through a conveyor belt, goes with a freezing tunnel. The temperature within the tunnel ranges from -25 to -33 as a function of the product.
- Packaging/canning and taping

  Then a specific number of pieces is counted and put within a polyethylene bag and sealed. Finally, a code is printed on the bag to identify it and fill a cardboard box sealed with adhesive tape.
- Labelling and palletising

  Different information are then printed on a label attached to the box.

  Through a automatic palletiser boxes are organized ready to be shipped.

  Before the pallet is shipped it is stored in specific cells.

- Product Distribution

  The distribution phase was modelled considering the different types of destination of the finished products leaving the Vinci plant. For the products in question, it was observed that the destinations all fall within the Italian national market. In this phase, account was taken of emissions from the movement of refrigerated road vehicles and consumption of energy and refrigerants due to the permanence in the logistics platforms of the large-scale distribution and in the points of sale.

- Phase of use of the products

  The use phase for the products distributed in the GDO channel includes storage at household units through emissions deriving from energy consumption for product cooling and cooking. Emissions from the transport of the product purchased by the consumer to the point of sale and transported to the point of consumption are also included.

  With regard to the phase of use of the products distributed in the Horeca channel, the emissions deriving from energy consumption for cooling and cooking have been considered, but in this case they take place directly at the point of sale.

- End of life of products

  In the end-of-life phase, all the elements constituting the primary packaging of each product analysed are considered. Depending on the type of material disposed of, landfilling, incineration and recycling processes were considered. Emissions from the transport of waste from the collection point to the site where final disposal takes place are also included. On the other hand, the end of life of each food, linked to the process of human digestion and the purification of the related biological fluids, has not been considered, as it is difficult to estimate these emissions.

Afterwards, a detailed description of databases used to model mass and energy fluxes as an input and output of processes in Vinci (FI) plant is presented. The following list is based on Sammontana product's life cycle phases.

- Raw Materials:
  Products under study are made using recipes in which quantity and raw materials typology are written. Below crema, egg yolk, fresh yeast, gluten, granulated sugar, malt rustyback, malt spray, margarin, enzyme improver, salt, teff seeds, semi-finished apricot, sourdough, sugar pearl, teff flour, water, wheat flour are described. In other to distinguish between Croissant Vegano and Fagottino Crema' raw materials a letter V is indicate for the first and letter F is associated to the second product.

Cream (F): this raw material is composed of different elements like water, sugar, glucose syrup, corn starch, milk powder, egg yolk, refined coconut oil, aroma and salt.

Water, sugar, glucose syrup, corn starch, milk powder, aroma, egg yolk have already been described. Then salt Ecoinvent dataset modelling includes the solution mining process of sodium chloride, its cleaning to remove impurities, and the drying step.

Egg yolk (F): it is modelled based on the work of Pelletier (2017), from which electrical and thermal energy needed for egg separation and production has been taken. Allocation of impacts has been based on mass distributed over egg yolk and egg white.

Fresh yeast (F,V): modelled using a Ecoinvent dataset in which yest are obtained from fermentation of whey including materials, energy uses, infrastructure, and emissions.

Gluten (F,V): modelled using Agri-Footprint datasets in which process describes the production of dried gluten meal from a maize wet milling process.

Granulated sugar (F,V): modelled using the database Econinvent appropriately by modifying the place of origin. It was considered a grinding process by attributing its electricity consumption via Ecoinvent database.

Malt rustyback (V): composed of malt extract and toasted wheat bran both modelled following Agro-footprint datasets. The bran comes from the wheat dry milling process already described. For the malt extract the inventory includes the processing water and energy for the malting process, as well as the barley grain input.

Malt spray (F): form available data sheet, malt spray is composed of barley malt mixed with corn. Both can be modelled through datasets available in software used. The barley has been already analysed. Instead, for corn an Ecoinvent dataset has been used.

Margarine (F,V): it is made using palm oil, sunflower oil, water, salt, mono and diglycerides and citric acid. To model palm oil a Econinvent datasets has been used in which processes considered are from the extraction of palm oil to the refinement operation and delivery to costumers. Sunflower oil is modelled using a Agri footprint dataset within which system boundaries of the process are from receiving of crude sunflower oil to delivery of refined sunflower oil and soap stock at factory gate. Also the considered activities include inputs of crude sunflower oil, water, various auxiliary materials heat from natural gas and diesel combusted in machinery and electricity. All the other ingredients have already been described.

Enzyme improver (F,V): from data sheet information it is made of wheat flour, calcium carbonate, mono and diglycerides, ascorbic acid, amylase and xylanase. Only for ascorbic acid, amylase and xylanase no information has been given yet. However, for all of them no datasets are available and so "Chemical, organic {GLO}| production | Alloc Rec,U" has been used.

Salt (F,V): this compound has already been described.

Teff seeds (V): since no specific database is available for this raw material, it was decided to assume the linseeds Agri-footprint dataset, considering flows and processes contained within this dataset a good approximation of those required.

Semi-finished Apricot (V): made of sugar, apricot puree, glucose syrup, pectin, citric acid, lemon juice and aroma. Apricot puree has been modelled considering and Ecoinvent dataset that asses impacts related to the cultivation of the fruit including tree nursery, soil cultivation, planting trees, sowing grass, and irrigation, machine operations, corresponding infrastructure, fuel use, sheds and fertiliser and pesticide application. Lemon juice is built considering firstly impacts related to its production that are pretty similar to the ones of apricots. Then a description of all the following processes needed to obtain the juice: juice extraction, pasteurization, juice concentration and cooling and finally freezing. All these phases has been modelled considering all electrical and thermal energy required for the processes.

Sourdough (F,V): no specific database is available for this raw material, so it was modelled considering primary data given by Vinci plant. Wheat flour and water are used to keep the yeasts alive and primary information about electrical an thermal energy consume has been added.

Sugar pearl (F): modeled through the database used to describe sugar appropriately modifying the place of origin. It was considered a grinding process by attributing its electricity consumption via an Ecoinvent database.

Teff flour (V): since no specific database is available for this raw material, it was decided to assume the oats flour Agri-footprint dataset, considering flows and processes contained within this dataset a good approximation of those required.

Water (F,V): this raw material has already been described.

Wheat flour (F,V): it is modelled starting and modifying based on primary information received by the suppliers the Agro-Footprint dataset in which the wheat dry milling process typically consists of several processing steps including receiving of dried wheat grain, and multiple grinding and sieving steps.

Wholemeal stone flour (V): modelled as the wheat flour g the bran in output.

Aroma (V,F), Sunflower lecithin (V), Vanillin (F): for all of them no datasets are available and so "Chemical, organic {GLO}| production | Alloc Rec,U" has been used.

For all the described raw materials it has been considered, as transport process from the producer to the supplier, and then from each supplier to Vinci production plant, a general Ecoinvent dataset. That has been done because primary information weren't available for the right vehicle type. Furthermore, raw materials that needs a transport at lower degrees a specific dataset taken from Ecoinvent has been selected.

- Packaging:

  As used in raw material description, packaging will be divided between "Croissant Vegano" and "Fagottino Crema" with the symbol V for the first product and F for the second one.

  - Primary Packaging:

  Plastic Coil (F,V): composed of polyethylene plastic material, these elements were modelled using Ecoinvent datasets; related production process like extrusion were considered using specific Ecoinvent datasets suitably modified on the basis of the country of origin of the manufacturer.

  - Secondary Packaging:

  Cardboard Box (F,V): this packaging material has already been described.

  Label (F,V): made of paper and applied onto the Cardboard box. It is modelled using an Ecoinvent dataset which includes the production of coated woodfree paper in an integrated paper mill - including transports to paper mill, wood handling, chemical pulping and bleaching, paper production, energy production on-site, recovery cycles of chemicals and internal waste water treatment.

  Tape (F,V): used to seal the cardboard boxes, it was modelled using a Ecoinvent dataset that describe the polypropylene production. Here it is considered also glue needed and modelled as describe above.

  - Tertiary Packaging:

  Adhesive tape (F,V) : used to wrap the cardboard boxes placed on pallets, it was modelled using a Ecoinvent dataset that describe the polypropylene production. Here it is considered also glue needed and modelled as describe above.

  Cardboard plan (F,V): used in pallet. Modelled treating it as a material that come from both recycled and virgin cardboard. Ecoinvent datasets can be used to consider both those processes

  Extensible film (F,V): this packaging material has already been described.

  Pallet (F,V): this packaging material has already been described.

- Production

  The energy components that intervene during the production cycle are mainly two: electricity and methane for the production of thermal energy in the form of steam and

hot water. In 2021, to meet the energy needs of the Vinci (FI) plant, all medium-voltage and thermal electricity was purchased from the grid.
Electrical energy from grid and methane used for boilers in Vinci plant are modelled as in the Empoli plant. So, starting from datasets available in the software and modifying them based on Italian residual mix.

For what concern chemical compounds, refrigerants and waste water treatment the same consideration used for Empoli's plant are applied for Vinci's plant.
For what concern waste streams only end of life waste scenario differs respect the description given for Empoli plant. Table 6 express Vinci's waste treatment scenario addressing for each waste type which is waste treatment submitted between: recovery of the material, incineration, landfill, biological treatment.

Table 6: Waste treatment scenario for different Vinci's materials

Waste type	**Recovery**	**Incineration**	**Landfill**	**Biological treatment**
Sludge from wastewater treatment	100%	0%	0%	0%
Paper/Cardboard	100%	0%	0%	0%
Plastic	100%	0%	0%	0%
Mixed packaging	100%	0%	0%	0%
Mixed packaging with dangerous substances	100%	0%	0%	0%
Iron	100%	0%	0%	0%

- Product Distribution:
  The distribution of all the products in question takes place in the Italian market. The primary distribution, or between plant and wholesaler is characterized by weighted average distances obtained on the basis of primary information provided directly by the company logistics hub. To assess the distribution Ecoinvent dataset has been used.
  For "Croissant Vegano" primary distribution consist of 355 km by car and 16 km by ship on average for every product. For "Fagottino Crema" primary distribution consist of 488 km by car and 10 km by ship on average for every product.
  Due to the lack of data in relation to secondary distribution, for which Sammontana S.p.A. does not hold operational or financial control, a distance travelled of 293 km by car and 5,9 km by ship has been assumed for each product. Secondary distribution consider the transport between wholesaler and the point of sale.
  In terms of representation into the software GDO and Horeca distribution processes are described in the same way as done for the Empoli's products. Also within Vinci

distribution processes secondary and tertiary packaging disposal are considered and scenario used are as expressed in Table 5.

Differently respect Empoli's products, with regard to the Horeca channel within the distribution phase, in addition to consumption related to the Montelupo plant, the consumption of the electricity consumed by the refrigeration unit of the point of sale for cooling the product and the electricity consumed by the oven of the point of sale for cooking the product were also considered.
The electricity consumed by the refrigerant unit of the point of sale was evaluated considering a period in the cell for each product equal to two weeks, an annual energy consumption of 1277.5 kWh and a cell capacity of 476 l. The energy consumption was estimated considering the energy required for each piece and then scaled based on the product amount considered.
The electricity consumed by the oven of the point of sale for cooking the product was considered to be equal to 1.23 kWh/pz. This consumption was modelled using the an Ecoinvent database.

- Use Phase

  For products that meant to follow the GDO channel, in addition to the processes considered for Empoli's product during the use phase, Vinci's products consider also the energy consumed by the domestic oven to cook the product. Following the PEFCR guidance document (European Commision, 2017) an evaluation of the energy consume by a domestic oven can be done, addressing a 1,23 kWh/pz consumption. While for the products of the Horeca channel the use phase considers both the energy necessary for cooking and refrigerating the product inside the store and the end of life of the baking paper and napkin used.

- End of life:
  The last modelled process corresponds to the last phase of the life cycle of each product studied, i.e. the end of life, which has been modelled considering the multi-component nature of each product. The end-of-life phase of each of the primary packaging has been modelled by distinguishing for each element three different types of disposal: recycling, incineration and disposal in landfills. The percentages of destination to the individual disposal processes for products destined for the Italian market are shown in Table 5.
  To conclude, all assumption done about the transportation and human digestion are the same as for Empoli's product. In addition also for pastry product the end-of-life

packaging disposal/treatment scenarios were then modelled using the Circular Footprint Formula as explained for Empoli's product.

3.3 Nitrogen inventory analysis

Thanks to the modelling described in the previous paragraph and the LCA software used, an inventory results for the four product system were calculated. In particular, the nitrogen inventory results were obtained selecting the nitrogen-containing substances emissions in air, water and soil compartment. Results are shown in Table 7.

Table 7: Nitrogen inventory results showing the emitted amount of nitrogen-containing substances in the various environmental compartments for the four analysed product systems.

Substance	Compartment	Unit	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
2,4-D, dimethylamine salt	Soil	kg	1,90E-07	0,00E+00	2,43E-07	3,56E-08
2,4-D, dimethylamine salt	Water	kg	5,95E-09	0,00E+00	0,00E+00	0,00E+00
2,4-D, dimethylamine salt	Air	kg	0,00E+00	0,00E+00	2,39E-08	0,00E+00
2-Aminopropanol	Water	kg	1,20E-08	0,00E+00	0,00E+00	0,00E+00
2-Aminopropanol	Air	kg	4,98E-09	0,00E+00	0,00E+00	0,00E+00
Acephate	Soil	kg	2,06E-06	8,65E-07	1,60E-07	5,81E-07
Acephate	Air	kg	7,02E-09	1,94E-08	0,00E+00	0,00E+00
Acetamide	Soil	kg	5,59E-08	0,00E+00	0,00E+00	1,74E-08
Acetamiprid	Soil	kg	4,73E-08	6,17E-08	0,00E+00	0,00E+00
Acetochlor	Soil	kg	1,19E-05	7,33E-08	6,82E-07	3,72E-06
Acetonitrile	Air	kg	2,97E-06	4,14E-06	2,62E-06	3,18E-06
Aclonifen	Soil	kg	4,51E-07	9,37E-08	2,71E-05	4,66E-06
Acrinathrin	Soil	kg	3,02E-09	0,00E+00	0,00E+00	0,00E+00
Alachlor	Soil	kg	3,88E-06	4,19E-06	2,90E-05	7,82E-06
Alachlor	Air	kg	3,51E-08	0,00E+00	9,22E-07	3,51E-07
Alachlor	Water	kg	3,14E-09	0,00E+00	1,02E-07	3,88E-08
Alanycarb	Soil	kg	1,26E-07	1,65E-07	3,05E-08	3,21E-08
Aldicarb	Soil	kg	1,39E-07	1,81E-07	4,25E-08	3,67E-08
Ammonia	Air	kg	5,03E-03	2,98E-03	2,88E-03	3,55E-03
Ammonia	Soil	kg	1,16E-06	1,32E-06	9,64E-07	8,06E-06
Ammonia	Water	kg	2,70E-07	8,21E-07	5,24E-07	2,31E-06
Ammonium carbonate	Air	kg	4,63E-09	2,34E-08	0,00E+00	0,00E+00
Ammonium, ion	Water	kg	1,92E-04	2,36E-04	1,96E-04	2,14E-04
Aniline	Water	kg	1,08E-07	4,85E-08	5,13E-08	7,00E-08
Aniline	Air	kg	8,50E-09	0,00E+00	1,29E-08	1,28E-08
Asulam	Soil	kg	7,15E-08	0,00E+00	1,21E-07	1,34E-08
Atrazine	Soil	kg	3,14E-05	1,13E-05	3,27E-06	1,17E-05
Atrazine	Water	kg	1,77E-07	0,00E+00	0,00E+00	3,43E-08
Atrazine	Air	kg	3,76E-08	0,00E+00	4,82E-08	1,40E-07
Azinphos-methyl	Soil	kg	2,94E-08	3,87E-08	0,00E+00	0,00E+00

Substance	**Compartment**	**Unit**	**Barattolino Crema (1 kg)**	**Biscotto Amando (1 kg)**	**Croissant Vegano (1 kg)**	**Fagottino Crema (1 kg)**
Aziprotryne	Soil	kg	1,13E-06	1,48E-06	2,70E-07	2,86E-07
Azoxystrobin	Soil	kg	1,88E-06	2,10E-06	1,50E-06	1,93E-06
Azoxystrobin	Air	kg	4,12E-09	0,00E+00	0,00E+00	2,74E-08
Benomyl	Soil	kg	0,00E+00	0,00E+00	2,86E-08	2,70E-08
Bentazone	Soil	kg	7,38E-07	0,00E+00	0,00E+00	1,87E-07
Bentazone	Water	kg	1,76E-08	0,00E+00	0,00E+00	0,00E+00
Bentazone	Air	kg	6,24E-09	0,00E+00	0,00E+00	1,88E-08
Benzene, pentachloronitro-	Soil	kg	1,26E-08	0,00E+00	0,00E+00	0,00E+00
Benzthiazuron	Soil	kg	0,00E+00	8,73E-07	2,18E-07	4,67E-08
Bifenox	Soil	kg	4,24E-08	0,00E+00	7,61E-07	5,52E-07
Bitertanol	Soil	kg	1,21E-08	0,00E+00	1,44E-08	1,46E-08
Bromofenoxim	Soil	kg	0,00E+00	4,33E-07	1,08E-07	2,31E-08
Bromoxynil	Soil	kg	1,44E-06	0,00E+00	2,59E-06	2,43E-06
Bromoxynil	Water	kg	6,64E-09	0,00E+00	0,00E+00	0,00E+00
Bromoxynil	Air	kg	0,00E+00	0,00E+00	1,51E-08	0,00E+00
Bromuconazole	Soil	kg	0,00E+00	0,00E+00	4,24E-08	4,34E-08
Buprofezin	Soil	kg	9,05E-08	6,17E-08	6,31E-08	6,46E-08
Butoxycarboxim	Soil	kg	1,26E-07	1,65E-07	3,05E-08	3,21E-08
Butralin	Soil	kg	0,00E+00	2,36E-07	2,85E-07	1,26E-08
Captan	Soil	kg	1,37E-07	1,72E-05	2,31E-05	2,38E-08
Carbaryl	Soil	kg	9,21E-09	1,04E-05	7,26E-08	1,46E-07
Carbaryl	Air	kg	2,52E-09	6,72E-08	0,00E+00	1,49E-08
Carbendazim	Soil	kg	1,93E-06	6,68E-07	2,84E-07	7,20E-07
Carbetamide	Soil	kg	2,83E-07	0,00E+00	2,30E-07	7,44E-08
Carbofuran	Soil	kg	4,54E-07	1,15E-06	7,81E-06	1,15E-05
Carbofuran	Air	kg	0,00E+00	4,92E-08	0,00E+00	0,00E+00
Carfentrazone-ethyl	Soil	kg	0,00E+00	0,00E+00	1,29E-08	0,00E+00
Chloramine	Water	kg	9,00E-08	8,03E-08	1,61E-07	7,45E-08
Chloramine	Air	kg	1,01E-08	0,00E+00	1,80E-08	0,00E+00
Chloridazon	Soil	kg	8,52E-08	3,12E-08	3,79E-06	3,24E-06
Chlorimuron-ethyl	Soil	kg	9,88E-08	0,00E+00	0,00E+00	5,06E-07
Chlorimuron-ethyl	Air	kg	6,43E-09	0,00E+00	0,00E+00	4,96E-08
Chlormequat	Soil	kg	1,24E-06	1,41E-07	1,98E-05	1,80E-05
Chlormequat	Air	kg	1,55E-08	0,00E+00	2,19E-08	1,11E-07
Chlormequat	Water	kg	0,00E+00	0,00E+00	0,00E+00	1,24E-08
Chlormequat chloride	Soil	kg	0,00E+00	0,00E+00	0,00E+00	2,33E-08
Chloropicrin	Soil	kg	3,22E-05	0,00E+00	0,00E+00	0,00E+00
Chlorothalonil	Soil	kg	9,44E-07	2,67E-05	7,11E-07	9,73E-07
Chlorothalonil	Air	kg	0,00E+00	0,00E+00	0,00E+00	2,27E-08
Chlorpyrifos	Soil	kg	1,32E-06	1,01E-05	1,33E-06	2,27E-06
Chlorpyrifos	Air	kg	3,88E-08	1,03E-06	5,39E-08	1,54E-07
Chlorpyrifos	Water	kg	0,00E+00	1,12E-07	0,00E+00	1,62E-08

Substance	Compartment	Unit	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
Chlorpyrifos methyl	Soil	kg	2,02E-06	1,47E-06	1,83E-07	5,94E-07
Chlorsulfuron	Soil	kg	0,00E+00	0,00E+00	5,96E-08	5,16E-08
Chlortoluron	Soil	kg	2,47E-07	0,00E+00	0,00E+00	1,18E-07
Choline chloride	Soil	kg	1,81E-07	0,00E+00	8,06E-06	6,90E-06
cis-4-[3-(p-tert-butylphenyl)-2-methylpropyl]-2,6-dimethylmorpholine	Soil	kg	1,02E-08	0,00E+00	1,49E-07	3,39E-07
cis-4-[3-(p-tert-butylphenyl)-2-methylpropyl]-2,6-dimethylmorpholine	Air	kg	0,00E+00	0,00E+00	1,49E-08	3,39E-08
Clethodim	Soil	kg	1,62E-08	0,00E+00	1,59E-07	3,33E-08
Clethodim	Air	kg	4,83E-09	0,00E+00	0,00E+00	0,00E+00
Clodinafop-propargyl	Soil	kg	3,66E-08	0,00E+00	1,09E-06	7,81E-07
Clofentezine	Soil	kg	4,69E-08	6,17E-08	0,00E+00	0,00E+00
Clomazone	Soil	kg	1,19E-08	0,00E+00	0,00E+00	1,72E-08
Clopyralid	Soil	kg	1,56E-08	0,00E+00	5,74E-07	4,94E-07
Cloquintocet-mexyl	Soil	kg	4,78E-09	0,00E+00	2,14E-07	1,84E-07
Cloransulam-methyl	Soil	kg	4,31E-09	0,00E+00	0,00E+00	0,00E+00
Clothianidin	Soil	kg	7,57E-08	6,17E-08	0,00E+00	0,00E+00
Cyanazine	Soil	kg	1,13E-06	1,48E-06	2,70E-07	2,90E-07
Cyanide	Air	kg	5,65E-05	7,89E-05	5,01E-05	6,07E-05
Cyanide	Water	kg	9,23E-07	5,37E-07	7,57E-07	9,11E-07
Cycloxydim	Soil	kg	1,95E-09	0,00E+00	1,49E-08	3,78E-08
Cyfluthrin	Soil	kg	2,48E-08	0,00E+00	1,22E-08	2,64E-08
Cyhalothrin	Soil	kg	0,00E+00	1,05E-06	0,00E+00	0,00E+00
Cyhalothrin, gamma-	Air	kg	1,92E-09	0,00E+00	0,00E+00	0,00E+00
Cypermethrin	Soil	kg	3,55E-07	6,98E-05	2,08E-06	6,06E-06
Cypermethrin	Air	kg	1,86E-09	1,65E-06	0,00E+00	1,74E-08
Cypermethrin	Water	kg	0,00E+00	1,83E-07	0,00E+00	0,00E+00
Cyproconazole	Soil	kg	2,87E-07	9,40E-08	4,13E-07	4,39E-07
Cyprodinil	Soil	kg	4,59E-07	7,04E-07	5,11E-06	4,46E-06
Cyromazine	Soil	kg	4,69E-08	6,17E-08	0,00E+00	0,00E+00
Deltamethrin	Soil	kg	2,84E-09	6,10E-08	3,16E-08	2,88E-08
Desmedipham	Soil	kg	7,80E-08	0,00E+00	3,25E-07	0,00E+00
Dialifor	Soil	kg	2,81E-08	3,73E-08	0,00E+00	0,00E+00
Diazinon	Soil	kg	3,28E-08	2,17E-06	0,00E+00	0,00E+00
Dichlobenil	Soil	kg	0,00E+00	1,57E-05	0,00E+00	0,00E+00
Diethylamine	Water	kg	1,77E-08	4,80E-08	1,71E-08	1,67E-08
Diethylamine	Air	kg	7,38E-09	2,00E-08	0,00E+00	0,00E+00
Difenoconazole	Soil	kg	5,45E-07	4,78E-06	3,98E-07	6,20E-07
Difenoconazole	Air	kg	0,00E+00	0,00E+00	0,00E+00	2,04E-08
Diflubenzuron	Soil	kg	2,36E-06	1,04E-06	2,17E-07	6,91E-07
Diflufenican	Soil	kg	1,92E-07	0,00E+00	1,51E-06	1,27E-06

Substance	**Compartment**	**Unit**	**Barattolino Crema (1 kg)**	**Biscotto Amando (1 kg)**	**Croissant Vegano (1 kg)**	**Fagottino Crema (1 kg)**
Diflufenzopyr-sodium	Soil	kg	1,06E-08	0,00E+00	0,00E+00	0,00E+00
Dimethachlor	Soil	kg	3,19E-06	4,17E-06	8,05E-07	8,14E-07
Dimethenamid	Soil	kg	4,05E-06	4,16E-06	8,26E-07	9,61E-07
Dimethenamid	Air	kg	5,16E-09	0,00E+00	0,00E+00	0,00E+00
Dimethenamid	Water	kg	1,84E-09	0,00E+00	0,00E+00	0,00E+00
Dimethenamid-P	Soil	kg	3,17E-06	4,16E-06	8,02E-07	8,05E-07
Dimethoate	Soil	kg	9,18E-08	1,00E-07	6,94E-08	8,30E-08
Dimethylamine	Water	kg	2,99E-08	0,00E+00	4,68E-08	3,10E-08
Dinitrogen monoxide	Air	kg	1,18E-03	7,21E-04	9,94E-04	1,05E-03
Dipropylamine	Water	kg	5,05E-09	0,00E+00	0,00E+00	0,00E+00
Dipropylamine	Air	kg	2,10E-09	0,00E+00	0,00E+00	0,00E+00
Dipropylthiocarbamic acid S-ethyl ester	Soil	kg	5,02E-08	6,12E-08	4,65E-08	1,94E-08
Diquat	Soil	kg	5,98E-08	7,06E-08	5,61E-08	3,83E-07
Diquat	Air	kg	0,00E+00	0,00E+00	0,00E+00	3,59E-08
Diquat dibromide	Soil	kg	0,00E+00	5,24E-08	0,00E+00	0,00E+00
Dithianone	Soil	kg	5,69E-09	0,00E+00	0,00E+00	0,00E+00
Diuron	Soil	kg	3,89E-07	7,25E-08	2,18E-07	1,16E-06
Diuron	Air	kg	1,68E-08	0,00E+00	0,00E+00	9,28E-08
Diuron	Water	kg	1,87E-09	0,00E+00	0,00E+00	0,00E+00
Epoxiconazole	Soil	kg	1,86E-07	3,76E-08	1,10E-06	1,18E-06
Epoxiconazole	Air	kg	0,00E+00	0,00E+00	3,71E-08	7,27E-08
Ethalfluralin	Soil	kg	5,89E-09	0,00E+00	0,00E+00	0,00E+00
Ethiofencarb	Soil	kg	1,26E-07	1,65E-07	3,05E-08	3,21E-08
Ethylamine	Water	kg	1,12E-07	1,15E-07	5,43E-08	6,25E-08
Ethylamine	Air	kg	4,66E-08	4,80E-08	2,26E-08	2,60E-08
Ethylene diamine	Water	kg	5,03E-08	5,09E-08	3,18E-08	2,76E-08
Ethylene diamine	Air	kg	2,08E-08	2,12E-08	1,31E-08	0,00E+00
Etoxazole	Soil	kg	4,69E-08	6,17E-08	0,00E+00	0,00E+00
Fenazaquin	Soil	kg	4,69E-08	6,17E-08	0,00E+00	0,00E+00
Fenbuconazole	Soil	kg	2,42E-09	0,00E+00	0,00E+00	0,00E+00
Fenitrothion	Soil	kg	2,81E-08	3,73E-08	0,00E+00	0,00E+00
Fenoxaprop	Soil	kg	8,93E-09	0,00E+00	1,53E-08	1,51E-08
Fenoxaprop-P ethyl ester	Soil	kg	3,52E-08	4,33E-07	2,19E-07	2,81E-08
Fenpiclonil	Soil	kg	2,32E-08	0,00E+00	0,00E+00	0,00E+00
Fenpropidin	Soil	kg	5,99E-07	0,00E+00	3,43E-06	2,44E-06
Fenpropimorph	Soil	kg	2,01E-06	1,54E-06	4,27E-06	2,26E-06
Fenpyroximate	Soil	kg	4,69E-08	6,17E-08	0,00E+00	0,00E+00
Fipronil	Soil	kg	3,11E-06	1,61E-07	1,66E-08	6,56E-08
Florasulam	Soil	kg	3,18E-06	4,16E-06	8,06E-07	8,09E-07
Fluazifop-P-butyl	Soil	kg	7,69E-09	0,00E+00	3,29E-07	3,82E-08
Fluazifop-p-butyl	Air	kg	1,94E-09	0,00E+00	0,00E+00	0,00E+00
Fluazinam	Soil	kg	0,00E+00	2,36E-07	2,85E-07	1,32E-08

Substance	Compartment	Unit	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
Fludioxonil	Soil	kg	9,01E-09	5,24E-08	9,08E-08	8,10E-08
Flufenacet	Soil	kg	3,30E-06	4,16E-06	1,18E-06	1,15E-06
Flumetsulam	Soil	kg	1,87E-08	0,00E+00	0,00E+00	0,00E+00
Flumioxazin	Soil	kg	5,30E-09	0,00E+00	3,59E-07	0,00E+00
Flumioxazin	Air	kg	2,86E-09	0,00E+00	0,00E+00	0,00E+00
Fluoroglycofen	Soil	kg	0,00E+00	0,00E+00	1,32E-07	0,00E+00
Fluquinconazole	Soil	kg	2,14E-09	0,00E+00	0,00E+00	0,00E+00
Flurochloridone	Soil	kg	0,00E+00	0,00E+00	9,37E-06	1,61E-06
Fluroxypyr	Soil	kg	6,70E-08	4,33E-07	2,63E-06	2,22E-06
Flurtamone	Soil	kg	1,48E-07	0,00E+00	3,08E-06	8,30E-07
Flusilazole	Soil	kg	1,97E-08	0,00E+00	0,00E+00	1,34E-08
Flutolanil	Soil	kg	2,31E-09	0,00E+00	0,00E+00	0,00E+00
Folpet	Soil	kg	0,00E+00	0,00E+00	0,00E+00	2,08E-08
Fomesafen	Soil	kg	3,32E-08	0,00E+00	0,00E+00	0,00E+00
Fomesafen	Air	kg	1,06E-08	0,00E+00	0,00E+00	0,00E+00
Foramsulfuron	Soil	kg	1,99E-09	0,00E+00	0,00E+00	0,00E+00
Formamide	Water	kg	5,39E-09	0,00E+00	1,79E-08	0,00E+00
Formamide	Air	kg	2,25E-09	0,00E+00	0,00E+00	0,00E+00
Furathiocarb	Soil	kg	1,26E-07	1,65E-07	3,05E-08	3,21E-08
Glufosinate	Soil	kg	3,69E-06	7,88E-06	1,31E-06	1,59E-06
Glyphosate	Soil	kg	7,25E-05	4,49E-04	7,02E-05	1,06E-04
Glyphosate	Air	kg	2,47E-06	1,83E-06	2,96E-07	3,05E-06
Glyphosate	Water	kg	6,79E-07	3,24E-08	0,00E+00	3,05E-07
Haloxyfop	Soil	kg	0,00E+00	0,00E+00	1,32E-07	0,00E+00
Haloxyfop- (R) Methylester	Soil	kg	9,23E-08	3,12E-08	0,00E+00	2,61E-08
Hexythiazox	Soil	kg	4,69E-08	6,17E-08	0,00E+00	0,00E+00
Imazamox	Soil	kg	3,04E-08	8,84E-07	3,84E-07	9,89E-08
Imazethapyr	Soil	kg	1,38E-08	0,00E+00	0,00E+00	0,00E+00
Imazethapyr	Air	kg	2,99E-09	0,00E+00	0,00E+00	0,00E+00
Imidacloprid	Soil	kg	9,09E-07	3,64E-07	2,67E-07	3,73E-07
Indoxacarb	Soil	kg	4,91E-08	7,65E-08	8,15E-07	0,00E+00
Iodosulfuron	Soil	kg	1,13E-06	1,48E-06	2,70E-07	2,86E-07
Iodosulfuron-methyl-sodium	Soil	kg	1,13E-06	1,48E-06	2,74E-07	2,89E-07
Ioxynil	Soil	kg	5,84E-07	1,13E-07	2,44E-06	2,10E-06
Iprodione	Soil	kg	4,22E-08	0,00E+00	1,04E-05	1,23E-07
Isocyanic acid	Air	kg	1,65E-06	7,85E-07	3,00E-07	4,76E-07
Isopropylamine	Water	kg	6,83E-08	4,81E-08	2,02E-08	3,08E-08
Isopropylamine	Air	kg	2,84E-08	2,01E-08	0,00E+00	1,28E-08
Isoproturon	Soil	kg	3,62E-06	7,81E-07	4,41E-06	3,62E-06
Isoproturon	Air	kg	2,04E-09	0,00E+00	1,20E-07	7,36E-08
Isoproturon	Water	kg	0,00E+00	0,00E+00	1,33E-08	0,00E+00
Isoxaflutole	Soil	kg	6,49E-08	0,00E+00	0,00E+00	2,03E-08

Substance	**Compartment**	**Unit**	**Barattolino Crema (1 kg)**	**Biscotto Amando (1 kg)**	**Croissant Vegano (1 kg)**	**Fagottino Crema (1 kg)**
Kresoxim-methyl	Soil	kg	9,67E-08	0,00E+00	3,93E-07	2,83E-07
Kresoxim-methyl	Air	kg	0,00E+00	0,00E+00	0,00E+00	1,63E-08
Lambda-cyhalothrin	Soil	kg	2,94E-07	9,54E-08	1,43E-07	1,87E-07
Lenacil	Soil	kg	4,24E-08	0,00E+00	1,76E-07	0,00E+00
Linuron	Soil	kg	3,41E-07	8,14E-08	1,88E-05	3,25E-06
Maleic hydrazide	Soil	kg	1,27E-08	0,00E+00	0,00E+00	0,00E+00
Mancozeb	Soil	kg	4,82E-07	4,10E-06	4,27E-07	2,59E-07
Mancozeb	Air	kg	0,00E+00	3,75E-08	0,00E+00	0,00E+00
Mefenpyr	Soil	kg	3,40E-08	0,00E+00	2,14E-07	1,88E-07
Mefenpyr-diethyl	Soil	kg	1,62E-08	0,00E+00	0,00E+00	0,00E+00
Mepiquat chloride	Soil	kg	1,16E-07	0,00E+00	7,76E-08	9,16E-08
Mesosulfuron-methyl (prop)	Soil	kg	0,00E+00	0,00E+00	1,95E-08	1,67E-08
Mesotrione	Soil	kg	6,33E-07	0,00E+00	3,62E-08	1,96E-07
Metalaxil	Soil	kg	9,29E-09	0,00E+00	3,80E-08	4,94E-08
Metamitron	Soil	kg	1,77E-05	1,71E-05	1,69E-05	1,80E-05
Metam-sodium dihydrate	Soil	kg	2,08E-06	2,53E-06	2,00E-06	8,63E-07
Metazachlor	Soil	kg	3,22E-06	4,20E-06	2,74E-06	1,57E-06
Metazachlor	Air	kg	0,00E+00	0,00E+00	0,00E+00	4,23E-08
Metconazole	Soil	kg	6,16E-09	0,00E+00	6,89E-08	5,66E-08
Methabenzthiazuron	Soil	kg	0,00E+00	0,00E+00	0,00E+00	1,45E-08
Methidathion	Soil	kg	8,85E-08	3,73E-08	0,00E+00	7,28E-08
Methidathion	Air	kg	6,04E-09	0,00E+00	0,00E+00	0,00E+00
Methiocarb	Soil	kg	1,26E-07	2,00E-07	3,05E-08	3,60E-08
Methomyl	Soil	kg	1,26E-07	3,54E-06	3,05E-08	3,21E-08
Methoxyfenozide	Soil	kg	0,00E+00	2,40E-06	0,00E+00	0,00E+00
Methylamine	Water	kg	3,81E-09	0,00E+00	0,00E+00	0,00E+00
Metolachlor	Soil	kg	2,86E-05	5,30E-06	2,33E-05	1,59E-05
Metolachlor	Air	kg	5,34E-08	0,00E+00	7,04E-08	3,07E-07
Metolachlor	Water	kg	2,07E-08	0,00E+00	0,00E+00	3,60E-08
Metolachlor, (S)	Soil	kg	3,17E-06	4,40E-06	8,02E-07	8,05E-07
Metolachlor, (S)	Air	kg	0,00E+00	2,34E-08	0,00E+00	0,00E+00
Metosulam	Soil	kg	3,18E-06	4,16E-06	8,13E-07	8,15E-07
Metribuzin	Soil	kg	1,27E-06	1,57E-06	6,42E-07	6,96E-07
Metribuzin	Air	kg	9,07E-09	0,00E+00	0,00E+00	0,00E+00
Metsulfuron-methyl	Soil	kg	1,15E-06	1,49E-06	4,10E-07	4,51E-07
Molinate	Soil	kg	1,53E-08	0,00E+00	0,00E+00	0,00E+00
Monocrotophos	Soil	kg	2,88E-07	3,75E-07	3,35E-08	1,07E-07
Monocrotophos	Air	kg	0,00E+00	2,49E-08	0,00E+00	0,00E+00
Monoethanolamine	Air	kg	1,45E-06	5,09E-06	2,60E-03	1,94E-03
Myclobutanil	Soil	kg	0,00E+00	6,08E-08	0,00E+00	0,00E+00
Napropamide	Soil	kg	1,75E-07	1,64E-05	1,81E-07	5,73E-08
Nicosulfuron	Soil	kg	2,73E-08	0,00E+00	0,00E+00	0,00E+00

Substance	**Compartment**	**Unit**	**Barattolino Crema (1 kg)**	**Biscotto Amando (1 kg)**	**Croissant Vegano (1 kg)**	**Fagottino Crema (1 kg)**
Nitrate	Water	kg	3,55E-02	3,62E-02	3,98E-02	3,22E-02
Nitrate	Air	kg	9,26E-07	1,23E-06	4,67E-07	6,54E-07
Nitrate	Soil	kg	4,61E-07	2,83E-07	3,65E-07	4,32E-07
Nitrite	Water	kg	9,59E-06	1,12E-05	8,05E-06	9,09E-06
Nitrobenzene	Water	kg	4,37E-07	2,12E-07	1,70E-07	2,53E-07
Nitrobenzene	Air	kg	1,09E-07	5,28E-08	4,24E-08	6,30E-08
Nitrogen dioxide	Air	kg	3,13E-06	4,70E-05	6,80E-05	8,33E-05
Nitrogen oxides	Air	kg	5,89E-03	6,76E-03	6,04E-03	7,35E-03
Nitrogen, organic bound	Water	kg	6,08E-05	1,01E-04	1,07E-04	1,21E-04
Orbencarb	Soil	kg	4,59E-08	5,59E-08	4,25E-08	1,64E-08
Oryzalin	Soil	kg	0,00E+00	1,53E-05	2,85E-07	1,26E-08
Oxamyl	Soil	kg	1,36E-07	2,00E-07	3,96E-08	3,57E-08
Oxasulfuron	Soil	kg	0,00E+00	0,00E+00	1,32E-07	0,00E+00
Oxyfluorfen	Soil	kg	0,00E+00	2,76E-06	7,52E-06	1,30E-06
Paraquat	Soil	kg	6,61E-07	2,21E-07	8,34E-08	2,48E-07
Paraquat	Air	kg	5,71E-09	0,00E+00	0,00E+00	0,00E+00
Paraquat dichloride	Soil	kg	3,69E-07	0,00E+00	0,00E+00	1,84E-06
Paraquat dichloride	Air	kg	3,69E-08	0,00E+00	0,00E+00	1,84E-07
Paraquat dichloride	Water	kg	4,10E-09	0,00E+00	0,00E+00	2,04E-08
Parathion	Soil	kg	1,69E-08	0,00E+00	4,61E-07	3,99E-07
Particulates, < 10 um	Air	kg	3,55E-05	7,33E-06	1,90E-06	4,42E-05
Particulates, < 2.5 um	Air	kg	1,04E-03	1,12E-03	9,71E-04	1,21E-03
Particulates, > 2.5 um, and < 10um	Air	kg	5,56E-04	6,94E-04	4,57E-04	5,77E-04
Particulates, unspecified	Air	kg	9,31E-09	2,92E-05	3,33E-08	3,52E-07
Pendimethalin	Soil	kg	9,98E-07	2,14E-07	1,34E-05	2,81E-06
Pendimethalin	Air	kg	9,16E-08	5,18E-08	0,00E+00	5,09E-08
Pendimethalin	Water	kg	2,91E-09	0,00E+00	0,00E+00	0,00E+00
Pethoxamid	Soil	kg	3,17E-06	4,16E-06	8,02E-07	8,05E-07
Phenmedipham	Soil	kg	3,10E-06	3,12E-06	2,51E-06	3,30E-06
Phosalone	Soil	kg	5,63E-08	7,45E-08	1,45E-08	1,47E-08
Phosmet	Soil	kg	5,86E-08	5,82E-06	1,66E-08	1,55E-08
Picoxystrobin	Soil	kg	2,69E-07	8,41E-08	1,65E-07	1,94E-07
Pirimicarb	Soil	kg	1,51E-07	7,67E-07	6,01E-08	9,66E-08
Primisulfuron	Soil	kg	6,65E-09	0,00E+00	0,00E+00	0,00E+00
Prochloraz	Soil	kg	3,04E-08	0,00E+00	4,92E-07	6,56E-07
Prochloraz	Air	kg	0,00E+00	0,00E+00	1,83E-08	3,92E-08
Procymidone	Soil	kg	2,73E-09	0,00E+00	0,00E+00	0,00E+00
Pronamide	Soil	kg	3,18E-06	4,16E-06	8,02E-07	8,10E-07
Propachlor	Soil	kg	3,17E-06	4,16E-06	8,02E-07	8,05E-07
Propamocarb	Soil	kg	0,00E+00	3,02E-08	0,00E+00	0,00E+00
Propanil	Soil	kg	3,95E-08	6,56E-05	0,00E+00	0,00E+00
Propaquizafop	Soil	kg	0,00E+00	0,00E+00	1,32E-07	0,00E+00

Substance	**Compartment**	**Unit**	**Barattolino Crema (1 kg)**	**Biscotto Amando (1 kg)**	**Croissant Vegano (1 kg)**	**Fagottino Crema (1 kg)**
Propiconazole	Soil	kg	1,95E-07	0,00E+00	1,79E-06	1,58E-06
Propoxycarbazone-sodium (prop)	Soil	kg	0,00E+00	0,00E+00	2,44E-08	2,09E-08
Prosulfocarb	Soil	kg	4,41E-09	1,10E-07	0,00E+00	1,51E-07
Prosulfocarb	Air	kg	0,00E+00	0,00E+00	0,00E+00	1,51E-08
Prothioconazol	Soil	kg	2,79E-07	1,04E-07	3,01E-08	8,43E-08
Pyraclostrobin (prop)	Soil	kg	3,73E-07	1,11E-07	5,68E-07	5,50E-07
Pyraclostrobin (prop)	Air	kg	2,48E-09	0,00E+00	0,00E+00	0,00E+00
Pyraflufen-ethyl	Soil	kg	6,87E-09	0,00E+00	0,00E+00	0,00E+00
Pyrazophos	Soil	kg	3,29E-07	4,31E-07	7,88E-08	8,33E-08
Pyridate	Soil	kg	5,19E-09	0,00E+00	8,82E-08	6,80E-07
Pyridate	Air	kg	0,00E+00	0,00E+00	0,00E+00	6,80E-08
Pyrimethanil	Soil	kg	0,00E+00	0,00E+00	0,00E+00	1,35E-08
Quinmerac	Soil	kg	3,27E-09	0,00E+00	4,72E-07	2,25E-07
Quinmerac	Air	kg	0,00E+00	0,00E+00	0,00E+00	1,44E-08
Quinoxyfen	Soil	kg	5,65E-09	0,00E+00	2,22E-07	1,86E-07
Quizalofop-p-ethyl	Soil	kg	0,00E+00	0,00E+00	2,11E-07	1,35E-08
Rimsulfuron	Soil	kg	6,96E-09	0,00E+00	0,00E+00	0,00E+00
Sethoxydim	Soil	kg	4,02E-09	0,00E+00	0,00E+00	0,00E+00
Silthiofam	Soil	kg	7,38E-09	0,00E+00	3,28E-07	2,81E-07
Simazine	Soil	kg	1,26E-06	1,20E-05	2,78E-07	3,43E-07
Spinosad	Soil	kg	2,32E-08	0,00E+00	0,00E+00	0,00E+00
Spiroxamine	Soil	kg	7,79E-08	0,00E+00	1,44E-06	1,24E-06
Starane	Soil	kg	0,00E+00	4,33E-07	1,52E-07	2,41E-08
Sulfentrazone	Soil	kg	2,11E-07	1,44E-06	0,00E+00	2,54E-08
Sulfentrazone	Air	kg	6,83E-09	0,00E+00	0,00E+00	0,00E+00
Sulfosate	Soil	kg	3,77E-06	6,51E-06	1,31E-06	1,06E-06
Sulfosulfuron	Soil	kg	4,59E-09	0,00E+00	9,08E-08	7,82E-08
t-Butylamine	Water	kg	2,96E-08	3,84E-08	2,21E-08	2,04E-08
t-Butylamine	Air	kg	1,24E-08	0,00E+00	0,00E+00	0,00E+00
Tebuconazole	Soil	kg	5,31E-07	2,76E-07	1,46E-06	1,29E-06
Tebufenpyrad	Soil	kg	4,69E-08	6,17E-08	0,00E+00	0,00E+00
Tebupirimphos	Soil	kg	5,58E-08	0,00E+00	0,00E+00	1,75E-08
Tebutam	Soil	kg	6,60E-07	0,00E+00	4,34E-07	2,00E-07
Teflubenzuron	Soil	kg	1,54E-07	5,47E-08	1,36E-08	4,17E-08
Terbuthylazin	Soil	kg	9,07E-06	1,55E-06	9,19E-06	3,23E-06
Terbuthylazin	Air	kg	0,00E+00	0,00E+00	8,47E-07	4,88E-08
Terbuthylazin	Water	kg	0,00E+00	0,00E+00	9,41E-08	0,00E+00
Terbutryn	Soil	kg	1,13E-06	1,48E-06	2,70E-07	2,86E-07
Thiacloprid	Soil	kg	0,00E+00	1,47E-07	0,00E+00	0,00E+00
Thiamethoxam	Soil	kg	2,05E-06	2,57E-07	1,95E-07	6,65E-07
Thiazole, 2-(thiocyanatemethylthio)benzo-	Soil	kg	1,96E-07	2,39E-07	1,82E-07	7,00E-08

Substance	Compartment	Unit	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
Thiobencarb	Soil	kg	8,45E-09	2,11E-05	0,00E+00	0,00E+00
Thiodicarb	Soil	kg	2,19E-07	8,21E-08	2,26E-08	5,52E-08
Thiophanate-methyl	Soil	kg	3,04E-07	2,26E-07	4,37E-08	8,59E-08
Thiram	Soil	kg	7,53E-09	6,05E-08	1,77E-07	2,73E-07
Tralkoxydim	Soil	kg	2,77E-07	0,00E+00	3,44E-08	8,06E-08
Triadimenol	Soil	kg	4,37E-09	0,00E+00	5,01E-08	4,70E-08
Triallate	Soil	kg	4,68E-09	0,00E+00	1,97E-07	1,82E-07
Triasulfuron	Soil	kg	1,13E-06	1,48E-06	3,29E-07	3,36E-07
Triazamate	Soil	kg	4,69E-08	6,17E-08	0,00E+00	0,00E+00
Tribenuron	Soil	kg	1,13E-06	1,48E-06	2,70E-07	2,86E-07
Tribenuron-methyl	Soil	kg	1,13E-06	1,48E-06	4,11E-07	3,58E-07
Triclopyr	Soil	kg	2,48E-08	0,00E+00	2,13E-08	4,01E-08
Trifloxystrobin	Soil	kg	3,81E-07	1,19E-07	3,98E-07	3,26E-07
Trifluralin	Soil	kg	4,63E-07	3,83E-07	9,65E-07	3,93E-07
Trifluralin	Air	kg	1,00E-07	7,10E-08	7,58E-08	5,04E-08
Triflusulfuron-methyl	Soil	kg	1,13E-06	1,48E-06	2,70E-07	2,86E-07
Trimethylamine	Water	kg	2,03E-09	0,00E+00	0,00E+00	0,00E+00
Urea	Water	kg	4,19E-09	0,00E+00	0,00E+00	0,00E+00
Vamidothion	Soil	kg	2,81E-08	3,73E-08	0,00E+00	0,00E+00
Ziram	Soil	kg	0,00E+00	1,84E-05	0,00E+00	0,00E+00

A mass cut-off criterion was applied to evaluate the nitrogen inventory results. An overall threshold set to 1 μg has been used, however including substances with fewer emissions considered to be particularly relevant due to potential environmental impacts.

In this paragraph nitrogen results can be accounted for all the emitted nitrogen-containing substances following formula (2.2) in Chapter 2. In order to do that nitrogen inventory results shown in Table 7 and nitrogen coefficients presented in Table 1 are needed. Thus, the reactive nitrogen indicator results were determined for the four analysed product systems. Results are presented in Table 8, in which total reactive nitrogen indicators value for each product system are shown in the last row.

Table 8: Reactive nitrogen results for the four analysed product systems. The reactive nitrogen indicator value for each product system is reported in the last row of the Table.

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
2,4-D, dimethylamine salt	Soil	0,052634	1,00E-08	0,00E+00	1,28E-08	1,87E-09
2,4-D, dimethylamine salt	Water	0,052634	3,13E-10	0,00E+00	0,00E+00	0,00E+00
2,4-D, dimethylamine salt	Air	0,052634	0,00E+00	0,00E+00	1,26E-09	0,00E+00
2-Aminopropanol	Water	0,186482	2,23E-09	0,00E+00	0,00E+00	0,00E+00

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
2-Aminopropanol	Air	0,186482	9,28E-10	0,00E+00	0,00E+00	0,00E+00
Acephate	Soil	0,076468	1,58E-07	6,61E-08	1,22E-08	4,44E-08
Acephate	Air	0,076468	5,37E-10	1,48E-09	0,00E+00	0,00E+00
Acetamide	Soil	0,23712	1,33E-08	0,00E+00	0,00E+00	4,12E-09
Acetamiprid	Soil	0,251614	1,19E-08	1,55E-08	0,00E+00	0,00E+00
Acetochlor	Soil	0,051921	6,20E-07	3,81E-09	3,54E-08	1,93E-07
Acetonitrile	Air	0,341211	1,01E-06	1,41E-06	8,94E-07	1,09E-06
Aclonifen	Soil	0,105847	4,77E-08	9,91E-09	2,87E-06	4,93E-07
Acrinathrin	Soil	0,025872	7,82E-11	0,00E+00	0,00E+00	0,00E+00
Alachlor	Soil	0,051921	2,01E-07	2,18E-07	1,51E-06	4,06E-07
Alachlor	Air	0,051921	1,82E-09	0,00E+00	4,79E-08	1,82E-08
Alachlor	Water	0,051921	1,63E-10	0,00E+00	5,31E-09	2,01E-09
Alanycarb	Soil	0,105131	1,33E-08	1,74E-08	3,20E-09	3,37E-09
Aldicarb	Soil	0,147235	2,05E-08	2,67E-08	6,25E-09	5,41E-09
Ammonia	Air	0,822	4,13E-03	2,45E-03	2,37E-03	2,92E-03
Ammonia	Soil	0,822	9,55E-07	1,09E-06	7,92E-07	6,62E-06
Ammonia	Water	0,822	2,22E-07	6,75E-07	4,31E-07	1,90E-06
Ammonium carbonate	Air	0,291533	1,35E-09	6,83E-09	0,00E+00	0,00E+00
Ammonium, ion	Water	0,776468	1,49E-04	1,83E-04	1,52E-04	1,66E-04
Aniline	Water	0,150401	1,63E-08	7,29E-09	7,72E-09	1,05E-08
Aniline	Air	0,150401	1,28E-09	0,00E+00	1,95E-09	1,92E-09
Asulam	Soil	0,121671	8,70E-09	0,00E+00	1,47E-08	1,64E-09
Atrazine	Soil	0,32471	1,02E-05	3,67E-06	1,06E-06	3,79E-06
Atrazine	Water	0,32471	5,76E-08	0,00E+00	0,00E+00	1,11E-08
Atrazine	Air	0,32471	1,22E-08	0,00E+00	1,57E-08	4,56E-08
Azinphos-methyl	Soil	0,132423	3,89E-09	5,13E-09	0,00E+00	0,00E+00
Aziprotryne	Soil	0,435014	4,90E-07	6,42E-07	1,18E-07	1,24E-07
Azoxystrobin	Soil	0,104166	1,96E-07	2,19E-07	1,56E-07	2,01E-07
Azoxystrobin	Air	0,104166	4,29E-10	0,00E+00	0,00E+00	2,86E-09
Benomyl	Soil	0,192981	0,00E+00	0,00E+00	5,53E-09	5,22E-09
Bentazone	Soil	0,116588	8,61E-08	0,00E+00	0,00E+00	2,18E-08
Bentazone	Water	0,116588	2,05E-09	0,00E+00	0,00E+00	0,00E+00
Bentazone	Air	0,116588	7,28E-10	0,00E+00	0,00E+00	2,19E-09
Benzene, pentachloronitro-	Soil	0,047429	5,99E-10	0,00E+00	0,00E+00	0,00E+00
Benzthiazuron	Soil	0,202654	0,00E+00	1,77E-07	4,42E-08	9,46E-09
Bifenox	Soil	0,04094	1,73E-09	0,00E+00	3,11E-08	2,26E-08
Bitertanol	Soil	0,124532	1,51E-09	0,00E+00	1,79E-09	1,82E-09
Bromofenoxim	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Bromoxynil	Soil	0,050581	7,30E-08	0,00E+00	1,31E-07	1,23E-07
Bromoxynil	Water	0,050581	3,36E-10	0,00E+00	0,00E+00	0,00E+00
Bromoxynil	Air	0,050581	0,00E+00	0,00E+00	7,64E-10	0,00E+00
Bromuconazole	Soil	0,111441	0,00E+00	0,00E+00	4,73E-09	4,84E-09
Buprofezin	Soil	0,13759	1,25E-08	8,48E-09	8,68E-09	8,89E-09

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
Butoxycarboxim	Soil	0,125979	1,59E-08	2,08E-08	3,84E-09	4,04E-09
Butralin	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Captan	Soil	0,046599	6,38E-09	8,03E-07	1,08E-06	1,11E-09
Carbaryl	Soil	0,069607	6,41E-10	7,23E-07	5,05E-09	1,02E-08
Carbaryl	Air	0,069607	1,75E-10	4,67E-09	0,00E+00	1,04E-09
Carbendazim	Soil	0,219782	4,24E-07	1,47E-07	6,24E-08	1,58E-07
Carbetamide	Soil	0,118565	3,35E-08	0,00E+00	2,73E-08	8,82E-09
Carbofuran	Soil	0,063304	2,87E-08	7,28E-08	4,94E-07	7,30E-07
Carbofuran	Air	0,063304	0,00E+00	3,11E-09	0,00E+00	0,00E+00
Carfentrazone-ethyl	Soil	0,101944	0,00E+00	0,00E+00	1,32E-09	0,00E+00
Chloramine	Water	0,272117	2,45E-08	2,19E-08	4,39E-08	2,03E-08
Chloramine	Air	0,272117	2,74E-09	0,00E+00	4,90E-09	0,00E+00
Chloridazon	Soil	0,189584	1,62E-08	5,91E-09	7,18E-07	6,14E-07
Chlorimuron-ethyl	Soil	0,135064	1,33E-08	0,00E+00	0,00E+00	6,84E-08
Chlorimuron-ethyl	Air	0,135064	8,69E-10	0,00E+00	0,00E+00	6,70E-09
Chlormequat	Soil	0,114232	1,42E-07	1,61E-08	2,26E-06	2,05E-06
Chlormequat	Air	0,114232	1,77E-09	0,00E+00	2,50E-09	1,27E-08
Chlormequat	Water	0,114232	0,00E+00	0,00E+00	0,00E+00	1,41E-09
Chlormequat chloride	Soil	0,088568	0,00E+00	0,00E+00	0,00E+00	2,06E-09
Chloropicrin	Soil	0,085216	2,75E-06	0,00E+00	0,00E+00	0,00E+00
Chlorothalonil	Soil	0,105352	9,94E-08	2,82E-06	7,50E-08	1,03E-07
Chlorothalonil	Air	0,105352	0,00E+00	0,00E+00	0,00E+00	2,40E-09
Chlorpyrifos	Soil	0,039954	5,27E-08	4,05E-07	5,30E-08	9,08E-08
Chlorpyrifos	Air	0,039954	1,55E-09	4,12E-08	2,15E-09	6,16E-09
Chlorpyrifos	Water	0,039954	0,00E+00	4,47E-09	0,00E+00	6,46E-10
Chlorpyrifos methyl	Soil	0,043433	8,77E-08	6,37E-08	7,94E-09	2,58E-08
Chlorsulfuron	Soil	0,195751	0,00E+00	0,00E+00	1,17E-08	1,01E-08
Chlortoluron	Soil	0,131722	3,25E-08	0,00E+00	0,00E+00	1,55E-08
Choline chloride	Soil	0,100318	1,82E-08	0,00E+00	8,09E-07	6,92E-07
cis-4-[3-(p-tert-butylphenyl)-2-methylpropyl]-2,6-dimethylmorpholine	Soil	0,045977	4,70E-10	0,00E+00	6,84E-09	1,56E-08
cis-4-[3-(p-tert-butylphenyl)-2-methylpropyl]-2,6-dimethylmorpholine	Air	0,045977	0,00E+00	0,00E+00	6,84E-10	1,56E-09
Clethodim	Soil	0,038917	6,29E-10	0,00E+00	6,17E-09	1,29E-09
Clethodim	Air	0,038917	1,88E-10	0,00E+00	0,00E+00	0,00E+00
Clodinafop-propargyl	Soil	0,040049	1,46E-09	0,00E+00	4,36E-08	3,13E-08
Clofentezine	Soil	0,184758	8,66E-09	1,14E-08	0,00E+00	0,00E+00
Clomazone	Soil	0,058435	6,94E-10	0,00E+00	0,00E+00	1,01E-09
Clopyralid	Soil	0,072953	1,14E-09	0,00E+00	4,19E-08	3,60E-08
Cloquintocet-mexyl	Soil	0,041708	2,00E-10	0,00E+00	8,93E-09	7,66E-09
Cloransulam-methyl	Soil	0,162942	7,03E-10	0,00E+00	0,00E+00	0,00E+00

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
Clothianidin	Soil	0,280495	2,12E-08	1,73E-08	0,00E+00	0,00E+00
Cyanazine	Soil	0,348982	3,93E-07	5,15E-07	9,43E-08	1,01E-07
Cyanide	Air	0,538367	3,04E-05	4,25E-05	2,70E-05	3,27E-05
Cyanide	Water	0,538367	4,97E-07	2,89E-07	4,08E-07	4,91E-07
Cycloxydim	Soil	0,043011	8,41E-11	0,00E+00	6,40E-10	1,62E-09
Cyfluthrin	Soil	0,032252	8,00E-10	0,00E+00	3,93E-10	8,50E-10
Cyhalothrin	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Cyhalothrin, gamma-	Air	0,031136	5,98E-11	0,00E+00	0,00E+00	0,00E+00
Cypermethrin	Soil	0,033646	1,19E-08	2,35E-06	7,00E-08	2,04E-07
Cypermethrin	Air	0,033646	6,26E-11	5,56E-08	0,00E+00	5,85E-10
Cypermethrin	Water	0,033646	0,00E+00	6,17E-09	0,00E+00	0,00E+00
Cyproconazole	Soil	0,144018	4,13E-08	1,35E-08	5,95E-08	6,32E-08
Cyprodinil	Soil	0,186512	8,56E-08	1,31E-07	9,53E-07	8,32E-07
Cyromazine	Soil	0,505476	2,37E-08	3,12E-08	0,00E+00	0,00E+00
Deltamethrin	Soil	0,027725	7,87E-11	1,69E-09	8,76E-10	7,99E-10
Desmedipham	Soil	0,09328	7,28E-09	0,00E+00	3,03E-08	0,00E+00
Dialifor	Soil	0,035551	1,00E-09	1,32E-09	0,00E+00	0,00E+00
Diazinon	Soil	0,092045	3,02E-09	1,99E-07	0,00E+00	0,00E+00
Dichlobenil	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Diethylamine	Water	0,191508	3,39E-09	9,19E-09	3,28E-09	3,20E-09
Diethylamine	Air	0,191508	1,41E-09	3,83E-09	0,00E+00	0,00E+00
Difenoconazole	Soil	0,103431	5,64E-08	4,94E-07	4,12E-08	6,41E-08
Difenoconazole	Air	0,103431	0,00E+00	0,00E+00	0,00E+00	2,11E-09
Diflubenzuron	Soil	0,090167	2,13E-07	9,37E-08	1,96E-08	6,23E-08
Diflufenican	Soil	0,071046	1,36E-08	0,00E+00	1,07E-07	9,03E-08
Diflufenzopyr-sodium	Soil	0,157262	1,67E-09	0,00E+00	0,00E+00	0,00E+00
Dimethachlor	Soil	0,054769	1,75E-07	2,29E-07	4,41E-08	4,46E-08
Dimethenamid	Soil	0,050787	2,06E-07	2,11E-07	4,20E-08	4,88E-08
Dimethenamid	Air	0,050787	2,62E-10	0,00E+00	0,00E+00	0,00E+00
Dimethenamid	Water	0,050787	9,32E-11	0,00E+00	0,00E+00	0,00E+00
Dimethenamid-P	Soil	0,050761	1,61E-07	2,11E-07	4,07E-08	4,09E-08
Dimethoate	Soil	0,061098	5,61E-09	6,13E-09	4,24E-09	5,07E-09
Dimethylamine	Water	0,31068	9,28E-09	0,00E+00	1,45E-08	9,62E-09
Dinitrogen monoxide	Air	0,63648	7,51E-04	4,59E-04	6,33E-04	6,70E-04
Dipropylamine	Water	0,138416	6,99E-10	0,00E+00	0,00E+00	0,00E+00
Dipropylamine	Air	0,138416	2,91E-10	0,00E+00	0,00E+00	0,00E+00
Dipropylthiocarbamic acid S-ethyl ester	Soil	0,073986	3,72E-09	4,53E-09	3,44E-09	1,44E-09
Diquat	Soil	0,152047	9,09E-09	1,07E-08	8,53E-09	5,82E-08
Diquat	Air	0,152047	0,00E+00	0,00E+00	0,00E+00	5,45E-09
Diquat dibromide	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Dithianone	Soil	0,094538	5,38E-10	0,00E+00	0,00E+00	0,00E+00
Diuron	Soil	0,120182	4,68E-08	8,72E-09	2,62E-08	1,39E-07

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
Diuron	Air	0,120182	2,02E-09	0,00E+00	0,00E+00	1,11E-08
Diuron	Water	0,120182	2,25E-10	0,00E+00	0,00E+00	0,00E+00
Epoxiconazole	Soil	0,127427	2,37E-08	4,79E-09	1,40E-07	1,50E-07
Epoxiconazole	Air	0,127427	0,00E+00	0,00E+00	4,73E-09	9,26E-09
Ethalfluralin	Soil	0,126088	7,42E-10	0,00E+00	0,00E+00	0,00E+00
Ethiofencarb	Soil	0,062137	7,84E-09	1,03E-08	1,89E-09	1,99E-09
Ethylamine	Water	0,31068	3,48E-08	3,58E-08	1,69E-08	1,94E-08
Ethylamine	Air	0,31068	1,45E-08	1,49E-08	7,03E-09	8,09E-09
Ethylene diamine	Water	0,466113	2,34E-08	2,37E-08	1,48E-08	1,29E-08
Ethylene diamine	Air	0,466113	9,68E-09	9,89E-09	6,13E-09	0,00E+00
Etoxazole	Soil	0,038954	1,83E-09	2,40E-09	0,00E+00	0,00E+00
Fenazaquin	Soil	0,091384	4,29E-09	5,63E-09	0,00E+00	0,00E+00
Fenbuconazole	Soil	0,166339	4,03E-10	0,00E+00	0,00E+00	0,00E+00
Fenitrothion	Soil	0,0505	1,42E-09	1,88E-09	0,00E+00	0,00E+00
Fenoxaprop	Soil	0,041971	3,75E-10	0,00E+00	6,43E-10	6,32E-10
Fenoxaprop-P ethyl ester	Soil	0,038716	1,36E-09	1,68E-08	8,46E-09	1,09E-09
Fenpiclonil	Soil	0,118159	2,74E-09	0,00E+00	0,00E+00	0,00E+00
Fenpropidin	Soil	0,05122	3,07E-08	0,00E+00	1,76E-07	1,25E-07
Fenpropimorph	Soil	0,046152	9,30E-08	7,12E-08	1,97E-07	1,04E-07
Fenpyroximate	Soil	0,099644	4,67E-09	6,14E-09	0,00E+00	0,00E+00
Fipronil	Soil	0,128166	3,98E-07	2,07E-08	2,13E-09	8,40E-09
Florasulam	Soil	0,194922	6,19E-07	8,11E-07	1,57E-07	1,58E-07
Fluazifop-P-butyl	Soil	0,036536	2,81E-10	0,00E+00	1,20E-08	1,39E-09
Fluazifop-p-butyl	Air	0,036536	7,07E-11	0,00E+00	0,00E+00	0,00E+00
Fluazinam	Soil	0,120407	0,00E+00	2,84E-08	3,44E-08	1,58E-09
Fludioxonil	Soil	0,112875	1,02E-09	5,92E-09	1,02E-08	9,15E-09
Flufenacet	Soil	0,115652	3,82E-07	4,81E-07	1,37E-07	1,34E-07
Flumetsulam	Soil	0,215293	4,03E-09	0,00E+00	0,00E+00	0,00E+00
Flumioxazin	Soil	0,079059	4,19E-10	0,00E+00	2,84E-08	0,00E+00
Flumioxazin	Air	0,079059	2,26E-10	0,00E+00	0,00E+00	0,00E+00
Fluoroglycofen	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Fluquinconazole	Soil	0,186162	3,98E-10	0,00E+00	0,00E+00	0,00E+00
Flurochloridone	Soil	0,044878	0,00E+00	0,00E+00	4,21E-07	7,24E-08
Fluroxypyr	Soil	0,109845	7,36E-09	4,75E-08	2,89E-07	2,43E-07
Flurtamone	Soil	0,042023	6,20E-09	0,00E+00	1,29E-07	3,49E-08
Flusilazole	Soil	0,133232	2,63E-09	0,00E+00	0,00E+00	1,78E-09
Flutolanil	Soil	0,043324	1,00E-10	0,00E+00	0,00E+00	0,00E+00
Folpet	Soil	0,04721	0,00E+00	0,00E+00	0,00E+00	9,80E-10
Fomesafen	Soil	0,063847	2,12E-09	0,00E+00	0,00E+00	0,00E+00
Fomesafen	Air	0,063847	6,78E-10	0,00E+00	0,00E+00	0,00E+00
Foramsulfuron	Soil	0,185748	3,70E-10	0,00E+00	0,00E+00	0,00E+00
Formamide	Water	0,310977	1,68E-09	0,00E+00	5,56E-09	0,00E+00
Formamide	Air	0,310977	6,99E-10	0,00E+00	0,00E+00	0,00E+00

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
Furathiocarb	Soil	0,073203	9,23E-09	1,21E-08	2,23E-09	2,35E-09
Glufosinate	Soil	0,077331	2,85E-07	6,09E-07	1,02E-07	1,23E-07
Glyphosate	Soil	0,082844	6,01E-06	3,72E-05	5,82E-06	8,77E-06
Glyphosate	Air	0,082844	2,05E-07	1,52E-07	2,45E-08	2,53E-07
Glyphosate	Water	0,082844	5,62E-08	2,69E-09	0,00E+00	2,53E-08
Haloxyfop	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Haloxyfop- (R) Methylester	Soil	0,03728	3,44E-09	1,16E-09	0,00E+00	9,72E-10
Hexythiazox	Soil	0,079343	3,72E-09	4,89E-09	0,00E+00	0,00E+00
Imazamox	Soil	0,13762	4,18E-09	1,22E-07	5,28E-08	1,36E-08
Imazethapyr	Soil	0,14523	2,00E-09	0,00E+00	0,00E+00	0,00E+00
Imazethapyr	Air	0,14523	4,35E-10	0,00E+00	0,00E+00	0,00E+00
Imidacloprid	Soil	0,27393	2,49E-07	9,97E-08	7,31E-08	1,02E-07
Indoxacarb	Soil	0,079608	3,91E-09	6,09E-09	6,49E-08	0,00E+00
Iodosulfuron	Soil	0,141988	1,60E-07	2,10E-07	3,84E-08	4,06E-08
Iodosulfuron-methyl-sodium	Soil	0,132329	1,49E-07	1,95E-07	3,62E-08	3,82E-08
Ioxynil	Soil	0,037762	2,21E-08	4,28E-09	9,22E-08	7,92E-08
Iprodione	Soil	0,12727	5,37E-09	0,00E+00	1,33E-06	1,56E-08
Isocyanic acid	Air	0,325548	5,36E-07	2,56E-07	9,76E-08	1,55E-07
Isopropylamine	Water	0,236952	1,62E-08	1,14E-08	4,79E-09	7,31E-09
Isopropylamine	Air	0,236952	6,74E-09	4,75E-09	0,00E+00	3,04E-09
Isoproturon	Soil	0,135803	4,91E-07	1,06E-07	5,99E-07	4,91E-07
Isoproturon	Air	0,135803	2,78E-10	0,00E+00	1,63E-08	9,99E-09
Isoproturon	Water	0,135803	0,00E+00	0,00E+00	1,81E-09	0,00E+00
Isoxaflutole	Soil	0,038981	2,53E-09	0,00E+00	0,00E+00	7,90E-10
Kresoxim-methyl	Soil	0,044699	4,32E-09	0,00E+00	1,76E-08	1,26E-08
Kresoxim-methyl	Air	0,044699	0,00E+00	0,00E+00	0,00E+00	7,29E-10
Lambda-cyhalothrin	Soil	0,031136	9,15E-09	2,97E-09	4,46E-09	5,83E-09
Lenacil	Soil	0,119565	5,07E-09	0,00E+00	2,11E-08	0,00E+00
Linuron	Soil	0,112463	3,84E-08	9,16E-09	2,12E-06	3,66E-07
Maleic hydrazide	Soil	0,249915	3,18E-09	0,00E+00	0,00E+00	0,00E+00
Mancozeb	Soil	0,103542	5,00E-08	4,25E-07	4,42E-08	2,68E-08
Mancozeb	Air	0,103542	0,00E+00	3,88E-09	0,00E+00	0,00E+00
Mefenpyr	Soil	0,088336	3,00E-09	0,00E+00	1,89E-08	1,66E-08
Mefenpyr-diethyl	Soil	0,075057	1,22E-09	0,00E+00	0,00E+00	0,00E+00
Mepiquat chloride	Soil	0,093589	1,09E-08	0,00E+00	7,27E-09	8,57E-09
Mesosulfuron-methyl (prop)	Soil	0,139094	0,00E+00	0,00E+00	2,72E-09	2,32E-09
Mesotrione	Soil	0,041279	2,61E-08	0,00E+00	1,49E-09	8,10E-09
Metalaxil	Soil	0,050145	4,66E-10	0,00E+00	1,90E-09	2,48E-09
Metamitron	Soil	0,277063	4,90E-06	4,74E-06	4,68E-06	4,99E-06
Metam-sodium dihydrate	Soil	0,10843	2,25E-07	2,74E-07	2,17E-07	9,36E-08
Metazachlor	Soil	0,151286	4,88E-07	6,36E-07	4,14E-07	2,38E-07
Metazachlor	Air	0,151286	0,00E+00	0,00E+00	0,00E+00	6,39E-09
Metconazole	Soil	0,131395	8,10E-10	0,00E+00	9,06E-09	7,44E-09

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
Methabenzthiazuron	Soil	0,189805	0,00E+00	0,00E+00	0,00E+00	2,75E-09
Methidathion	Soil	0,092623	8,20E-09	3,45E-09	0,00E+00	6,75E-09
Methidathion	Air	0,092623	5,59E-10	0,00E+00	0,00E+00	0,00E+00
Methiocarb	Soil	0,062137	7,84E-09	1,24E-08	1,89E-09	2,24E-09
Methomyl	Soil	0,172702	2,18E-08	6,11E-07	5,26E-09	5,54E-09
Methoxyfenozide	Soil	0,075984	0,00E+00	1,83E-07	0,00E+00	0,00E+00
Methylamine	Water	0,451	1,72E-09	0,00E+00	0,00E+00	0,00E+00
Metolachlor	Soil	0,049356	1,41E-06	2,62E-07	1,15E-06	7,82E-07
Metolachlor	Air	0,049356	2,63E-09	0,00E+00	3,48E-09	1,51E-08
Metolachlor	Water	0,049356	1,02E-09	0,00E+00	0,00E+00	1,77E-09
Metolachlor, (S)	Soil	0,049332	1,57E-07	2,17E-07	3,96E-08	3,97E-08
Metolachlor, (S)	Air	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Metosulam	Soil	0,167425	5,32E-07	6,97E-07	1,36E-07	1,36E-07
Metribuzin	Soil	0,261457	3,31E-07	4,11E-07	1,68E-07	1,82E-07
Metribuzin	Air	0,261457	2,37E-09	0,00E+00	0,00E+00	0,00E+00
Metsulfuron-methyl	Soil	0,183638	2,11E-07	2,73E-07	7,52E-08	8,28E-08
Molinate	Soil	0,074784	1,14E-09	0,00E+00	0,00E+00	0,00E+00
Monocrotophos	Soil	0,062764	1,81E-08	2,35E-08	2,10E-09	6,69E-09
Monocrotophos	Air	0,062764	0,00E+00	1,56E-09	0,00E+00	0,00E+00
Monoethanolamine	Air	0,229302	3,33E-07	1,17E-06	5,97E-04	4,45E-04
Myclobutanil	Soil	0,194019	0,00E+00	1,18E-08	0,00E+00	0,00E+00
Napropamide	Soil	0,051619	9,04E-09	8,46E-07	9,36E-09	2,96E-09
Nicosulfuron	Soil	0,204776	5,60E-09	0,00E+00	0,00E+00	0,00E+00
Nitrate	Water	0,225897	8,01E-03	8,18E-03	8,98E-03	7,28E-03
Nitrate	Air	0,225897	2,09E-07	2,78E-07	1,05E-07	1,48E-07
Nitrate	Soil	0,225897	1,04E-07	6,40E-08	8,24E-08	9,77E-08
Nitrite	Water	0,304454	2,92E-06	3,41E-06	2,45E-06	2,77E-06
Nitrobenzene	Water	0,113773	4,97E-08	2,41E-08	1,93E-08	2,87E-08
Nitrobenzene	Air	0,113773	1,24E-08	6,01E-09	4,83E-09	7,17E-09
Nitrogen dioxide	Air	0,30446	9,54E-07	1,43E-05	2,07E-05	2,53E-05
Nitrogen oxides	Air	0,30446	1,79E-03	2,06E-03	1,84E-03	2,24E-03
Nitrogen, organic bound	Water	0,16	9,72E-06	1,62E-05	1,71E-05	1,94E-05
Orbencarb	Soil	0,054336	2,49E-09	3,04E-09	2,31E-09	8,90E-10
Oryzalin	Soil	0,161681	0,00E+00	2,47E-06	4,62E-08	2,04E-09
Oxamyl	Soil	0,191645	2,61E-08	3,84E-08	7,58E-09	6,84E-09
Oxasulfuron	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Oxyfluorfen	Soil	0,038725	0,00E+00	1,07E-07	2,91E-07	5,02E-08
Paraquat	Soil	0,150405	9,94E-08	3,32E-08	1,25E-08	3,74E-08
Paraquat	Air	0,150405	8,58E-10	0,00E+00	0,00E+00	0,00E+00
Paraquat dichloride	Soil	0,108882	4,02E-08	0,00E+00	0,00E+00	2,00E-07
Paraquat dichloride	Air	0,108882	4,02E-09	0,00E+00	0,00E+00	2,00E-08
Paraquat dichloride	Water	0,108882	4,47E-10	0,00E+00	0,00E+00	2,22E-09
Parathion	Soil	0,04809	8,13E-10	0,00E+00	2,22E-08	1,92E-08

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
Particulates, < 10 um	Air	0,05757	2,05E-06	4,22E-07	1,09E-07	2,54E-06
Particulates, < 2.5 um	Air	0,08714	9,10E-05	9,76E-05	8,46E-05	1,06E-04
Particulates, > 2.5 um, and < 10um	Air	0,028	1,56E-05	1,94E-05	1,28E-05	1,61E-05
Particulates, unspecified	Air	0,062	5,77E-10	1,81E-06	2,07E-09	2,18E-08
Pendimethalin	Soil	0,149372	1,49E-07	3,20E-08	2,01E-06	4,20E-07
Pendimethalin	Air	0,149372	1,37E-08	7,73E-09	0,00E+00	7,61E-09
Pendimethalin	Water	0,149372	4,34E-10	0,00E+00	0,00E+00	0,00E+00
Pethoxamid	Soil	0,047329	1,50E-07	1,97E-07	3,79E-08	3,81E-08
Phenmedipham	Soil	0,09328	2,89E-07	2,91E-07	2,34E-07	3,08E-07
Phosalone	Soil	0,038064	2,14E-09	2,84E-09	5,51E-10	5,59E-10
Phosmet	Soil	0,044144	2,59E-09	2,57E-07	7,33E-10	6,84E-10
Picoxystrobin	Soil	0,038135	1,03E-08	3,21E-09	6,28E-09	7,40E-09
Pirimicarb	Soil	0,235121	3,54E-08	1,80E-07	1,41E-08	2,27E-08
Primisulfuron	Soil	0,123323	8,20E-10	0,00E+00	0,00E+00	0,00E+00
Prochloraz	Soil	0,111548	3,39E-09	0,00E+00	5,48E-08	7,32E-08
Prochloraz	Air	0,111548	0,00E+00	0,00E+00	2,04E-09	4,38E-09
Procymidone	Soil	0,049298	1,34E-10	0,00E+00	0,00E+00	0,00E+00
Pronamide	Soil	0,054662	1,74E-07	2,28E-07	4,38E-08	4,43E-08
Propachlor	Soil	0,066134	2,10E-07	2,75E-07	5,30E-08	5,32E-08
Propamocarb	Soil	0,148723	0,00E+00	4,49E-09	0,00E+00	0,00E+00
Propanil	Soil	0,064228	2,54E-09	4,22E-06	0,00E+00	0,00E+00
Propaquizafop	Soil	0,094616	0,00E+00	0,00E+00	1,25E-08	0,00E+00
Propiconazole	Soil	0,122787	2,39E-08	0,00E+00	2,20E-07	1,94E-07
Propoxycarbazone-sodium (prop)	Soil	0,133271	0,00E+00	0,00E+00	3,26E-09	2,78E-09
Prosulfocarb	Soil	0,05569	2,45E-10	6,12E-09	0,00E+00	8,44E-09
Prosulfocarb	Air	0,05569	0,00E+00	0,00E+00	0,00E+00	8,44E-10
Prothioconazol	Soil	0,122045	3,41E-08	1,27E-08	3,67E-09	1,03E-08
Pyraclostrobin (prop)	Soil	0,072236	2,70E-08	8,03E-09	4,10E-08	3,98E-08
Pyraclostrobin (prop)	Air	0,072236	1,79E-10	0,00E+00	0,00E+00	0,00E+00
Pyraflufen-ethyl	Soil	0,067795	4,66E-10	0,00E+00	0,00E+00	0,00E+00
Pyrazophos	Soil	0,112489	3,70E-08	4,85E-08	8,87E-09	9,37E-09
Pyridate	Soil	0,073898	3,83E-10	0,00E+00	6,52E-09	5,03E-08
Pyridate	Air	0,073898	0,00E+00	0,00E+00	0,00E+00	5,03E-09
Pyrimethanil	Soil	0,21079	0,00E+00	0,00E+00	0,00E+00	2,85E-09
Quinmerac	Soil	0,063197	2,06E-10	0,00E+00	2,98E-08	1,42E-08
Quinmerac	Air	0,063197	0,00E+00	0,00E+00	0,00E+00	9,09E-10
Quinoxyfen	Soil	0,045463	2,57E-10	0,00E+00	1,01E-08	8,48E-09
Quizalofop-p-ethyl	Soil	0,075142	0,00E+00	0,00E+00	1,58E-08	1,02E-09
Rimsulfuron	Soil	0,162341	1,13E-09	0,00E+00	0,00E+00	0,00E+00
Sethoxydim	Soil	0,042769	1,72E-10	0,00E+00	0,00E+00	0,00E+00
Silthiofam	Soil	0,05237	3,87E-10	0,00E+00	1,72E-08	1,47E-08
Simazine	Soil	0,347288	4,38E-07	4,15E-06	9,65E-08	1,19E-07

		Reactive Nitrogen Results [kg/functional unit (1kg)]				
Substance	**Comp**	**Nitrogen Coeff**	**Barattolino Crema**	**Biscotto Amando**	**Croissant Vegano**	**Fagottino Crema**
Spinosad	Soil	0,019135	4,44E-10	0,00E+00	0,00E+00	0,00E+00
Spiroxamine	Soil	0,047082	3,67E-09	0,00E+00	6,77E-08	5,85E-08
Starane	Soil	0,076253	0,00E+00	3,30E-08	1,16E-08	1,84E-09
Sulfentrazone	Soil	0,144704	3,06E-08	2,08E-07	0,00E+00	3,68E-09
Sulfentrazone	Air	0,144704	9,89E-10	0,00E+00	0,00E+00	0,00E+00
Sulfosate	Soil	0,057115	2,15E-07	3,72E-07	7,50E-08	6,05E-08
Sulfosulfuron	Soil	0,178618	8,20E-10	0,00E+00	1,62E-08	1,40E-08
t-Butylamine	Water	0,191508	5,68E-09	7,36E-09	4,23E-09	3,90E-09
t-Butylamine	Air	0,191508	2,37E-09	0,00E+00	0,00E+00	0,00E+00
Tebuconazole	Soil	0,136508	7,25E-08	3,77E-08	2,00E-07	1,76E-07
Tebufenpyrad	Soil	0,125786	5,90E-09	7,76E-09	0,00E+00	0,00E+00
Tebupirimphos	Soil	0,08799	4,91E-09	0,00E+00	0,00E+00	1,54E-09
Tebutam	Soil	0,060023	3,96E-08	0,00E+00	2,61E-08	1,20E-08
Teflubenzuron	Soil	0,073506	1,14E-08	4,02E-09	9,98E-10	3,07E-09
Terbuthylazin	Soil	0,304875	2,77E-06	4,74E-07	2,80E-06	9,86E-07
Terbuthylazin	Air	0,304875	0,00E+00	0,00E+00	2,58E-07	1,49E-08
Terbuthylazin	Water	0,304875	0,00E+00	0,00E+00	2,87E-08	0,00E+00
Terbutryn	Soil	0,290023	3,27E-07	4,28E-07	7,84E-08	8,28E-08
Thiacloprid	Soil	0	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Thiamethoxam	Soil	0,240073	4,92E-07	6,17E-08	4,68E-08	1,60E-07
Thiazole, 2-(thiocyanatemethylthio)benzo-	Soil	0,117504	2,30E-08	2,81E-08	2,14E-08	8,23E-09
Thiobencarb	Soil	0,054337	4,59E-10	1,15E-06	0,00E+00	0,00E+00
Thiodicarb	Soil	0,158045	3,46E-08	1,30E-08	3,57E-09	8,73E-09
Thiophanate-methyl	Soil	0,16363	4,98E-08	3,69E-08	7,15E-09	1,41E-08
Thiram	Soil	0,116527	8,77E-10	7,05E-09	2,06E-08	3,18E-08
Tralkoxydim	Soil	0,042517	1,18E-08	0,00E+00	1,46E-09	3,43E-09
Triadimenol	Soil	0,142075	6,21E-10	0,00E+00	7,12E-09	6,68E-09
Triallate	Soil	0,04597	2,15E-10	0,00E+00	9,08E-09	8,36E-09
Triasulfuron	Soil	0,174301	1,97E-07	2,57E-07	5,73E-08	5,86E-08
Triazamate	Soil	0,178111	8,35E-09	1,10E-08	0,00E+00	0,00E+00
Tribenuron	Soil	0,183638	2,07E-07	2,71E-07	4,96E-08	5,25E-08
Tribenuron-methyl	Soil	0,177122	2,01E-07	2,62E-07	7,28E-08	6,34E-08
Triclopyr	Soil	0,054608	1,36E-09	0,00E+00	1,17E-09	2,19E-09
Trifloxystrobin	Soil	0,068597	2,62E-08	8,18E-09	2,73E-08	2,24E-08
Trifluralin	Soil	0,125327	5,81E-08	4,80E-08	1,21E-07	4,93E-08
Trifluralin	Air	0,125327	1,26E-08	8,90E-09	9,50E-09	6,32E-09
Triflusulfuron-methyl	Soil	0,170593	1,92E-07	2,52E-07	4,61E-08	4,87E-08
Trimethylamine	Water	0,236952	4,81E-10	0,00E+00	0,00E+00	0,00E+00
Urea	Water	0,466455	1,95E-09	0,00E+00	0,00E+00	0,00E+00
Vamidothion	Soil	0,04873	1,37E-09	1,82E-09	0,00E+00	0,00E+00
Ziram	Soil	0,091563	0,00E+00	1,69E-06	0,00E+00	0,00E+00
Total (product systems reactive nitrogen indicator)			**1.50E-02**	**1.36E-02**	**1.48E-02**	**1.40E-02**

Reactive nitrogen indicator results presents some differences especially between the two ice cream products. Further analysis are proposed in the following pages but those differences can be associated essentially to the different type of raw materials used because all the other phases are pretty similar for both Barattolino Crema and Biscotto Amando. As regard pastry product results are similar to each other and also with Barattolino Crema. Also for pastry products differences can be attributed to different type of raw materials used because all the other phases for them are very similar.

Analysing the results presented above, it can be seen that the largest contributions come from emission of nitrate, ammonia, nitrogen oxides, dinitrogen monoxide, ammonium cation and particulates smaller than 2.5 μm. Their relative contribution expressed in percentage is shown in Table 9, in which is clear how the nitrogen-containing substances with highest influence to the product system's reactive nitrogen indicator are similar to every product analysed, except for monoethanolamine which is relatively influent only for pastry products. Substances indicated in Table 9 are the ones with a relative contribution to the reactive nitrogen indicator ≥ 1%.

Table 9: Main substances contribution [%] to reactive nitrogen indicator for the four analysed product systems

Substance	**Compartment**	**Barattolino Crema (1 kg)**	**Biscotto Amando (1 kg)**	**Croissant Vegano (1 kg)**	**Fagottino Crema (1 kg)**
Ammonia	Air	27%	18%	16%	21%
Ammonium, ion	Water	1%	1%	1%	1%
Dinitrogen monoxide	Air	5%	3%	4%	5%
Monoethanolamine	Air	0%	0%	4%	3%
Nitrate	Water	53%	59%	61%	52%
Nitrogen oxides	Air	12%	16%	12%	16%
Particulates, < 2.5 um	Air	1%	1%	1%	1%

With the exception of the monoethanolamine case, the ranking of compounds with the greatest contribution in terms of the reactive nitrogen indicator is the same for all four product systems that were analysed. To clarify this concept, only the compounds presented in Table 9 are shown in Figure 16 with their respective reactive nitrogen results in absolute value.

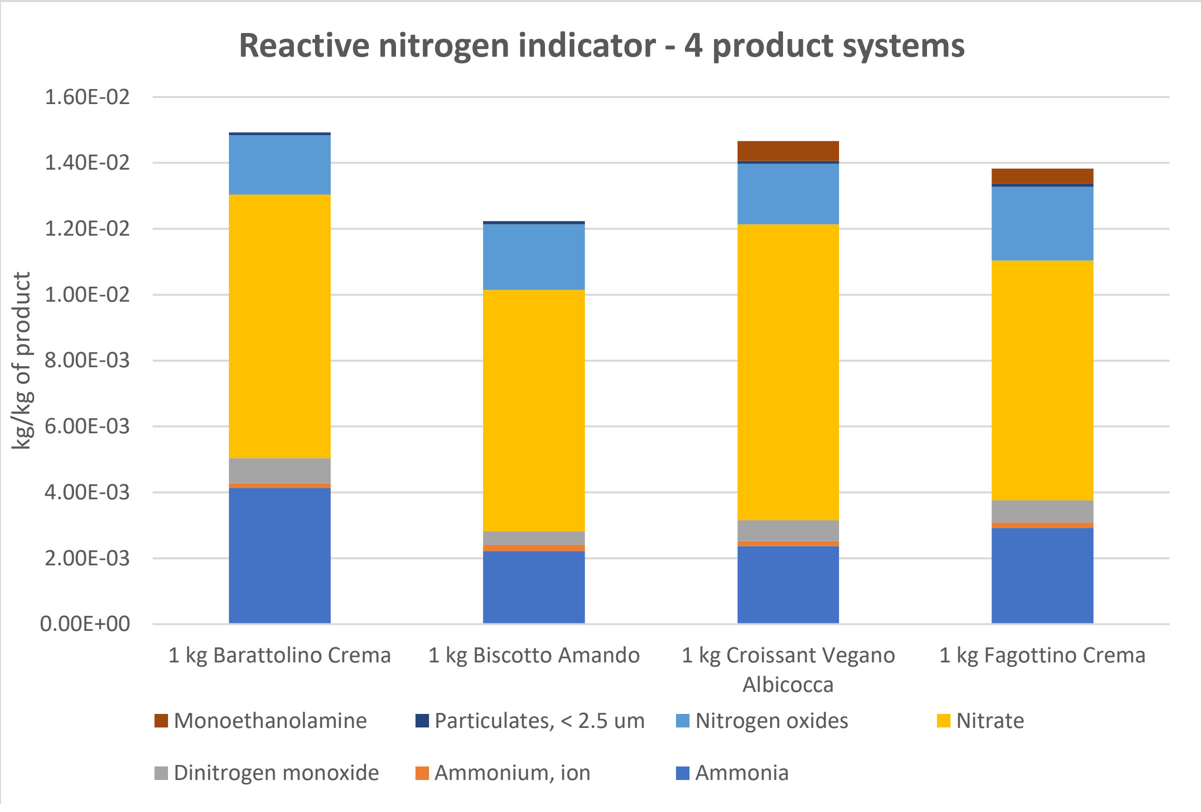


Figure 16: Reactive nitrogen indicator results for the four analysed product systems showing output substances contribution (percentage ≥ 1%)

Based on the functional unit considered (1 kg of product), from Figure 16 is more clear how nitrate is the main reactive nitrogen compound emitted from each product system considered.

3.4 Nitrogen impact assessment: Characterization

Following the proposed method, reactive nitrogen inventory results obtained are used to evaluate the nitrogen impact assessment profile. This is done starting from the selection of the impact categories and their related impact characterization models as discussed in Chapter 2. Impact categories chosen for the four product systems are: Climate Change, Marine eutrophication, Freshwater Ecotoxicity, Terrestrial Eutrophication, Acidification, Photochemical ozone formation, Particulate matter, Human toxicity cancer effect and Human toxicity non-cancer effect. Applying the characterization factors related to the nitrogen containing substances selected through the inventory analysis, category indicator results can be obtained. The characterization factors chosen for this work are presented in Appendix B together with the approximation used.

The results obtained for the four analysed product systems are presented in Table 10 for ice cream product “Barattolino Crema” and “Biscotto Amando” and in Table 11 for pastry products “Croissant Vegano” and Fagottino Crema”.

Table 10: Nitrogen impact assessment profile calculated for products “Barattolino Crema” and “ Biscotto Amando”. Cut-off criterion of 1% applied to the categories Freshwater ecotoxicity ecotoxicity, Human toxicity cancer effect and Human toxicity non-cancer effect.

Impact category	Substance	Comp	Unit	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)
Climate change	Dinitrogen monoxide	Air	[kg CO2 eq]	3,13E-01	1,75E-01
Climate change	Nitrogen fluoride	Air	[kg CO2 eq]	2,76E-12	6,00E-12
Climate change	**Total**		**[kg CO2 eq]**	**3,13E-01**	**1,75E-01**
Marine eutrophication	Nitrate	Water	[kg N eq]	8,01E-03	7,32E-03
Marine eutrophication	Ammonia	Air	[kg N eq]	4,63E-04	2,48E-04
Marine eutrophication	Nitrogen oxides	Air	[kg N eq]	2,29E-03	2,55E-03
Marine eutrophication	Ammonium, ion	Water	[kg N eq]	1,49E-04	1,83E-04
Marine eutrophication	Nitrite	Water	[kg N eq]	2,91E-06	3,41E-06
Marine eutrophication	Nitrogen dioxide	Air	[kg N eq]	1,22E-06	3,37E-06
Marine eutrophication	Ammonia	Water	[kg N eq]	2,23E-07	1,28E-07
Marine eutrophication	Nitrate	Air	[kg N eq]	2,59E-08	3,45E-08
Marine eutrophication	Ammonium, ion	Air	[kg N eq]	1,64E-13	-5,07E-15
Marine eutrophication	Ammonia, as N	Water	[kg N eq]	1,62E-16	5,30E-15
Marine eutrophication	Nitrogen, total	Water	[kg N eq]	7,72E-12	5,32E-11
Marine eutrophication	**Total**		**[kg N eq]**	**1,09E-02**	**1,03E-02**
Freshwater ecotoxicity	Acetochlor	Soil	[CTUe]	9,09E-02	0,00E+00
Freshwater ecotoxicity	Alachlor	Soil	[CTUe]	3,60E-02	0,00E+00
Freshwater ecotoxicity	Atrazine	Soil	[CTUe]	3,58E-01	1,29E-01
Freshwater ecotoxicity	Captan	Soil	[CTUe]	0,00E+00	1,74E-01
Freshwater ecotoxicity	Carbendazim	Soil	[CTUe]	1,05E-01	0,00E+00
Freshwater ecotoxicity	Chloropicrin	Soil	[CTUe]	1,35E-01	0,00E+00
Freshwater ecotoxicity	Chlorothalonil	Soil	[CTUe]	5,45E-02	1,56E+00
Freshwater ecotoxicity	Chlorpyrifos	Soil	[CTUe]	1,40E-01	0,00E+00
Freshwater ecotoxicity	Cypermethrin	Soil	[CTUe]	0,00E+00	3,74E+00
Freshwater ecotoxicity	Diflubenzuron	Soil	[CTUe]	4,02E-01	1,77E-01
Freshwater ecotoxicity	Dimethenamid	Soil	[CTUe]	8,31E-02	0,00E+00
Freshwater ecotoxicity	Fipronil	Soil	[CTUe]	1,00E-01	0,00E+00
Freshwater ecotoxicity	Isoproturon	Soil	[CTUe]	3,42E-02	0,00E+00
Freshwater ecotoxicity	Lambda-cyhalothrin	Soil	[CTUe]	3,94E-02	0,00E+00
Freshwater ecotoxicity	Metolachlor	Soil	[CTUe]	1,70E-01	0,00E+00
Freshwater ecotoxicity	Metolachlor, (S)	Soil	[CTUe]	3,24E-02	0,00E+00
Freshwater ecotoxicity	Oryzalin	Soil	[CTUe]	0,00E+00	1,61E-01
Freshwater ecotoxicity	Phosmet	Soil	[CTUe]	2,79E-02	2,78E+00

Impact category	Substance	Comp	Unit	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)
Freshwater ecotoxicity	Simazine	Soil	[CTUe]	0,00E+00	1,51E-01
Freshwater ecotoxicity	Terbuthylazin	Soil	[CTUe]	4,86E-01	0,00E+00
Freshwater ecotoxicity	Ziram	Soil	[CTUe]	0,00E+00	2,71E-01
Freshwater ecotoxicity	**Total**		**[CTUe]**	**2,30E+00**	**9,13E+00**
Terrestrial eutrophication	Ammonia	Air	[molc N eq]	6,79E-02	3,64E-02
Terrestrial eutrophication	Nitrogen oxides	Air	[molc N eq]	2,51E-02	2,79E-02
Terrestrial eutrophication	Nitrogen dioxide	Air	[molc N eq]	1,33E-05	3,70E-05
Terrestrial eutrophication	Nitrate	Air	[molc N eq]	2,93E-06	3,89E-06
Terrestrial eutrophication	Ammonium, ion	Air	[molc N eq]	2,39E-11	-7,41E-13
Terrestrial eutrophication	**Total**		**[molc N eq]**	**9,30E-02**	**6,44E-02**
Acidification	Ammonia	Air	[molc H+ eq]	1,52E-02	8,15E-03
Acidification	Nitrogen oxides	Air	[molc H+ eq]	4,36E-03	4,85E-03
Acidification	Nitrogen dioxide	Air	[molc H+ eq]	2,32E-06	6,42E-06
Acidification	**Total**		**[molc H+ eq]**	**1,95E-02**	**1,30E-02**
Photochemical ozone formation	Nitrogen oxides	Air	[kg NMVOC eq]	5,89E-03	6,55E-03
Photochemical ozone formation	Nitrogen dioxide	Air	[kg NMVOC eq]	3,13E-06	8,67E-06
Photochemical ozone formation	**Total**		**[kg NMVOC eq]**	**5,89E-03**	**6,56E-03**
Particulate matter	Ammonia	Air	[kg PM2.5 eq]	3,35E-04	1,80E-04
Particulate matter	Nitrogen oxides	Air	[kg PM2.5 eq]	4,25E-05	4,73E-05
Particulate matter	Particulates, < 2.5 um	Air	[kg PM2.5 eq]	1,04E-03	1,11E-03
Particulate matter	Particulates, < 10 um	Air	[kg PM2.5 eq]	8,10E-06	7,75E-07
Particulate matter	Nitrogen dioxide	Air	[kg PM2.5 eq]	2,26E-08	6,26E-08
Particulate matter	**Total**		**[kg PM2.5 eq]**	**1,43E-03**	**1,34E-03**
Human toxicity, cancer effects	Atrazine	Soil	[CTUh]	1,53E-11	5,49E-12
Human toxicity, cancer effects	Atrazine	Water	[CTUh]	6,62E-13	0,00E+00
Human toxicity, cancer effects	Captan	Soil	[CTUh]	0,00E+00	4,11E-13
Human toxicity, cancer effects	Carbaryl	Soil	[CTUh]	0,00E+00	4,62E-12
Human toxicity, cancer effects	Chlorothalonil	Soil	[CTUh]	0,00E+00	3,12E-13
Human toxicity, cancer effects	Cyanazine	Soil	[CTUh]	1,05E-11	1,38E-11
Human toxicity, cancer effects	Methidathion	Soil	[CTUh]	6,21E-13	0,00E+00
Human toxicity, cancer effects	Nitrobenzene	Water	[CTUh]	4,98E-13	0,00E+00
Human toxicity, cancer effects	Pronamide	Soil	[CTUh]	1,16E-12	1,51E-12
Human toxicity, cancer effects	Ziram	Soil	[CTUh]	0,00E+00	1,92E-12
Human toxicity, cancer effects	**Total**		**[CTUh]**	**2,87E-11**	**2,80E-11**
Human toxicity, non-cancer effects	Atrazine	Soil	[CTUh]	1,77E-11	6,38E-12
Human toxicity, non-cancer effects	Fipronil	Soil	[CTUh]	1,63E-11	0,00E+00
Human toxicity, non-cancer effects	Terbutryn	Soil	[CTUh]	1,15E-11	1,51E-11
Human toxicity, non-cancer effects	Triasulfuron	Soil	[CTUh]	1,33E-11	1,74E-11
Human toxicity, non-cancer effects	Acephate	Soil	[CTUh]	5,75E-10	2,12E-10
Human toxicity, non-cancer effects	Chlorpyrifos methyl	Soil	[CTUh]	1,07E-11	7,77E-12
Human toxicity, non-cancer effects	Chlorpyrifos	Soil	[CTUh]	1,20E-11	0,00E+00
Human toxicity, non-cancer effects	Monocrotophos	Soil	[CTUh]	1,14E-11	5,00E-12

Impact category	Substance	Comp	Unit	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)
Human toxicity, non-cancer effects	Dialifor	Soil	[CTUh]	9,37E-12	1,24E-11
Human toxicity, non-cancer effects	Aldicarb	Soil	[CTUh]	0,00E+00	4,69E-12
Human toxicity, non-cancer effects	Carbofuran	Soil	[CTUh]	0,00E+00	4,74E-12
Human toxicity, non-cancer effects	Chlorothalonil	Soil	[CTUh]	0,00E+00	9,39E-12
Human toxicity, non-cancer effects	Diazinon	Soil	[CTUh]	0,00E+00	1,12E-11
Human toxicity, non-cancer effects	Glyphosate	Soil	[CTUh]	0,00E+00	2,32E-11
Human toxicity, non-cancer effects	Methomyl	Soil	[CTUh]	0,00E+00	7,91E-12
Human toxicity, non-cancer effects	Phosmet	Soil	[CTUh]	0,00E+00	1,61E-11
Human toxicity, non-cancer effects	Simazine	Soil	[CTUh]	0,00E+00	5,44E-11
Human toxicity, non-cancer effects	Ziram	Soil	[CTUh]	0,00E+00	1,38E-11
Human toxicity, non-cancer effects	**Total**		**[CTUh]**	**6,77E-10**	**4,22E-10**

Table 11: Nitrogen impact assessment profile calculated for products "Croissant Vegano" and "Fagottino Crema". Cut-off criterion of 1% applied to the categories Freshwater ecotoxicity ecotoxicity, Human toxicity cancer effect and Human toxicity non-cancer effect

Impact category	Substance	Comp	Unit	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
Climate change	Dinitrogen monoxide	Air	[kg CO2 eq]	2,63E-01	2,79E-01
Climate change	Nitrogen fluoride	Air	[kg CO2 eq]	4,18E-12	4,70E-12
Climate change	**Total**		**[kg CO2 eq]**	**2,63E-01**	**2,79E-01**
Marine eutrophication	Ammonia	Air	[kg N eq]	2,65E-04	3,27E-04
Marine eutrophication	Ammonia	Water	[kg N eq]	4,32E-07	1,90E-06
Marine eutrophication	Ammonia, as N	Water	[kg N eq]	1,32E-16	3,59E-15
Marine eutrophication	Ammonium, ion	Air	[kg N eq]	5,18E-15	3,40E-12
Marine eutrophication	Ammonium, ion	Water	[kg N eq]	1,52E-04	1,66E-04
Marine eutrophication	Nitrate	Air	[kg N eq]	1,31E-08	1,83E-08
Marine eutrophication	Nitrate	Water	[kg N eq]	8,99E-03	7,28E-03
Marine eutrophication	Nitrite	Water	[kg N eq]	2,45E-06	2,76E-06
Marine eutrophication	Nitrogen dioxide	Air	[kg N eq]	2,65E-05	3,24E-05
Marine eutrophication	Nitrogen oxides	Air	[kg N eq]	2,35E-03	2,86E-03
Marine eutrophication	Nitrogen, total	Water	[kg N eq]	3,42E-11	2,06E-10
Marine eutrophication	**Total**		**[kg N eq]**	**1,18E-02**	**1,07E-02**
Freshwater ecotoxicity	Aclonifen	Soil	[CTUe]	2,30E-01	0,00E+00
Freshwater ecotoxicity	Alachlor	Soil	[CTUe]	2,69E-01	0,00E+00
Freshwater ecotoxicity	Atrazine	Soil	[CTUe]	3,72E-02	1,33E-01
Freshwater ecotoxicity	Captan	Soil	[CTUe]	2,31E-01	0,00E+00
Freshwater ecotoxicity	Carbofuran	Soil	[CTUe]	1,69E-01	2,49E-01
Freshwater ecotoxicity	Chlorothalonil	Soil	[CTUe]	4,11E-02	0,00E+00
Freshwater ecotoxicity	Chlorpyrifos	Water	[CTUe]	3,45E-02	0,00E+00
Freshwater ecotoxicity	Chlorpyrifos	Soil	[CTUe]	1,41E-01	2,41E-01
Freshwater ecotoxicity	Cyfluthrin	Water	[CTUe]	5,09E-02	0,00E+00

Impact category	Substance	Comp	Unit	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
Freshwater ecotoxicity	Cypermethrin	Soil	[CTUe]	1,46E-01	4,24E-01
Freshwater ecotoxicity	Diflubenzuron	Soil	[CTUe]	3,69E-02	0,00E+00
Freshwater ecotoxicity	Iprodione	Soil	[CTUe]	1,69E-01	0,00E+00
Freshwater ecotoxicity	Isoproturon	Soil	[CTUe]	4,17E-02	0,00E+00
Freshwater ecotoxicity	Linuron	Soil	[CTUe]	2,09E-01	0,00E+00
Freshwater ecotoxicity	Metolachlor	Soil	[CTUe]	1,39E-01	0,00E+00
Freshwater ecotoxicity	Parathion	Soil	[CTUe]	3,83E-02	0,00E+00
Freshwater ecotoxicity	Pendimethalin	Soil	[CTUe]	3,94E-02	0,00E+00
Freshwater ecotoxicity	Terbuthylazin	Water	[CTUe]	4,46E-02	0,00E+00
Freshwater ecotoxicity	Terbuthylazin	Soil	[CTUe]	4,93E-01	1,73E-01
Freshwater ecotoxicity	**Total**		**[CTUe]**	**2,56E+00**	**1,22E+00**
Terrestrial eutrophication	Ammonia	Air	[molc N eq]	3,89E-02	4,80E-02
Terrestrial eutrophication	Ammonium, ion	Air	[molc N eq]	7,57E-13	4,97E-10
Terrestrial eutrophication	Nitrate	Air	[molc N eq]	1,48E-06	2,07E-06
Terrestrial eutrophication	Nitrogen dioxide	Air	[molc N eq]	2,90E-04	3,55E-04
Terrestrial eutrophication	Nitrogen oxides	Air	[molc N eq]	2,57E-02	3,13E-02
Terrestrial eutrophication	**Total**		**[molc N eq]**	**6,49E-02**	**7,96E-02**
Acidification	Ammonia	Air	[molc H+ eq]	8,70E-03	1,07E-02
Acidification	Nitrogen dioxide	Air	[molc H+ eq]	5,03E-05	6,16E-05
Acidification	Nitrogen oxides	Air	[molc H+ eq]	4,47E-03	5,44E-03
Acidification	**Total**		**[molc H+ eq]**	**1,32E-02**	**1,62E-02**
Photochemical ozone formation	Nitrogen dioxide	Air	[kg NMVOC eq]	6,80E-05	8,33E-05
Photochemical ozone formation	Nitrogen oxides	Air	[kg NMVOC eq]	6,04E-03	7,35E-03
Photochemical ozone formation	**Total**		**[kg NMVOC eq]**	**6,11E-03**	**7,43E-03**
Particulate matter	Ammonia	Air	[kg PM2.5 eq]	1,92E-04	2,37E-04
Particulate matter	Nitrogen dioxide	Air	[kg PM2.5 eq]	4,91E-07	6,01E-07
Particulate matter	Nitrogen oxides	Air	[kg PM2.5 eq]	4,36E-05	5,31E-05
Particulate matter	Particulates, < 10 um	Air	[kg PM2.5 eq]	4,33E-07	1,01E-05
Particulate matter	Particulates, < 2.5 um	Air	[kg PM2.5 eq]	9,71E-04	1,21E-03
Particulate matter	**Total**		**[kg PM2.5 eq]**	**1,21E-03**	**1,52E-03**
Human toxicity, cancer effects	Atrazine	Soil	[CTUh]	1,59E-12	5,68E-12
Human toxicity, cancer effects	Captan	Soil	[CTUh]	5,48E-13	0,00E+00
Human toxicity, cancer effects	Cyanazine	Soil	[CTUh]	2,52E-12	2,70E-12
Human toxicity, cancer effects	Nitrobenzene	Water	[CTUh]	1,94E-13	2,88E-13
Human toxicity, cancer effects	Prochloraz	Water	[CTUh]	3,69E-13	7,89E-13
Human toxicity, cancer effects	Prochloraz	Soil	[CTUh]	4,34E-12	5,79E-12
Human toxicity, cancer effects	Pronamide	Soil	[CTUh]	2,92E-13	2,95E-13
Human toxicity, cancer effects	Atrazine	Air	[CTUh]	0,00E+00	1,70E-13
Human toxicity, cancer effects	Methidathion	Soil	[CTUh]	0,00E+00	5,11E-13
Human toxicity, cancer effects	**Total**		**[CTUh]**	**9,84E-12**	**1,62E-11**
Human toxicity, non-cancer effects	Acephate	Soil	[CTUh]	4,46E-11	1,62E-10
Human toxicity, non-cancer effects	Captan	Soil	[CTUh]	5,75E-12	0,00E+00
Human toxicity, non-cancer effects	Carbofuran	Soil	[CTUh]	5,61E-11	8,29E-11
Human toxicity, non-cancer effects	Chlorpyrifos	Water	[CTUh]	2,81E-12	8,19E-12

Impact category	Substance	Comp	Unit	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
Human toxicity, non-cancer effects	Chlorpyrifos	Soil	[CTUh]	1,21E-11	2,07E-11
Human toxicity, non-cancer effects	Dialifor	Soil	[CTUh]	2,41E-12	0,00E+00
Human toxicity, non-cancer effects	Glyphosate	Soil	[CTUh]	3,65E-12	5,49E-12
Human toxicity, non-cancer effects	Iprodione	Soil	[CTUh]	2,56E-11	0,00E+00
Human toxicity, non-cancer effects	Linuron	Soil	[CTUh]	3,97E-11	6,87E-12
Human toxicity, non-cancer effects	Metolachlor	Soil	[CTUh]	2,64E-12	0,00E+00
Human toxicity, non-cancer effects	Oxyfluorfen	Soil	[CTUh]	1,02E-11	0,00E+00
Human toxicity, non-cancer effects	Prochloraz	Soil	[CTUh]	8,11E-12	1,08E-11
Human toxicity, non-cancer effects	Terbutryn	Soil	[CTUh]	2,76E-12	0,00E+00
Human toxicity, non-cancer effects	Triasulfuron	Soil	[CTUh]	3,88E-12	3,97E-12
Human toxicity, non-cancer effects	Atrazine	Soil	[CTUh]	0,00E+00	6,59E-12
Human toxicity, non-cancer effects	Monocrotophos	Soil	[CTUh]	0,00E+00	4,21E-12
Human toxicity, non-cancer effects	**Total**		**[CTUh]**	**2,20E-10**	**3,12E-10**

To sum up all the results above presented Table 12 collects total outputs for each impact category analysed.

Table 12: Nitrogen impact assessment profile calculated for all four products

Impact Categories	Unit	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
Climate change	[kg CO2 eq]	3,13E-01	1,75E-01	2,63E-01	2,79E-01
Marine eutrophication	[kg N eq]	1,09E-02	1,03E-02	1,18E-02	1,07E-02
Freshwater ecotoxicity	[CTUe]	2,30E+00	9,13E+00	2,56E+00	1,22E+00
Terrestrial eutrophication	[molc N eq]	9,30E-02	6,44E-02	6,49E-02	7,96E-02
Acidification	[molc H+ eq]	1,95E-02	1,30E-02	1,32E-02	1,62E-02
Photochemical ozone formation	[kg NMVOC eq]	5,89E-03	6,56E-03	6,11E-03	7,43E-03
Particulate matter	[kg PM2.5 eq]	1,43E-03	1,34E-03	1,21E-03	1,52E-03
Human toxicity, cancer effects	[CTUh]	2,87E-11	2,80E-11	9,84E-12	1,62E-11
Human toxicity, non-cancer effects	[CTUh]	1,77E-11	4,22E-10	2,20E-10	3,12E-10

From the results above presented some differences can be spotted. No clear predominance in none of the products analysed has been found. Instead, some products are better than others in terms of impact category, but worse in others. The case of Biscotto Amando has a greater impact on freshwater ecotoxicity than other products but, in contrast, has the least impact on climate change.

3.5 Nitrogen impact assessment: Normalization and Weighting

Once concluded characterization step, normalization and weighting can be applied as described in Chapter 2. The aim is to obtain a single score nitrogen impact indicator by first applying a normalization procedure, and then aggregating those results using weighting factors.

As explained in Chapter 2, objective of normalisation is to better understand the relative contribution of the studied system to the reference system for each indicator result. Normalization factors, in fact, help interpret the scores of each impact category, converting them in fraction of impact of a reference situation's system that in this case is the global system. After applying normalization procedure and using the normalization factor described in Chapter 2, it is possible to obtain the nitrogen impact assessment profile results after normalization as shown in Table 13 for the four analysed product systems.

Table 13: Results of normalized impact assessment profile calculated for the four analysed product systems

Impact Categories	**Normalization Factors**	**Barattolino Crema (1 kg)**	**Biscotto Amando (1 kg)**	**Croissant Vegano (1 kg)**	**Fagottino Crema (1 kg)**
Climate change	8,10E+03	3,86E-05	2,16E-05	3,25E-05	3,45E-05
Marine eutrophication	1,95E+01	5,59E-04	5,28E-04	6,03E-04	5,46E-04
Freshwater ecotoxicity	4,27E+04	5,38E-05	2,14E-04	6,00E-05	2,86E-05
Terrestrial eutrophication	1,77E+02	5,26E-04	3,64E-04	3,67E-04	4,51E-04
Acidification	5,56E+01	3,52E-04	2,34E-04	2,38E-04	2,92E-04
Photochemical ozone formation	4,06E+01	1,45E-04	1,62E-04	1,50E-04	1,83E-04
Particulate matter	1,34E+01	1,06E-04	9,99E-05	8,98E-05	1,13E-04
Human toxicity, cancer effects	1,69E-05	1,70E-06	1,66E-06	5,82E-07	9,60E-07
Human toxicity, non-cancer effects	2,30E-04	7,72E-08	1,84E-06	9,59E-07	1,36E-06

Although the comparison of different impacts is not part of the objective of the applied method, results of this operation can be helpful. Normalized results are represented in a graph in Figure 17.

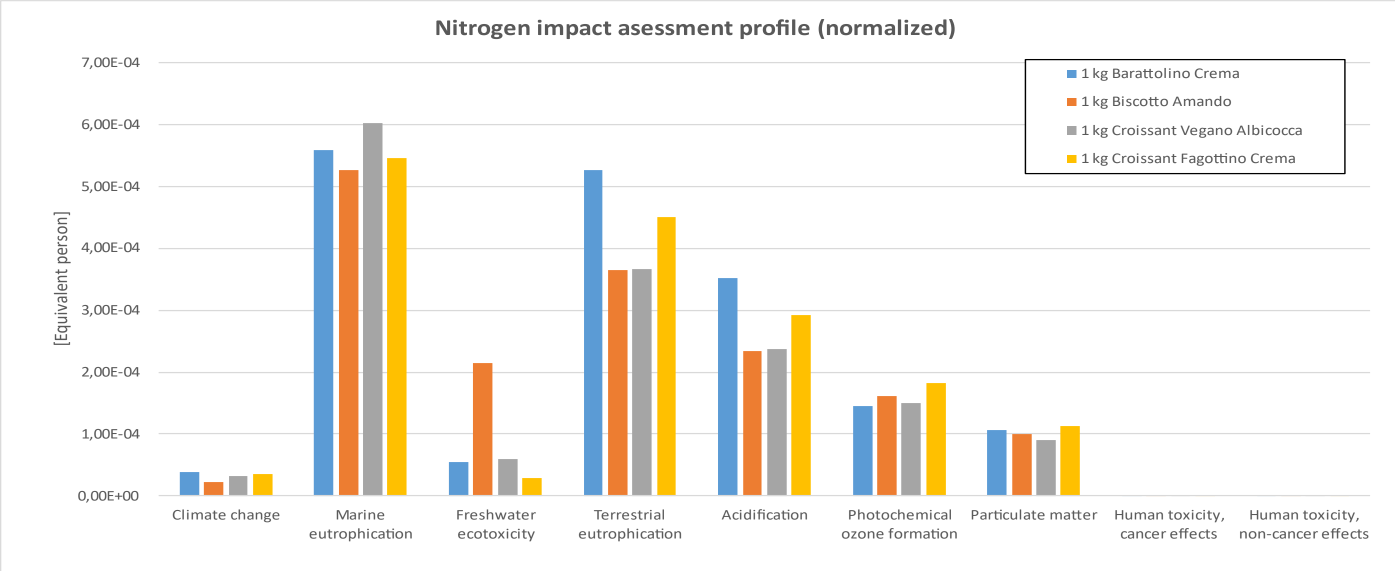


Figure 17: Graphic representation of the normalized impact assessment profile obtained using PEF's normalization factors (European Commission, 2021)

Even though normalization factor shall be used with care (Crenna et al., 2019), results obtained are reasonable because the greatest impact recognized by the normalized procedure are also associate with the highest nitrogen-containing substances emitted like nitrate, ammonia and nitrogen oxides.

Thanks to the normalized obtained results, an easily comparison between product systems profile under study can be done. In fact, significant differences can be spotted for the Freshwater Ecotoxicity, Terrestrial Eutrophication and Acidification impact categories. Regarding the Freshwater Ecotoxicity impact category, Biscotto Amando presents a relevant higher impact respect the other products. This can be explained, analysing nitrogen inventory results, by the use of coconut oil to produce the ice crem part. During cultivation, an insecticide containing a dangerous nitrogen-containing substance (Cypermethrin) is used. When this substance is released into the water environment, it becomes highly toxic to the aquatic biotope.

For both Terrestrial Eutrophication and Acidification impact categories, the high impact found for Barattolino Crema and Fagottino Crema is associated with a bigger ammonia and nitrogen oxides release into air. Ammonia, for both products, presents a high value because associated with dairy raw materials like cow milk used in ice crem and in the cream of pastry product. Nitrogen oxides instead are especially associated with electric energy production generated by coal and transport emissions, explaining also why they are presents in every phase of the life cycle.

Furthermore, a weighting procedure can be done on to the normalized results. Weighting is the process of converting normalised results of the different impact categories by using numerical factors based on the expressed relative importance of the impact categories considered. Therefore, all weighted results have the same unit and can be added up to create one single score that summarize all the nitrogen related impact. From what was proposed in Chapter 2 two weighting procedure were applied using the weighting factors obtained from the proposed method and those suggested *Development of a weighting approach for the Environmental Footprint*" (Sala & Cerutti, 2018). In Appendix B, Table 20 shows a recall of the category reactive nitrogen calculation for each impact category, which are needed to obtain weighting factors using the proposed method.

Then, obtained the category reactive nitrogen results, the weighting factors for each impact category selected can be calculated through the calculation procedure defined in the proposed method. Since four product systems were analysed in this study, it is necessary to add up all the category reactive nitrogen results for all the product systems for a specific impact category in order to obtain the average weighting factors. The weighting factors evaluated are shown in Table 14, together with the summation of the category reactive nitrogen results for all the four analysed product systems .

Table 14: Results of category reactive nitrogen summation for the four product systems and average weighting factors calculation determined by applying the internal method proposed.

Impact categories	**Product systems category reactive N**	**Weighting Factors**
Climate change	2,47E-03	2,04%
Marine eutrophication	5,18E-02	42,64%
Freshwater ecotoxicity	6,08E-05	0,05%
Terrestrial eutrophication	1,96E-02	16,10%
Acidification	1,95E-02	16,10%
Photochemical ozone formation	7,91E-03	6,51%
Particulate matter	2,00E-02	16,47%
Human toxicity, cancer effects	2,78E-05	0,02%
Human toxicity, non-cancer effects	8,92E-05	0,07%
Total	**1,22E-01**	**100,00%**

Applying the proposed weighting method to the product systems under study, the weighting factors results are relatively high for the impact linked to the major emissions of nitrogen-containing substances, such as Marine Eutrophication, Terrestrial Eutrophication, Acidification and Particulate Matter.

Thanks to the weighting factors shown in Table 14 weighted nitrogen impact assessment profile and the single score nitrogen impact indictor, which represent the summation of categories weighted results, can be evaluated for the four analysed product systems. Results are expressed in Table 15.

Table 15: Weighting factors (second column), weighted nitrogen assessment profile and single score nitrogen impact indicator (last row) results calculated for the four analysed product systems. Weighting factors calculated by applying the proposed internal method to the reference product system.

Impact categories	Weighting Factors	Barattolino Crema (1 kg)	Biscotto Amando (1 kg)	Croissant Vegano (1 kg)	Fagottino Crema (1 kg)
Climate change	2,04%	7,87E-07	4,40E-07	6,63E-07	7,02E-07
Marine eutrophication	42,69%	2,38E-04	2,25E-04	2,57E-04	2,33E-04
Freshwater ecotoxicity	0,04%	2,69E-08	1,07E-07	3,00E-08	1,43E-08
Terrestrial eutrophication	16,11%	8,47E-05	5,86E-05	5,91E-05	7,25E-05
Acidification	16,11%	5,66E-05	3,77E-05	3,83E-05	4,70E-05
Photochemical ozone formation	6,52%	9,45E-06	1,05E-05	9,80E-06	1,19E-05
Particulate matter	16,48%	1,75E-05	1,64E-05	1,48E-05	1,86E-05
Human toxicity, cancer effects	0,00%	3,88E-10	3,79E-10	1,33E-10	2,19E-10
Human toxicity, non-cancer effects	0,00%	5,67E-11	1,35E-09	7,04E-10	9,97E-10
Total (single score nitrogen impact indictor)	**100%**	**4,07E-04**	**3,49E-04**	**3,80E-04**	**3,84E-04**

The obtained single score indicator results address the highest impact to “Barattolino Crema” product confirming the results also obtained from the reactive nitrogen indicator results. Instead, looking to the pastry products it can be notice how higher impact is associated to the “Fagottino Crema” respect the “Croissant Vegano”. This is in contrast on what obtained in reactive nitrogen indicator results and can be explained considering that “Fagottino Crema” presents a higher impact for every impact category except marine eutrophication and freshwater ecotoxicity. However, it is important to highlight that results at the inventory and impact level differ slightly.

The calculation of the weighted nitrogen impact assessment profile and of the single score nitrogen indicator results was also made using a different weighting factor sets taken from “*Development of a weighting approach for the Environmental* Footprint” (Sala & Cerutti, 2018). Results of the calculation carried out are reported in Table 16.

Table 16: Weighting factors (second column), weighted nitrogen assessment profile and single score nitrogen impact indicator (last row) results calculated for the four analysed product systems. Weighting factors taken from "Development of a weighting approach for the Environmental Footprint" (Sala & Cerutti, 2018).

Impact categories	**Weighting Factors**	**Barattolino Crema (1 kg)**	**Biscotto Amando (1 kg)**	**Croissant Vegano (1 kg)**	**Fagottino Crema (1 kg)**
Climate change	39,32%	1,52E-05	8,50E-06	1,28E-05	1,36E-05
Marine eutrophication	5,53%	3,09E-05	2,92E-05	3,33E-05	3,02E-05
Freshwater ecotoxicity	3,58%	1,93E-06	7,67E-06	2,15E-06	1,03E-06
Terrestrial eutrophication	6,93%	3,64E-05	2,52E-05	2,54E-05	3,12E-05
Acidification	11,58%	4,07E-05	2,71E-05	2,75E-05	3,38E-05
Photochemical ozone formation	8,92%	1,29E-05	1,44E-05	1,34E-05	1,63E-05
Particulate matter	16,73%	1,78E-05	1,67E-05	1,50E-05	1,89E-05
Human toxicity, cancer effects	3,98%	6,76E-08	6,60E-08	2,32E-08	3,82E-08
Human toxicity, non-cancer effects	3,44%	2,65E-09	6,31E-08	3,29E-08	4,66E-08
Total (single score nitrogen impact indictor)	**100,00%**	**1,56E-04**	**1,29E-04**	**1,30E-04**	**1,45E-04**

The single score impact indicator results obtained by applying the two different weighting sets are also graphically represented in the Figure 18.

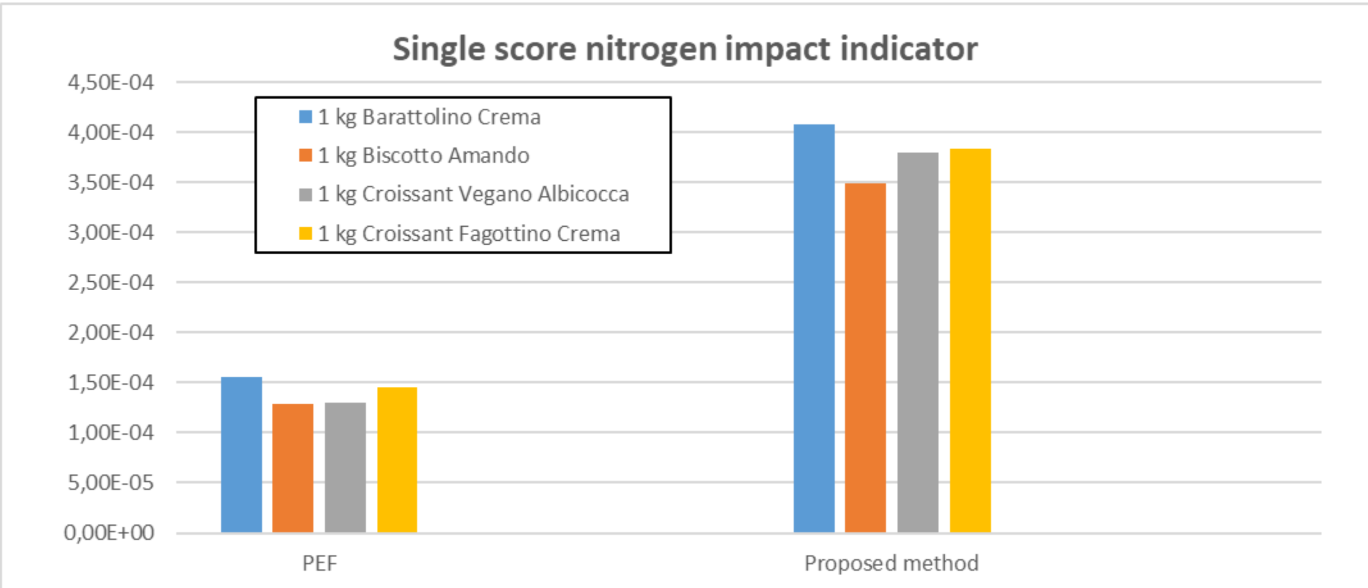


Figure 18: Graphic representation of single score nitrogen impact indicator results for the four analysed product systems obtained using 2 different weighting sets

Weighted results do not highlight any product systems selected as the best, because the overall results are pretty the same. The only comment that can be appropriate is the different magnitude of the two group results. (Sala & Cerutti, 2018) weighting factors clearly address more importance onto impact categories like climate change or particulate matter, so, impact categories which are nowadays perceived as most dangerous by experts and public. In contrast, Zuliani's approach weights more the impact categories which presents a higher value of total reactive nitrogen indicator, so the ones whit higher influence in the nitrogen cycle. In fact, the proposed method and weighing factors were designed specifically for application to nitrogen and thus to amplify the results of the impact categories considered, whereas the Sala & Cerutti (2018) weighing method is for general applications.

3.6 Interpretation of the results

This paragraph presents a deeper analysis of the results presented above, along with additional considerations on the method applied. It also incorporates results already available to Sammontana related to the impacts of its products.

By analysing the reactive nitrogen results, it is possible to identify the phase(s) of the product system with the highest release. The same results can also be used to evaluate the reactive nitrogen output for each specific phase of the product system, such as raw material acquisition, packaging, production, distribution, use, and end of life. To perform this analysis, simply select the relevant phase and associate each elementary flow with its corresponding category. In this way every emission evaluated through the inventory analysis can be linked to the specific phase in which it happens. In the case of this work only nitrogen containing substance are selected thus obtaining the results shown in Figure 19.

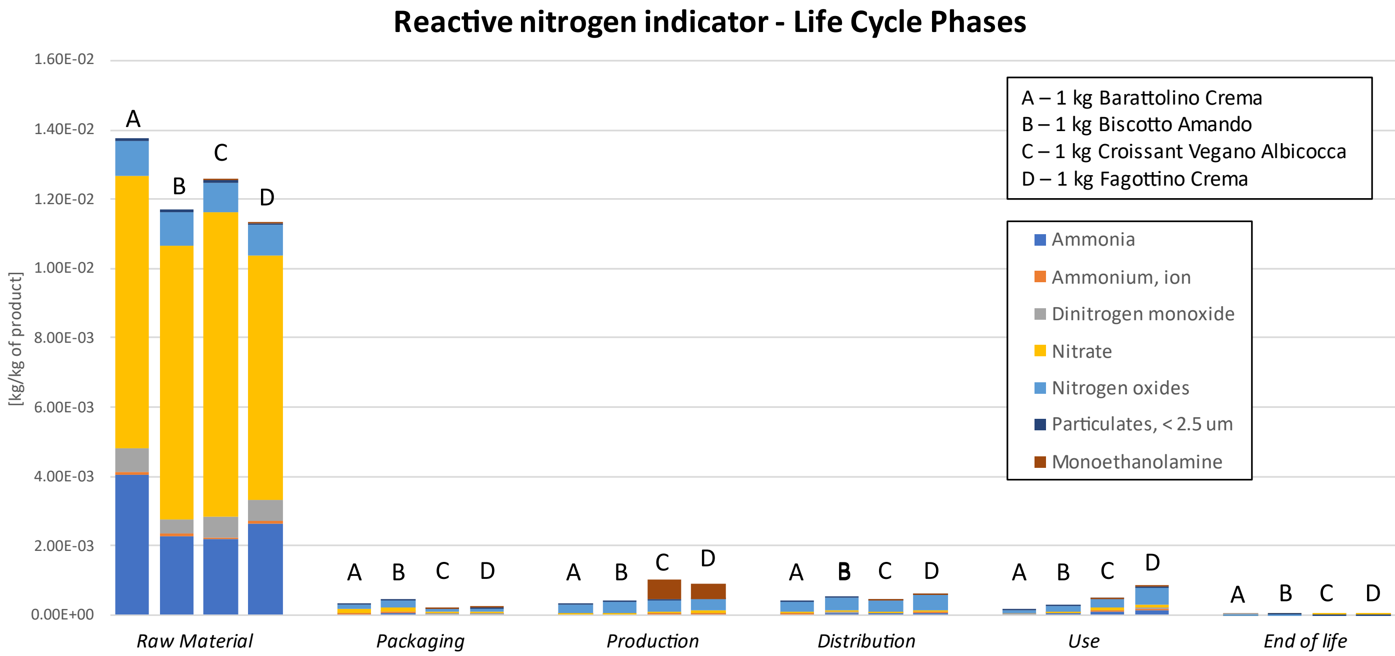
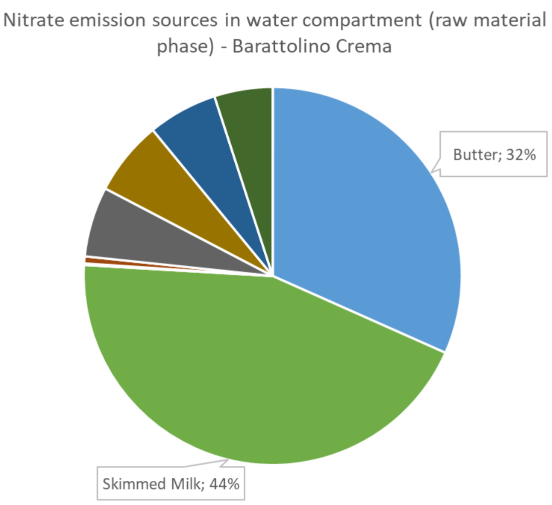


Figure 19: Reactive Nitrogen Indicator evaluated considering the 6 phases in which a product life cycle can be divided

From Figure 19 it is evident that the raw materials phase presents the highest emission of reactive nitrogen compounds and that the nitrates, released in the water compartment, are the primary substance released. Hence, the presence of nitrates in water, which is associated with raw materials production, indicates a strong correlation with the use of fertilizers required for the product's raw materials.

Interesting is the fact that ice cream raw materials are different in the products presented: Barattolino Crema is made by butter and milk and, instead, Biscotto Amando doesn't use any dairy products to form the ice cream part, but almond milk. Even if products present a different set of raw materials, the nitrate amount released during raw material production for 1 kg of product is pretty the same.

In Figure 20 main sources of nitrate emissions for ice cream products are shown. For Barattolino Crema main sources of nitrate in water compartment are related to dairy products production that will be used to for the ice cream part. Instead, the main source of nitrates to the water compartment in Biscotto Amando is not associated with the ice cream but with the biscuits production which are used to cover the ice cream part.



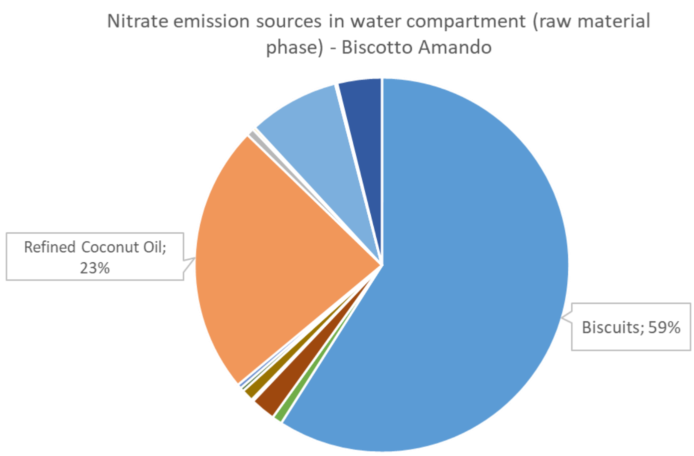


Figure 20: Nitrate emission sources in water compartment in raw material phase for "Barattolino Crema" (o the left) and for "Biscotto Amando" (on the right)

Moving on to pastry products, even though the recipes are quite similar, a higher amount of margarine and flour used in the Croissant Vegano leads to greater nitrate water emissions. Figure 21 highlights the contribution of each pastry product analysed to nitrate emissions. The higher nitrate emission associated with the Croissant Vegano is linked not only to a higher amount of margarine and flour used per kg, which as shown, represents the highest contribution, but also because the margarine used in the Croissant Vegano contains a different type of margarine that uses a higher quantity of sunflower oil in its production, resulting in increased nitrate emissions compared to the margarine used in the Fagottino Crema.

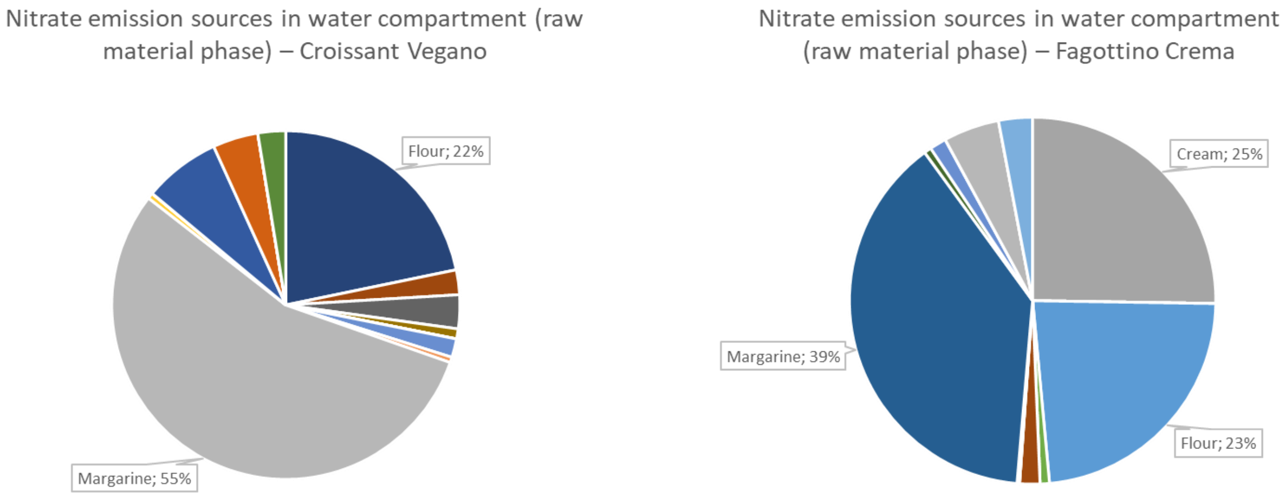


Figure 21: Nitrate emission sources in water compartment in raw material phase for "Croissant Vegano" (on the left) and for "Fagottino Crema" (on the right)

In terms of ammonia released into air, “Barattolino Crema” shows roughly a double amount of reactive nitrogen indicator/amount (because the Nc depends only on the substance) respect other products. As shown in Figure 22 butter and skimmed milk are the main source of ammonia to air, not only because within it there is the ammonia released during crops cultivation, but also the one associated with livestock’s manure (Hristov et al., 2011).

For Biscotto Amando and the other two pastry products ammonia sources are highlighted in Figure 22 and Figure 23. For “Biscotto Amando” and “Croissant Vegano” main source is the flour production associated in the production of biscuits for “Biscotto Amando “ and used as a raw material for “Croissant Vegano” for the dough. Also “Fagottino Crema” presents a significant influence in the ammonia emission by flour use but, in this case, the highest contribute is associated to the production of the cream, in which milk is used and so the same consideration done for Barattolino Crema are valid.

Figure 22: Ammonia emission sources in air compartment in raw material phase for "Barattolino Crema" (o the left) and for "Biscotto Amando" (on the right)

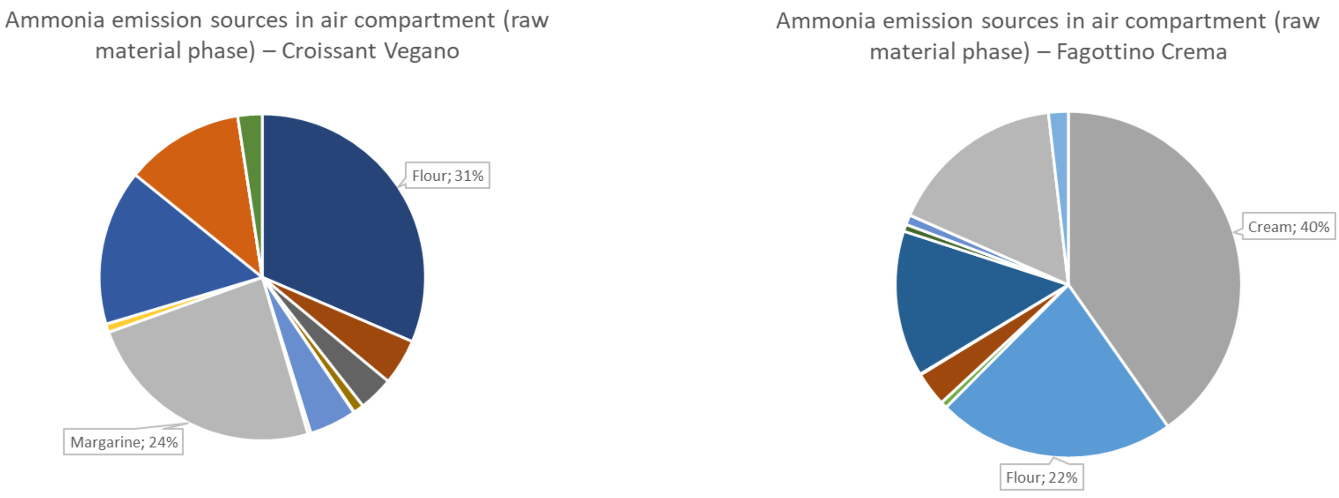


Figure 23: Ammonia emission sources in air compartment in raw material phase for "Croissant Vegano" (o the left) and for "Fagottino Crema" (on the right)

Compared to the raw materials phase, the packaging production phase presents different results in terms of nitrogen-containing substance emissions, with "Biscotto Amando" having the highest emissions. Figure 24 provides a detailed view of the nitrogen emissions associated with the packaging production phase, based on the results of the reactive nitrogen indicator.

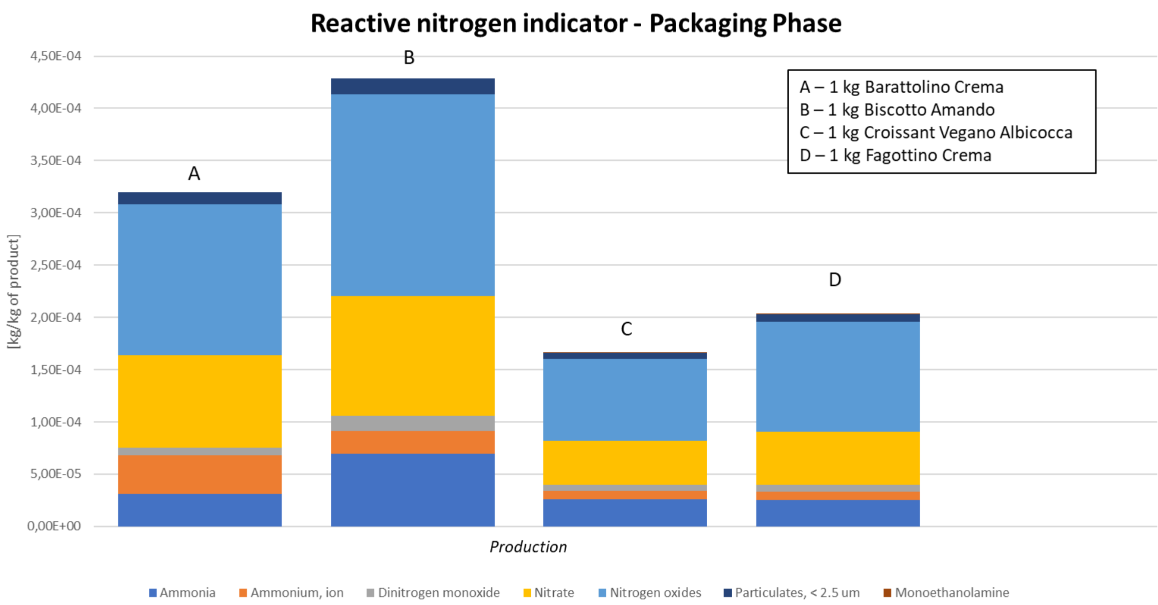


Figure 24: Reactive Nitrogen Indicator evaluated considering the packaging phase for the four product systems

Inside packaging phase all the emissions of nitrogen containing substance related to the production of packaging are considered. The relevant difference between ice cream product and bakery product can be attributed to the higher usage of paper/cardboard in the packaging for "Barattolino Crema" and "Biscotto Amando". In fact, as described in packaging composition in paragraph 3.2.2 "Barattolino Crema" has, for primary packaging, a cap and a can made of a poly-coupled material composed of an external layer of paper and an internal one made of polyethylene. In the “Biscotto Amando” intended for LOD (large organised distribution) distribution, a box of cardboard is used as a secondary packaging containing 4 products, each one within a plastic sealed bag. Instead for bakery products all the pieces produced are wrapped within plastic bags as a primary packaging. The number of pieces within those plastic bags are 6 for “Fagottino Crema” and 50 for “Croissant Vegano”. Thus, Biscotto Amando uses a higher amount of cardboard/paper per kg of product produced compared to Barattolino. Additionally, due to the higher nitrogen-containing substance emissions associated with its production, the final reactive nitrogen indicator score for packaging production is significant for Biscotto Amando.

While the production phase does not have the highest contribution to nitrogen-containing substance emissions, some interesting observations can still be made. Figure 25 shows clear differences between products, particularly in pastry production at the Vinci plant, which has an additional emission related to monoethanolamine.

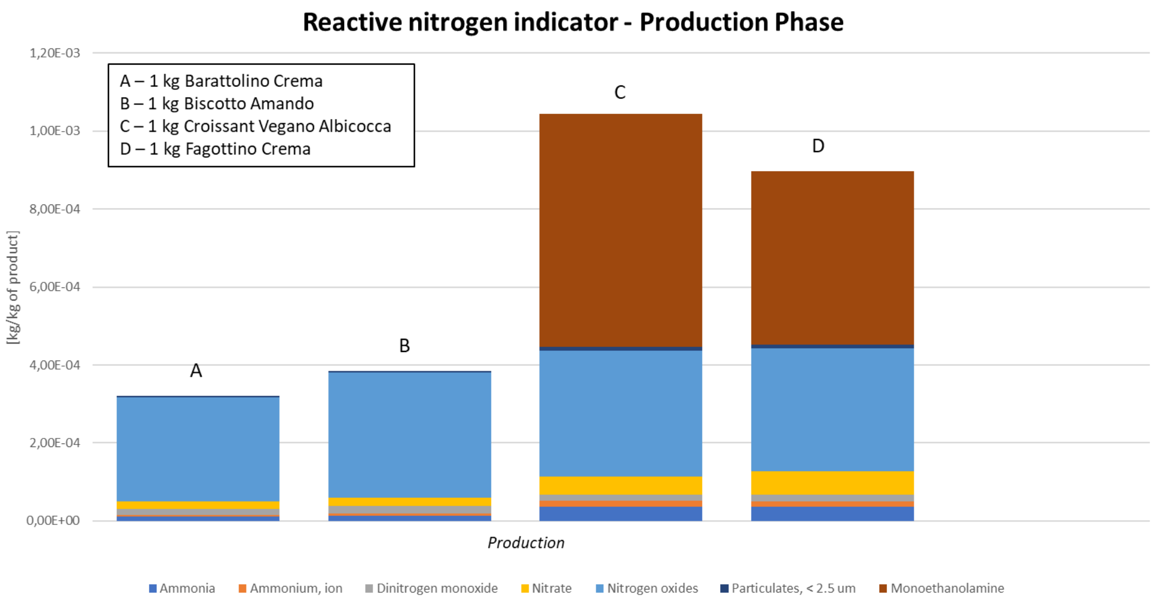


Figure 25: Reactive Nitrogen Indicator evaluated considering the production phase for the four product systems

This reactive nitrogen compound, monoethanolamine, is only present in the production phase and only affects pastry products such as “Fagottino Crema” and “Croissant Vegano”. It is related to carbon dioxide production, which is used to cool down the dough during the production phase. However, carbon dioxide as a refrigerant is not used in ice cream production.

Another interesting analysis can be done on the Distribution and Use phase. As in the production phase also in distribution and use phases nitrogen-containing substance emissions are not significant respect raw material phase, as shown in Figure 19. Except for that, Figure 26 shows reactive nitrogen indicator only for the phases under study. There is a clear difference between the two pastry product in terms of distribution and use phases. This can be explained considering that "Fagottino Crema" is related to the LOD distribution process in which the product after reaching the point of sale is brought to the buyer house in which it is consumed. Instead, "Croissant Vegano" is linked to the Horeca channel, in which the product is consumed at the point of sale.

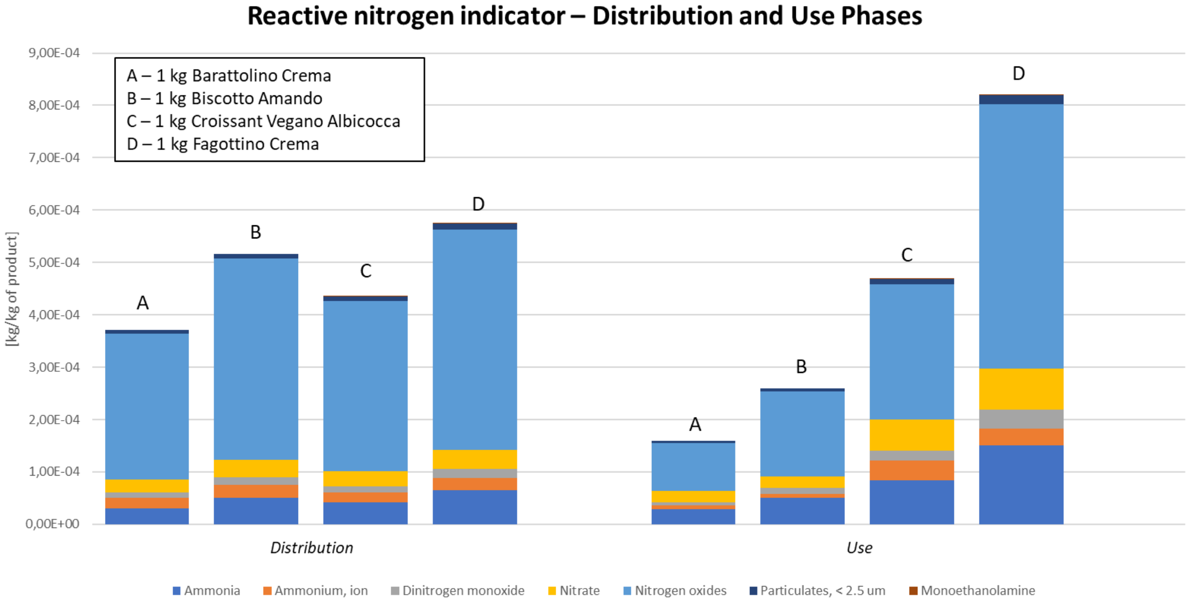


Figure 26: Reactive Nitrogen Indicator evaluated considering the distribution and use phases for the four product systems

Thus, for "Fagottino Crema" products it shall be considered not only the nitrogen containing substance emissions to store the product in the point of sale but also the ones associated to the cooking and storage at the buyer's home. Differently, for "Croissant Vegano", emissions of nitrogen containing substances are related only to the cooking and storage processes at the point of sale. Another useful consideration is that, in the present study, more efficient cooking and storage is attributed to the point of sale assessing for them a lower amount of energy consumed per unit of product treated. This assumption is based on the fact that generally, point of sale process and treat more products and so the energy consume can be allocated to a large number of units reducing energy consumption. No consideration were done on the different appliances that can be used which characteristic cannot be easily obtained and express for all the point of sales and houses that are interested by Sammontana's products.

In the case of ice creams products, “Barattolino Crema” uses a LOD system of distribution which, differently respect bakery products consider only refrigeration related emissions. Instead, within “Biscotto Amando” life cycle both LOD and Horeca processes are considered even if LOD distribution system is the main one considering roughly 90% of the total sold product. The difference in terms of nitrogen-containing substance emissions depends only on the different volume occupied by 1 kg of product in the freezer. In fact volume is used to allocate energy consumed by a representative refrigeration unit.

For all the cases analyzed, the distribution and use phases are essentially related to nitrogen oxide emissions, which are strictly associated with the energy consumed by point-of-sales and consumers' homes during the cooking and storage processes for pastry products. For ice cream products, nitrogen oxide emissions are only associated with storage operations.

In conclusion, it will be interesting to observe whether the results presented above alter Sammontana's perspective on the products analysed in this study. Sammontana has in previous works (Sammontana S.p.A, 2022a, 2022b) evaluated the environmental performance of its products through a Carbon Footprint assessment, and it remains to be seen if our findings will influence their viewpoint. In fact, it is noteworthy that the reactive nitrogen indicator produces the same results as the metric known as the Nitrogen Footprint (Leach et al., 2012). Based on this, another interesting analysis can be conducted. As reported in literature (Leach et al., 2013 *or* Singh & Bakshi, 2015), a comparison between the Reactive Nitrogen Indicator (Nitrogen Footprint) and the Carbon Footprint indicator, can offer a more comprehensive understanding of the environmental impact of a particular activity or system. This comparison can also help identify solutions that address multiple environmental concerns.

In this case, the Carbon Fottprint indicator has already been evaluated by Sammontana for Barattolino Crema and Fagottino Crema. In Figure 27 and Figure 28 results for the reactive nitrogen indicator for “Barattolino Crema” and “Fagottino Crema” are shown addressing singularly each product and addressing the reactive nitrogen content for each phase of the product life cycle.

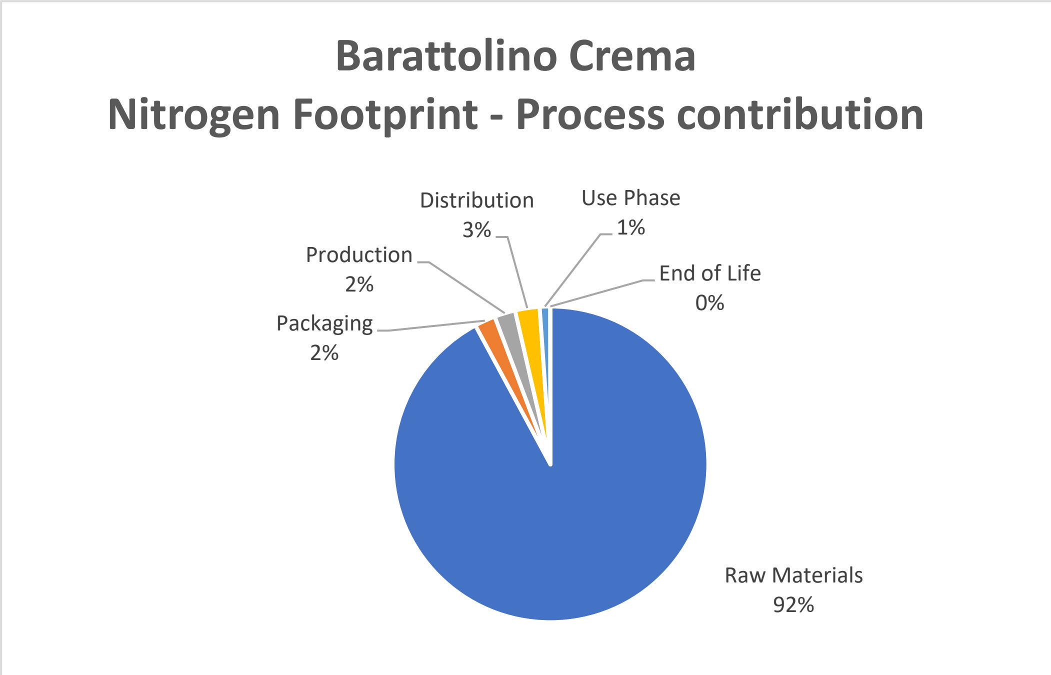


Figure 27: Graphic representation of the nitrogen footprint indicator contribution for the life cycle processes referred to the product "Barattolino Crema"

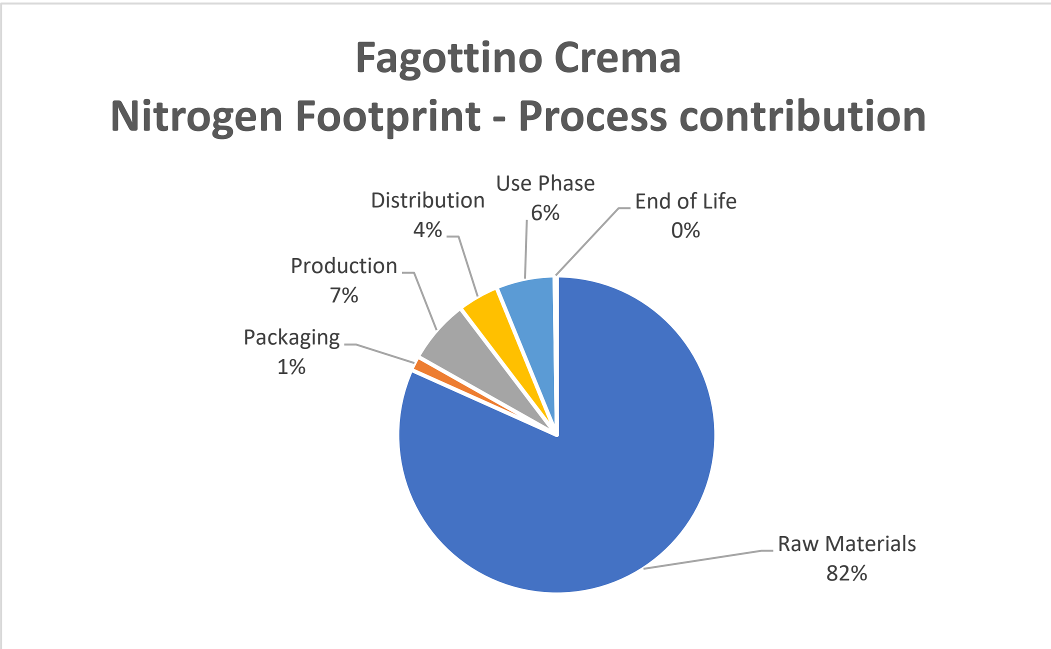


Figure 28: Graphic representation of the nitrogen footprint indicator contribution for the life cycle processes referred to the product "Fagottino Crema"

As already stated for the reactive nitrogen indicator group analysis the highest contribution in nitrogen-containing substances is given by the raw material phase.

In the following Figure 29 and Figure 30 a graphic representation of the results of the Carbon Footprint indicator done by Sammontana are presented for, respectively, “Barattolino Crema” and “Fagottino Crema”.

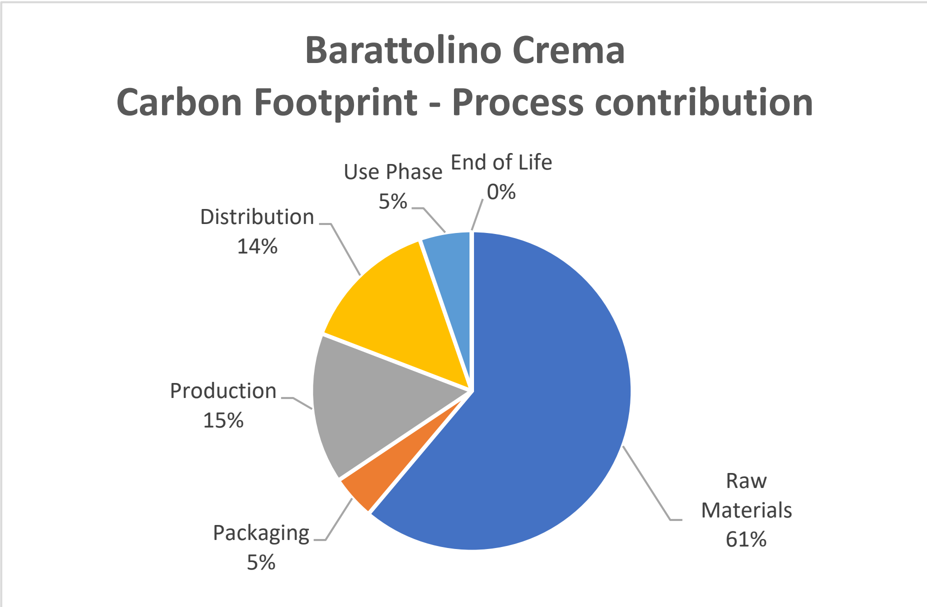


Figure 29: Graphic representation of the carbon footprint indicator contribution for the life cycle processes referred to the product “Barattolino Crema”

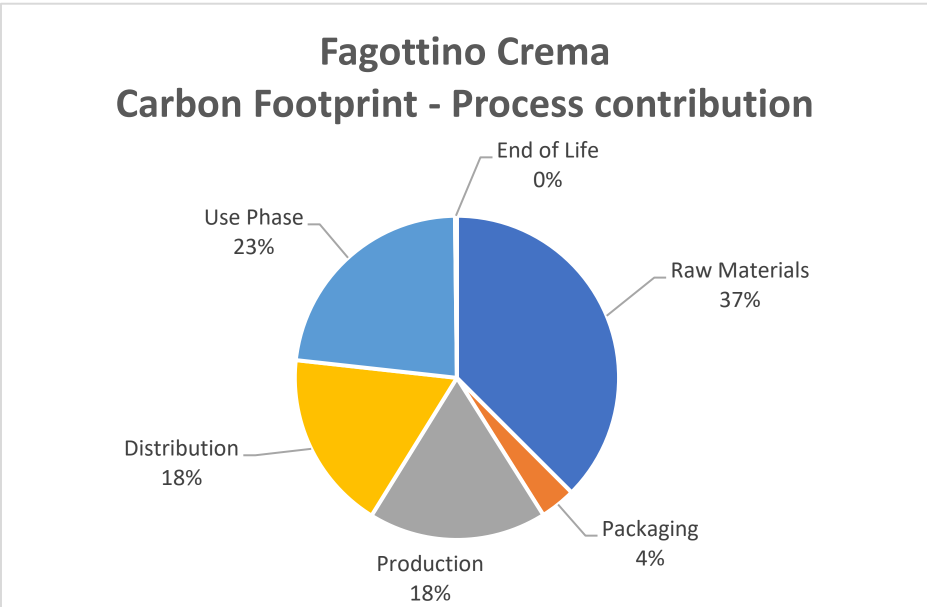


Figure 30: Graphic representation of the carbon footprint indicator contribution for the life cycle processes referred to the product “Fagottino Crema”

Respect on what observed for the reactive nitrogen indicator, it is evident that Carbon Footprint indictor results are more influenced by other processes that constitute the product's life cycle, such as production and distribution. Nonetheless, even for the Carbon Footprint, the effects are primarily concentrated in the raw materials phase.

Noteworthy is the difference in terms of influence between the use phase of Barattolino Crema and Fagottino Crema with respect to the overall results. In both the Nitrogen and Carbon Footprint indicators, the use phase for Fagottino Crema represents a significant phase primarily due to the higher energy consumption required to cook the pastry product compared to Barattolino Crema.

The results presented on Carbon Footprint and Nitrogen Footprint are consistent with the literature (Singh & Bakshi, 2015), which considers the agricultural sector as the primary contributor to both footprints. Additionally, within Leach et al. (2013), it is also confirmed that energy contribution has a greater influence on the Carbon Footprint compared to the Nitrogen Footprint.

In conclusion, the set objectives have been achieved, as the methodology was successfully applied to the four products under study, allowing for the description and quantification of their environmental impacts in relation to the nitrogen cycle. The information gathered in this work will be used by the company to further improve its products. As indicated by the results, the raw materials used exert a significant influence at the impact level. Therefore, new products can be developed with a focus on reducing nitrogen-related impacts, considering the increasing influence of anthropogenic activities on the nitrogen cycle and the proposed method can be used to verify these improvements.

Conclusions

Throughout this work, an assessment at inventory and impact level of the emissions related to nitrogen-containing substances of four Sammontana's product during their life cycle is observed. This need comes from the increasing attention that companies like Sammontana are paying to the environmental consequences of their operations and follows years of actions in this regards.

Firstly a brief presentation of nitrogen cycle disruption related problems was faced observing which are currently the most important consequences of this alteration, especially due to anthropogenic influence. This short introduction wants to show the importance of the nitrogen cycle from an environmental perspective and to highlight the problems in different environmental compartments related to its disruption, which then can be associated with different environmental impacts.

In order to quantify anthropogenic influence in the nitrogen cycle, in this work a new method is used and explained. This method was developed within a research group at University of Padua. Their goal was to test an innovative methodology for assessing the environmental impacts related to alteration of the nitrogen cycle. The proposed method was designed using a comprehensive Life Cycle Assessment (LCA) approach, in order to allow the application to any product system. The aim of this approach is to support the use of databases and software for LCA applications, and to formulate an assessment method oriented to provide results and information on the actual nature of the impacts generated by a product system in its life cycle.

The method proposed is composed of a multistep framework: goal and scope definition, inventory analysis, assessment at inventory level, impact assessment limited to characterization, impact assessment extended to normalization and weighting and finally interpretation of the results. All the steps listed are similar to the ones of a standard LCA study but in the method proposed they are focused only on nitrogen-containing substances.

Defined the method, a case study was used to test the approach presented. In particular four different Sammontana's products were tested in their life cycle: Barattolino Crema, Biscotto Amando, Croissant Vegano and Fagottino Crema. The first two belong to the ice cream sector and are produced in Empoli (FI) plant, on the other hand the last two come from the pastry sector and are produced in Vinci (FI) plant.

The method made it possible to verify the phases of life cycle that causes the greatest impact and to assess which reactive nitrogen compounds are most emitted. It also highlights in which phase nitrogen substances comes from.

The application of the method results in series of different steps, each one related to a defined output: nitrogen inventory, reactive nitrogen indicator, impact assessment profile and single score impact indicator. To obtain the nitrogen inventory a first screening of the overall inventory was done considering only nitrogen containing substances. From the chosen databases a set of approximately 300 nitrogen-containing substances were evaluated.

Then, developing the reactive nitrogen indicator, an indicative evaluation of nitrogen containing substances emissions were done. It was analysed not only the entirely product system contribution for each product, but also significance of the different phases that characterize each product system (Raw Materials, Packaging, Production, Distribution, Phase of Use and End of Life). From this evaluation, results show how Raw material phase, or in other words the emission of nitrogen containing substances caused by raw materials production and distribution to the plant, contribute most to reactive nitrogen release into the environment.

To develop the impact assessment profile, several impact categories that reflect the changes to the nitrogen cycle caused by the product systems were chosen. Then, the influence of each product system on these impact categories was quantified, and single score nitrogen indicators were calculated to represent the overall impact. The analysis showed that, for products in the ice cream sector, the Barattolino Crema has a greater impact than the Biscotto Amando. However, for products in the pastry sector (Fagottino Crema and Croissant Vegano), the individual scores were found to be roughly equivalent.

Furthermore, within this work a comparison between the results obtained from the Nitrogen Footprint assessment for Barattolino Crema and Fagottino Crema with the evaluation already carried out by Sammontana analysing the results of the Carbon Footprint indicator were done. In fact, it is possible to use the results of the reactive nitrogen indicator as representative of the Nitrogen Footprint for the products under consideration since they present the same results. It's worth noting that, according to the comparison cited above, the Carbon Footprint shows that the raw material stage has the greatest impact, as observed in the Nitrogen Footprint indicator results. However, unlike the Nitrogen Footprint, the Carbon Footprint indicator assigns also a greater importance to all other phases, including packaging and distribution, which significantly influence the final result.

To review, this method evaluates environmental issues related to the nitrogen cycle, providing valuable information about an increasingly concerning topic. However, it should be noted that the proposed method only assesses a specific environmental issue, thus providing a partial assessment of the analysed product system. Therefore, use of other evaluation tools focused on different environmental issues are recommended.

From a company perspective, Sammontana's products are closely linked to agricultural and livestock processes, which have been found to have the highest emissions of nitrogen-containing substances and impacts related to the disruption of the nitrogen cycle, compared to all other phases of the product systems, as described in the study and shown through the presented results. The results presented will guide Sammontana's decision-making and improve their understanding of their products' impact.

Considering these results and the environmental concerns expressed in Chapter 1, the relevance of these issues will continue to increase as the population grows. Therefore, a tool that can assess where to focus efforts to reduce this type of impacts will be increasingly necessary.

Before concluding, it could be interesting to consider, as a possible future insight, the influence of the wastewater treatment associated with the disposal of organic matter at the end of the products' life cycle. Currently, this aspect has not been analysed due to the lack of available information.

Looking ahead to future developments, it would be desirable to expand the use of this methodology to various fields, enabling the testing of a large number of cases and identifying areas for improvement and increased efficiency. To achieve greater accuracy and efficiency in the calculation process, a more automated procedure is recommended, particularly in evaluating the final step of the proposed method.

As a long-term goal, it may be possible to introduce this research topic to national and international standardization working groups. In doing so, a partnership could be established to further develop the proposed methodology within Life Cycle Assessment software applications. Such an initiative would be a significant step forward in promoting practices that contribute to the creation of a more sustainable future.

Appendix A

Some assumption were required to evaluate some nitrogen coefficients:

- Some are related to nomenclature inconsistencies. The different names used were all taken into account, in some cases formulating hypotheses regarding the composition of the substance, specifically:
    - "nitrogen total", voice of the World database, was considered as "nitrogen" emission to water or soil with a nitrogen coefficient equal to 1;
    - "nitrogen oxides" emissions were considered as "nitrogen dioxide", estimated as the substance most likely present among the various forms of nitrogen oxides;
    - for the determination of nitrogen content in the "nitrogen organic bound" emissions the standard nitrogen-to-protein conversion factor of 0.16 was used;
    - "ammonia as N" emissions to water were considered equivalent to ammonia emissions to water with a nitrogen coefficient equal to 0.882.
    - "Nitrogenous Matter (unspecified, as N)" emissions to water were considered equivalent to nitrogen emissions to water with a nitrogen coefficient equal to 1.

- Regarding the different nitrogen compartment some clarification needs to be done:
    - the flow "Nitrogen" in the compartment "air" was considered as a result of denitrification processes or, in any case, an emission molecular nitrogen (N_2): a coefficient of 0 was assigned
    - the flow "Nitrogen" in the compartment "water" was considered as an emission of various forms of nitrogen to water accounted as nitrogen: to this flow was assigned a nitrogen coefficient equal to 1;
    - the flow "Nitrogen" in the compartment "soil" was considered as an emission of various forms of nitrogen to soil accounted as nitrogen: to this flow was assigned a nitrogen coefficient equal to 1.

- Different types of emissions particulate matter are included (Particulates, < 2.5 µm; Particulates, > 10 µm; Particulates, > 2.5 µm, and < 10 µm; Particulates, < 10 µm, Particulates, unspecified) which may contain nitrogen compounds, in particular classified as ammonium ion (NH_4^+) and nitrate ion (NO_3^-). To estimate the nitrogen content of particulate, reference was made to the results reported by Sillanpää et al. (2006) related to the chemical composition of particulate matter at six urban sites in

Europe. Specifically the average of the reported values was calculated, obtaining the following results:

- 8,52 % for the average content of NO_3^- in $PM_{2.5}$ (Particulates, < 2.5 µm);
- 8,78 % for the average content of NO_3^- in $PM_{2.5-10}$ (Particulates, > 2.5 µm, and < 10 µm);
- 7,9 % for the average content of NH_4^+ in $PM_{2.5}$ (Particulates, < 2.5 µm);
- 1,04 % for the average content of NH_4^+ in $PM_{2.5-10}$ (Particulates, > 2.5 µm, and < 10 µm);
- for Particulates, unspecified an average of the above obtained nitrogen content is done;

For the output named as "Particulates, < 10 µm", the nitrogen content was estimated as the average of the outputs "Particulates, < 2.5 µm" and "Particulates, > 2.5 µm, and < 10 µm". No estimates were made regarding the output "Particulates, > 10 µm" as no reliable studies were found in the literature: however, it is supposed a non-relevant nitrogen content that does not affect the validity of the results.

Appendix B

B.1 Residual Mix

The electricity residual mix of a country represents the share of electricity supply for which the energy source is not proven through cancellation of Guarantees of Origin. Guarantees of origin are the only precise defined instrument evidencing the origin of electricity generated from renewable resources.
To define the electricity emission factor, reference was made to the Residual Mix for the Italian market proposed by AIB – Association of issuing bodies in the report (Treyer & Bauer, 2016), whose values are summarized in Table 17

Table 17: Peracentages represents how is redistributed in terms of sources the electrical energy from the grid

Fonte	**Residual Mix 2021**
Renewables Unspecified	0,00%
Solar	5,24%
Wind	0,76%
Hydro&Marine	2,48%
Geothermal	0,00%
Biomass	2,33%
Nuclear	6,42%
Fossil Unspecified	1,80%
Lignite	0,19%
Hard Coal	12,75%
Gas	63,60%
Oil	4,43%
TOTALE	100,00%

Subsequently, the energy mix was modelled using Ecoinvent 3.6 datasets, as shown in Table 18. In modelling, the components "Renewables Unspecified" and "Non Renewable Unspecified" have been distributed proportionally among the other items present.
In particular, the characterization of the contribution of electricity from nuclear power was carried out considering the main countries from which Italy imports the energy carrier (the latest data available on the Eurostat portal, referring to 2018, were considered: Switzerland 50.47%, France 34.45% and Slovenia 15.09%).
The distribution of solar in the different voltages was made on the basis of data referring to 2020 provided by the GSE (Agrillo et al., 2020): high voltage 7.30%, medium voltage 55.60% and low voltage 37.10%.

Table 18: values assigned to different production processes of high tension electrical energy

<table>
<tr><th>Source</th><th>Dataset Ecoinvent</th><th>Quantity (kWh)</th></tr>
<tr><td>Solar</td><td>Electricity, low voltage {IT}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, U</td><td>0,0041</td></tr>
<tr><td>Wind</td><td>Electricity, high voltage {IT}| electricity production, wind, <1MW turbine, onshore | Cut-off, U</td><td>0,0022</td></tr>
<tr><td>Wind</td><td>Electricity, high voltage {IT}| electricity production, wind, >3MW turbine, onshore | Cut-off, U</td><td>0,0007</td></tr>
<tr><td>Wind</td><td>Electricity, high voltage {IT}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U</td><td>0,0051</td></tr>
<tr><td>Hydro</td><td>Electricity, high voltage {IT}| electricity production, hydro, pumped storage | Cut-off, U</td><td>0,0011</td></tr>
<tr><td>Hydro</td><td>Electricity, high voltage {IT}| electricity production, hydro, reservoir, alpine region | Cut-off, U</td><td>0,0160</td></tr>
<tr><td>Hydro</td><td>Electricity, high voltage {IT}| electricity production, hydro, run-of-river | Cut-off, U</td><td>0,0090</td></tr>
<tr><td>Geo</td><td>Electricity, high voltage {IT}| electricity production, deep geothermal | Cut-off, U</td><td>0,0000</td></tr>
<tr><td>Bio</td><td>Electricity, high voltage {IT}| heat and power co-generation, biogas, gas engine | Cut-off, U</td><td>0,0184</td></tr>
<tr><td>Bio</td><td>Electricity, high voltage {IT}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U</td><td>0,0060</td></tr>
<tr><td>Nuclear</td><td>Electricity, high voltage {CH}|electricity production, nuclear, pressure water reactor | Cut-off, U</td><td>0,0194</td></tr>
<tr><td>Nuclear</td><td>Electricity, high voltage {CH}|electricity production, nuclear, boiler water reactor | Cut-off, U</td><td>0,0155</td></tr>
<tr><td>Nuclear</td><td>Electricity, high voltage {FR}|electricity production, nuclear, pressure water reactor | Cut-off, U</td><td>0,0254</td></tr>
<tr><td>Nuclear</td><td>Electricity, high voltage {SI}|electricity production, nuclear, pressure water reactor | Cut-off, U</td><td>0,0072</td></tr>
<tr><td>Lignite</td><td>Electricity, high voltage {IT}| electricity production, lignite | Cut-off, U</td><td>0,0020</td></tr>
<tr><td>Coal</td><td>Electricity, high voltage {IT}| electricity production, hard coal | Cut-off, U</td><td>0,1364</td></tr>
<tr><td>Coal</td><td>Electricity, high voltage {IT}| heat and power co-generation, hard coal | Cut-off, U</td><td>0,0005</td></tr>
<tr><td>Coal</td><td>Electricity, high voltage {IT}| treatment of coal gas, in power plant | Cut-off, U</td><td>0,0000</td></tr>
<tr><td>Gas</td><td>Electricity, high voltage {IT}| electricity production, natural gas, combined cycle power plant | Cut-off, U</td><td>0,2152</td></tr>
<tr><td>Gas</td><td>Electricity, high voltage {IT}| electricity production, natural gas, conventional power plant | Cut-off, U</td><td>0,0574</td></tr>
<tr><td>Gas</td><td>Electricity, high voltage {IT}| heat and power co-generation, natural gas, combined cycle power plant, 400MW electrical | Cut-off, U</td><td>0,2542</td></tr>
<tr><td>Gas</td><td>Electricity, high voltage {IT}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U</td><td>0,1565</td></tr>
<tr><td>Oil</td><td>Electricity, high voltage {IT}| heat and power co-generation, oil | Cut-off, U</td><td>0,0391</td></tr>
<tr><td>Oil</td><td>Electricity, high voltage {IT}| electricity production, oil | Cut-off, U</td><td>0,0085</td></tr>
<tr><td>Losses</td><td>Electricity, high voltage {IT}| market for | Cut-off, U</td><td>0,0250</td></tr>
</table>

B.2 Characterization Factors

Table 19 shows characterization factors' value used within work referred to products systems analysed. Specifically, the factors are derived from the above presented "ILCD 2011 Midpoint +" characterization methodology (Joint Research Centre, 2011) with the exception of the characterization factors for the category "Climate Change" which are updated to the result presented in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker et al., 2014), according to the method known as "IPCC 2013 GWP 100a". In detail the following cut-off criteria were applied to select records to be reported:

- for the category "Human toxicity cancer effect", the nitrogen-containing substances are reported whose characterization factor value provides a contribution > 1% with respect to the sum of the values of all the characterization factors for the substances assigned to the category applying the characterization method;
- for the category "Human toxicity non-cancer effect", the nitrogen-containing substances are reported whose characterization factor value provides a contribution > 1% with respect to the sum of the values of all the characterization factors for the substances assigned to the category applying the characterization method;
- for the category "Freshwater ecotoxicity" the nitrogen-containing substances are reported whose characterization factor value provides a contribution > 1% with respect to the sum of the values of all the characterization factors for the substances assigned to the category applying the characterization method: for this category, furthermore, are reported the characterization factors of all the substance resulting from inventory analysis carried out as part of the present work.
- for all other impact categories, are reported the characterization factors of all the nitrogen-containing substances assigned to the specific category applying the characterization method.

Table 19: Characterization factors for nitrogen-containing substances assigned to the nitrogen-related impact categories as defined by the "ILCD 2011 Midpoint +" characterization methodology. Cut-off criteria were applied for the impact categories Ecotoxity fresh water, Human toxicity cancer effect and Human toxicity non cancer effect

Impact category	**Substance/ Compound**	**Compartment**	**Unit of measure**	**Characterization factor**
Climate change	Dinitrogen monoxide	Air	kg CO2 eq/kg	265
Climate change	Nitrogen fluoride	Air	kg CO2 eq/kg	16100
Marine eutrophication	Ammonia	Air	kg N eq/kg	0,092
Marine eutrophication	Ammonia	Water	kg N eq/kg	0,824
Marine eutrophication	Ammonia, as N	Water	kg N eq/kg	0,824
Marine eutrophication	Ammonium, ion	Air	kg N eq/kg	0,087
Marine eutrophication	Ammonium, ion	Water	kg N eq/kg	0,778
Marine eutrophication	Nitrate	Air	kg N eq/kg	0,028

Impact category	Substance/ Compound	Compartment	Unit of measure	Characterization factor
Marine eutrophication	Nitrate	Water	kg N eq/kg	0,226
Marine eutrophication	Nitrite	Water	kg N eq/kg	0,304
Marine eutrophication	Nitrogen dioxide	Air	kg N eq/kg	0,389
Marine eutrophication	Nitrogen oxides	Air	kg N eq/kg	0,389
Marine eutrophication	Nitrogen, total	Water	kg N eq/kg	1
Freshwater ecotoxicity	Acetochlor	Soil	CTUe/kg	7610
Freshwater ecotoxicity	Aclonifen	Soil	CTUe/kg	8500
Freshwater ecotoxicity	Alachlor	Soil	CTUe/kg	9280
Freshwater ecotoxicity	Atrazine	Soil	CTUe/kg	11400
Freshwater ecotoxicity	Captan	Soil	CTUe/kg	10000
Freshwater ecotoxicity	Carbendazim	Soil	CTUe/kg	54600
Freshwater ecotoxicity	Carbofuran	Soil	CTUe/kg	21600
Freshwater ecotoxicity	Chloropicrin	Soil	CTUe/kg	4190
Freshwater ecotoxicity	Chlorothalonil	Soil	CTUe/kg	57800
Freshwater ecotoxicity	Chlorpyrifos	Water	CTUe/kg	6210000
Freshwater ecotoxicity	Chlorpyrifos	Soil	CTUe/kg	106000
Freshwater ecotoxicity	Cyfluthrin	Water	CTUe/kg	490000000
Freshwater ecotoxicity	Cypermethrin	Soil	CTUe/kg	70100
Freshwater ecotoxicity	Diflubenzuron	Soil	CTUe/kg	170000
Freshwater ecotoxicity	Dimethenamid	Soil	CTUe/kg	20500
Freshwater ecotoxicity	Fipronil	Soil	CTUe/kg	32300
Freshwater ecotoxicity	Iprodione	Soil	CTUe/kg	16200
Freshwater ecotoxicity	Isoproturon	Soil	CTUe/kg	9460
Freshwater ecotoxicity	Lambda-cyhalothrin	Soil	CTUe/kg	134000
Freshwater ecotoxicity	Linuron	Soil	CTUe/kg	11100
Freshwater ecotoxicity	Metolachlor	Soil	CTUe/kg	5960
Freshwater ecotoxicity	Metolachlor, (S)	Soil	CTUe/kg	10200
Freshwater ecotoxicity	Oryzalin	Soil	CTUe/kg	10500
Freshwater ecotoxicity	Parathion	Soil	CTUe/kg	83100
Freshwater ecotoxicity	Pendimethalin	Soil	CTUe/kg	2930
Freshwater ecotoxicity	Phosmet	Soil	CTUe/kg	477000
Freshwater ecotoxicity	Simazine	Soil	CTUe/kg	12600
Freshwater ecotoxicity	Terbuthylazin	Water	CTUe/kg	474000
Freshwater ecotoxicity	Terbuthylazin	Soil	CTUe/kg	53600
Freshwater ecotoxicity	Ziram	Soil	CTUe/kg	14700
Terrestrial eutrophication	Ammonia	Air	molc N eq/kg	13,5
Terrestrial eutrophication	Ammonium, ion	Air	molc N eq/kg	12,7
Terrestrial eutrophication	Nitrate	Air	molc N eq/kg	3,16
Terrestrial eutrophication	Nitrogen dioxide	Air	molc N eq/kg	4,26
Terrestrial eutrophication	Nitrogen oxides	Air	molc N eq/kg	4,26
Acidification	Ammonia	Air	molc H+ eq/kg	3,02
Acidification	Nitrogen dioxide	Air	molc H+ eq/kg	0,74
Acidification	Nitrogen oxides	Air	molc H+ eq/kg	0,74
Photochemical ozone formation	Nitrogen dioxide	Air	kg NMVOC eq/kg	1

Impact category	**Substance/ Compound**	**Compartment**	**Unit of measure**	**Characterization factor**
Photochemical ozone formation	Nitrogen oxides	Air	kg NMVOC eq/kg	1
Particulate matter	Ammonia	Air	kg PM2.5 eq/kg	0,0667
Particulate matter	Nitrogen dioxide	Air	kg PM2.5 eq/kg	0,00722
Particulate matter	Nitrogen oxides	Air	kg PM2.5 eq/kg	0,00722
Particulate matter	Particulates, < 10 um	Air	kg PM2.5 eq/kg	0,228
Particulate matter	Particulates, < 2.5 um	Air	kg PM2.5 eq/kg	1
Particulate matter	Particulates, > 2.5 um, and < 10um	Air	kg PM2.5 eq/kg	0
Particulate matter	Particulates, unspecified	Air	kg PM2.5 eq/kg	0
Human toxicity, cancer effects	Acephate	Soil	CTUh/kg	0,0000001
Human toxicity, cancer effects	Atrazine	Air	CTUh/kg	0,00000121
Human toxicity, cancer effects	Atrazine	Soil	CTUh/kg	0,000000486
Human toxicity, cancer effects	Atrazine	Water	CTUh/kg	0,00000373
Human toxicity, cancer effects	Captan	Soil	CTUh/kg	2,37E-08
Human toxicity, cancer effects	Carbaryl	Soil	CTUh/kg	0,000000475
Human toxicity, cancer effects	Chlorothalonil	Soil	CTUh/kg	1,16E-08
Human toxicity, cancer effects	Cyanazine	Soil	CTUh/kg	0,00000932
Human toxicity, cancer effects	Methidathion	Soil	CTUh/kg	0,00000701
Human toxicity, cancer effects	Nitrobenzene	Water	CTUh/kg	0,00000114
Human toxicity, cancer effects	Prochloraz	Air	CTUh/kg	0,00000423
Human toxicity, cancer effects	Prochloraz	Water	CTUh/kg	0,000181
Human toxicity, cancer effects	Prochloraz	Soil	CTUh/kg	0,00000882
Human toxicity, cancer effects	Pronamide	Soil	CTUh/kg	0,000000364
Human toxicity, cancer effects	Ziram	Soil	CTUh/kg	0,000000104
Human toxicity, non-cancer effects	Acephate	Soil	CTUh/kg	0,000279
Human toxicity, non-cancer effects	Acephate	Air	CTUh/kg	0,000453
Human toxicity, non-cancer effects	Aldicarb	Soil	CTUh/kg	0,0000259
Human toxicity, non-cancer effects	Atrazine	Soil	CTUh/kg	0,000000564
Human toxicity, non-cancer effects	Captan	Soil	CTUh/kg	0,000000249
Human toxicity, non-cancer effects	Carbaryl	Soil	CTUh/kg	0,000000352
Human toxicity, non-cancer effects	Carbofuran	Soil	CTUh/kg	0,00000719
Human toxicity, non-cancer effects	Chlormequat	Soil	CTUh/kg	6,63E-08
Human toxicity, non-cancer effects	Chlorothalonil	Soil	CTUh/kg	0,000000349
Human toxicity, non-cancer effects	Chlorpyrifos	Water	CTUh/kg	0,000506
Human toxicity, non-cancer effects	Chlorpyrifos	Soil	CTUh/kg	0,00000911
Human toxicity, non-cancer	Chlorpyrifos methyl	Soil	CTUh/kg	0,0000053

Impact category	**Substance/ Compound**	**Compartment**	**Unit of measure**	**Characterization factor**
effects				
Human toxicity, non-cancer effects	Dialifor	Soil	CTUh/kg	0,000333
Human toxicity, non-cancer effects	Diazinon	Soil	CTUh/kg	0,00000537
Human toxicity, non-cancer effects	Fipronil	Soil	CTUh/kg	0,00000526
Human toxicity, non-cancer effects	Glyphosate	Soil	CTUh/kg	5,19E-08
Human toxicity, non-cancer effects	Iprodione	Soil	CTUh/kg	0,00000246
Human toxicity, non-cancer effects	Linuron	Soil	CTUh/kg	0,00000211
Human toxicity, non-cancer effects	Methomyl	Soil	CTUh/kg	0,00000223
Human toxicity, non-cancer effects	Metolachlor	Soil	CTUh/kg	0,000000113
Human toxicity, non-cancer effects	Monocrotophos	Soil	CTUh/kg	0,0000395
Human toxicity, non-cancer effects	Oxyfluorfen	Soil	CTUh/kg	0,00000135
Human toxicity, non-cancer effects	Phosmet	Soil	CTUh/kg	0,00000277
Human toxicity, non-cancer effects	Prochloraz	Soil	CTUh/kg	0,0000165
Human toxicity, non-cancer effects	Simazine	Soil	CTUh/kg	0,00000455
Human toxicity, non-cancer effects	Terbutryn	Soil	CTUh/kg	0,0000102
Human toxicity, non-cancer effects	Triasulfuron	Soil	CTUh/kg	0,0000118
Human toxicity, non-cancer effects	Tribenuron-methyl	Soil	CTUh/kg	0,00000171
Human toxicity, non-cancer effects	Ziram	Soil	CTUh/kg	0,000000749

B.3 Reactive Nitrogen Indicator

Table 20 shows a recall of the category reactive nitrogen calculation for each impact category, which are needed to obtain weighting factors following proposed method.

Table 20: Results of category reactive nitrogen calculation for the four analysed product

Impact category	Substance	Compartment	Barattolino Crema	Biscotto Amando	Croissant Vegano	Fagottino Crema
Climate change	Dinitrogen monoxide	Air	7,51E-04	4,20E-04	6,33E-04	6,70E-04
Climate change	Nitrogen fluoride	Air	3,38E-17	7,36E-17	5,12E-17	5,76E-17
Climate change	**Total**		**7,51E-04**	**4,20E-04**	**6,33E-04**	**6,70E-04**
Marine eutrophication	Nitrate	Water	8,01E-03	7,32E-03	8,98E-03	7,28E-03
Marine eutrophication	Ammonia	Air	4,13E-03	2,22E-03	2,37E-03	2,92E-03
Marine eutrophication	Nitrogen oxides	Air	1,79E-03	1,99E-03	1,84E-03	2,24E-03
Marine eutrophication	Ammonium, ion	Water	1,49E-04	1,83E-04	1,52E-04	1,66E-04
Marine eutrophication	Nitrite	Water	2,92E-06	3,41E-06	2,45E-06	2,77E-06
Marine eutrophication	Nitrogen dioxide	Air	9,54E-07	2,64E-06	2,07E-05	2,53E-05
Marine eutrophication	Ammonia	Water	2,22E-07	1,28E-07	4,31E-07	1,90E-06
Marine eutrophication	Nitrate	Air	2,09E-07	2,78E-07	1,05E-07	1,48E-07
Marine eutrophication	Ammonium, ion	Air	1,46E-12	-4,53E-14	4,63E-14	3,04E-11
Marine eutrophication	Ammonia, as N	Water	1,62E-16	5,28E-15	1,32E-16	3,58E-15
Marine eutrophication	Nitrogen, total	Water	7,72E-12	5,32E-11	3,42E-11	2,06E-10
Marine eutrophication	**Total**		**1,41E-02**	**1,17E-02**	**1,34E-02**	**1,26E-02**
Freshwater ecotoxicity	Atrazine	Soil	1,02E-05	3,67E-06	1,06E-06	3,79E-06
Freshwater ecotoxicity	Terbuthylazin	Soil	2,77E-06	0,00E+00	2,80E-06	9,86E-07
Freshwater ecotoxicity	Chloropicrin	Soil	2,75E-06	0,00E+00	0,00E+00	0,00E+00
Freshwater ecotoxicity	Metolachlor	Soil	1,41E-06	0,00E+00	1,15E-06	0,00E+00
Freshwater ecotoxicity	Acetochlor	Soil	6,20E-07	0,00E+00	0,00E+00	0,00E+00
Freshwater ecotoxicity	Isoproturon	Soil	4,91E-07	0,00E+00	5,99E-07	0,00E+00
Freshwater ecotoxicity	Carbendazim	Soil	4,24E-07	0,00E+00	0,00E+00	0,00E+00
Freshwater ecotoxicity	Fipronil	Soil	3,98E-07	0,00E+00	0,00E+00	0,00E+00
Freshwater ecotoxicity	Diflubenzuron	Soil	2,13E-07	9,37E-08	1,96E-08	0,00E+00
Freshwater ecotoxicity	Dimethenamid	Soil	2,06E-07	0,00E+00	0,00E+00	0,00E+00
Freshwater ecotoxicity	Alachlor	Soil	2,01E-07	0,00E+00	1,51E-06	0,00E+00
Freshwater ecotoxicity	Metolachlor, (S)	Soil	1,57E-07	0,00E+00	0,00E+00	0,00E+00
Freshwater ecotoxicity	Chlorothalonil	Soil	9,94E-08	2,84E-06	7,50E-08	0,00E+00
Freshwater ecotoxicity	Chlorpyrifos	Soil	5,27E-08	0,00E+00	5,30E-08	9,08E-08
Freshwater ecotoxicity	Lambda-cyhalothrin	Soil	9,15E-09	0,00E+00	0,00E+00	0,00E+00
Freshwater ecotoxicity	Phosmet	Soil	2,59E-09	2,57E-07	0,00E+00	0,00E+00
Freshwater ecotoxicity	Aclonifen	Soil	0,00E+00	0,00E+00	2,87E-06	0,00E+00
Freshwater ecotoxicity	Captan	Soil	0,00E+00	8,09E-07	1,08E-06	0,00E+00
Freshwater ecotoxicity	Carbofuran	Soil	0,00E+00	0,00E+00	4,94E-07	7,30E-07
Freshwater ecotoxicity	Chlorpyrifos	Water	0,00E+00	0,00E+00	2,22E-10	0,00E+00
Freshwater ecotoxicity	Cyfluthrin	Water	0,00E+00	0,00E+00	3,35E-12	0,00E+00

Impact category	Substance	Compartment	Barattolino Crema	Biscotto Amando	Croissant Vegano	Fagottino Crema
Freshwater ecotoxicity	Cypermethrin	Soil	0,00E+00	1,79E-06	7,00E-08	2,04E-07
Freshwater ecotoxicity	Iprodione	Soil	0,00E+00	0,00E+00	1,33E-06	0,00E+00
Freshwater ecotoxicity	Linuron	Soil	0,00E+00	0,00E+00	2,12E-06	0,00E+00
Freshwater ecotoxicity	Oryzalin	Soil	0,00E+00	2,47E-06	0,00E+00	0,00E+00
Freshwater ecotoxicity	Parathion	Soil	0,00E+00	0,00E+00	2,22E-08	0,00E+00
Freshwater ecotoxicity	Pendimethalin	Soil	0,00E+00	0,00E+00	2,01E-06	0,00E+00
Freshwater ecotoxicity	Simazine	Soil	0,00E+00	4,15E-06	0,00E+00	0,00E+00
Freshwater ecotoxicity	Terbuthylazin	Water	0,00E+00	0,00E+00	2,87E-08	0,00E+00
Freshwater ecotoxicity	Ziram	Soil	0,00E+00	1,69E-06	0,00E+00	0,00E+00
Freshwater ecotoxicity	**Total**		**2,00E-05**	**1,78E-05**	**1,73E-05**	**5,80E-06**
Terrestrial eutrophication	Ammonia	Air	4,13E-03	2,22E-03	2,37E-03	2,92E-03
Terrestrial eutrophication	Nitrogen oxides	Air	1,79E-03	1,99E-03	1,84E-03	2,24E-03
Terrestrial eutrophication	Nitrogen dioxide	Air	9,54E-07	2,64E-06	2,07E-05	2,53E-05
Terrestrial eutrophication	Nitrate	Air	2,09E-07	2,78E-07	1,05E-07	1,48E-07
Terrestrial eutrophication	Ammonium, ion	Air	1,46E-12	-4,53E-14	4,63E-14	3,04E-11
Terrestrial eutrophication	**Total**		**5,93E-03**	**4,22E-03**	**4,23E-03**	**5,19E-03**
Acidification	Ammonia	Air	4,13E-03	2,22E-03	2,37E-03	2,92E-03
Acidification	Nitrogen oxides	Air	1,79E-03	1,99E-03	1,84E-03	2,24E-03
Acidification	Nitrogen dioxide	Air	9,54E-07	2,64E-06	2,07E-05	2,53E-05
Acidification	**Total**		**5,93E-03**	**4,22E-03**	**4,23E-03**	**5,19E-03**
Photochemical ozone formation	Nitrogen oxides	Air	1,79E-03	1,99E-03	1,84E-03	2,24E-03
Photochemical ozone formation	Nitrogen dioxide	Air	9,54E-07	2,64E-06	2,07E-05	2,53E-05
Photochemical ozone formation	**Total**		**1,79E-03**	**2,00E-03**	**1,86E-03**	**2,26E-03**
Particulate matter	Ammonia	Air	4,13E-03	2,22E-03	2,37E-03	2,92E-03
Particulate matter	Nitrogen oxides	Air	1,79E-03	1,99E-03	1,84E-03	2,24E-03
Particulate matter	Particulates, < 2.5 um	Air	9,10E-05	9,71E-05	8,46E-05	1,06E-04
Particulate matter	Particulates, > 2.5 um, and < 10um	Air	1,56E-05	1,93E-05	1,28E-05	1,61E-05
Particulate matter	Particulates, < 10 um	Air	2,05E-06	1,96E-07	1,09E-07	2,54E-06
Particulate matter	Nitrogen dioxide	Air	9,54E-07	2,64E-06	2,07E-05	2,53E-05
Particulate matter	Particulates, unspecified	Air	5,77E-10	1,33E-07	2,07E-09	2,18E-08
Particulate matter	**Total**		**6,04E-03**	**4,33E-03**	**4,33E-03**	**5,31E-03**
Human toxicity, cancer effects	Atrazine	Soil	1,02E-05	3,67E-06	1,06E-06	3,79E-06
Human toxicity, cancer effects	Cyanazine	Soil	3,93E-07	5,15E-07	9,43E-08	1,01E-07
Human toxicity, cancer effects	Pronamide	Soil	1,74E-07	2,28E-07	4,38E-08	4,43E-08
Human toxicity, cancer effects	Atrazine	Water	5,76E-08	0,00E+00	0,00E+00	0,00E+00
Human toxicity, cancer effects	Nitrobenzene	Water	4,97E-08	0,00E+00	1,93E-08	2,87E-08
Human toxicity, cancer effects	Methidathion	Soil	8,20E-09	0,00E+00	0,00E+00	6,75E-09
Human toxicity, cancer effects	Atrazine	Air	0,00E+00	0,00E+00	0,00E+00	4,56E-08
Human toxicity, cancer effects	Captan	Soil	0,00E+00	8,09E-07	1,08E-06	0,00E+00
Human toxicity, cancer effects	Carbaryl	Soil	0,00E+00	6,77E-07	0,00E+00	0,00E+00

Impact category	Substance	Compartment	Barattolino Crema	Biscotto Amando	Croissant Vegano	Fagottino Crema
Human toxicity, cancer effects	Chlorothalonil	Soil	0,00E+00	2,84E-06	0,00E+00	0,00E+00
Human toxicity, cancer effects	Prochloraz	Water	0,00E+00	0,00E+00	2,27E-10	4,86E-10
Human toxicity, cancer effects	Prochloraz	Soil	0,00E+00	0,00E+00	5,48E-08	7,32E-08
Human toxicity, cancer effects	Ziram	Soil	0,00E+00	1,69E-06	0,00E+00	0,00E+00
Human toxicity, cancer effects	**Total**		**1,09E-05**	**1,04E-05**	**2,35E-06**	**4,09E-06**
Human toxicity, non-cancer effects	Acephate	Soil	1,58E-07	5,82E-08	1,22E-08	4,44E-08
Human toxicity, non-cancer effects	Aldicarb	Soil	0,00E+00	2,67E-08	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	Atrazine	Soil	1,02E-05	3,67E-06	0,00E+00	3,79E-06
Human toxicity, non-cancer effects	Captan	Soil	0,00E+00	0,00E+00	1,08E-06	0,00E+00
Human toxicity, non-cancer effects	Carbofuran	Soil	0,00E+00	4,17E-08	4,94E-07	7,30E-07
Human toxicity, non-cancer effects	Chlorothalonil	Soil	0,00E+00	2,84E-06	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	Chlorpyrifos	Soil	5,27E-08	0,00E+00	5,30E-08	9,08E-08
Human toxicity, non-cancer effects	Chlorpyrifos	Water	0,00E+00	0,00E+00	2,22E-10	6,46E-10
Human toxicity, non-cancer effects	Chlorpyrifos methyl	Soil	8,77E-08	6,37E-08	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	Dialifor	Soil	1,00E-09	1,32E-09	2,57E-10	0,00E+00
Human toxicity, non-cancer effects	Diazinon	Soil	0,00E+00	1,92E-07	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	Fipronil	Soil	3,98E-07	0,00E+00	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	Glyphosate	Soil	0,00E+00	3,70E-05	5,82E-06	8,77E-06
Human toxicity, non-cancer effects	Iprodione	Soil	0,00E+00	0,00E+00	1,33E-06	0,00E+00
Human toxicity, non-cancer effects	Linuron	Soil	0,00E+00	0,00E+00	2,12E-06	3,66E-07
Human toxicity, non-cancer effects	Methomyl	Soil	0,00E+00	6,12E-07	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	Metolachlor	Soil	0,00E+00	0,00E+00	1,15E-06	0,00E+00
Human toxicity, non-cancer effects	Monocrotophos	Soil	1,81E-08	7,94E-09	0,00E+00	6,69E-09
Human toxicity, non-cancer effects	Oxyfluorfen	Soil	0,00E+00	0,00E+00	2,91E-07	0,00E+00
Human toxicity, non-cancer effects	Phosmet	Soil	0,00E+00	2,57E-07	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	Prochloraz	Soil	0,00E+00	0,00E+00	5,48E-08	7,32E-08

Impact category	Substance	Compartment	Barattolino Crema	Biscotto Amando	Croissant Vegano	Fagottino Crema
Human toxicity, non-cancer effects	Simazine	Soil	0,00E+00	4,15E-06	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	Terbutryn	Soil	3,27E-07	4,28E-07	7,84E-08	0,00E+00
Human toxicity, non-cancer effects	Triasulfuron	Soil	1,97E-07	2,57E-07	5,73E-08	5,86E-08
Human toxicity, non-cancer effects	Ziram	Soil	0,00E+00	1,69E-06	0,00E+00	0,00E+00
Human toxicity, non-cancer effects	**Total**		**1,14E-05**	**5,13E-05**	**1,25E-05**	**1,39E-05**

Bibliography

Acree, W. E., & Chickos, J. S. (1998). IST Chemistry WebBook, NIST Standard Reference Database Number 69. *National Institute of Standards and Technology*.

Agrillo, A., Surace, V., & Liberatore, P. (2020). *Rapporto Statistico GSE*. *21*(1), 1–9. http://journal.um-surabaya.ac.id/index.php/JKM/article/view/2203

Battye, W., Aneja, V. P., & Schlesinger, W. H. (2017). Is nitrogen the next carbon? In *Earth's Future* (Vol. 5, Issue 9, pp. 894–904). John Wiley and Sons Inc. https://doi.org/10.1002/2017EF000592

Beccali, M., Cellura, M., Iudicello, M., & Mistretta, M. (2010). Life cycle assessment of Italian citrus-based products. Sensitivity analysis and improvement scenarios. *Journal of Environmental Management*, *91*(7), 1415–1428. https://doi.org/10.1016/j.jenvman.2010.02.028

Bolan, N. S., Hedley, M. J., & White, R. E. (1991). Processes of soil acidification during nitrogen cycling with emphasis on legume based pastures. In *Plant and Soil* (Vol. 134).

Crenna, E., Secchi, M., Benini, L., & Sala, S. (2019). Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA. *International Journal of Life Cycle Assessment*, *24*(10), 1851–1877. https://doi.org/10.1007/s11367-019-01604-y

Dentener, F., Keating, T., Akimoto, H., Convention on Long-range Transboundary Air Pollution. Task Force on Hemispheric Transport of Air Pollution., & United Nations. Economic Commission for Europe. (2010). *Hemispheric transport of air pollution 2010. Part A, Ozone and particulate matter*.

EPA. (2004). *Photochemical smog — what it means for us*.

Erisman, J. W., Sutton, M. A., Galloway, J., Klimont, Z., & Winiwarter, W. (2008). How a century of ammonia synthesis changed the world. *Nature Geoscience*, *1*(10), 636–639. https://doi.org/10.1038/ngeo325

European Commision. (2017). *PEFCR Guidance document, -Guidance for the 13development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3*.

European Commission. Joint Research Centre. Institute for Environment and Sustainability. (2011). *International reference life cycle data system (ILCD) handbook general guide for life cycle assessment: provisions and action steps.* Publications Office.

European Commission. (2021). *Understanding Product Environmental Footprint and Organisation Environmental Footprint methods*.

Fowler, D., Coyle, M., Skiba, U., Sutton, M. A., Cape, J. N., Reis, S., Sheppard, L. J., Jenkins, A., Grizzetti, B., Galloway, J. N., Vitousek, P., Leach, A., Bouwman, A. F., Butterbach-Bahl, K., Dentener, F., Stevenson, D., Amann, M., & Voss, M. (2013). The global nitrogen cycle in the Twentyfirst century. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *368*(1621). https://doi.org/10.1098/rstb.2013.0164

Galloway, J. N., Winiwarter, W., Leip, A., Leach, A. M., Bleeker, A., & Erisman, J. W. (2014). Nitrogen footprints: Past, present and future. *Environmental Research Letters*, *9*(11). https://doi.org/10.1088/1748-9326/9/11/115003

Gazey, C., & Davies, S. (2009). *Soil acidity : a guide for WA farmers and consultants*. https://researchlibrary.agric.wa.gov.au/bulletins

Hristov, A. N., Hanigan, M., Cole, A., Todd, R., McAllister, T. A., Ndegwa, P. M., & Rotz, A. (2011). Review: Ammonia emissions from dairy farms and beef feedlots. In *Canadian Journal of Animal Science* (Vol. 91, Issue 1, pp. 1–35). Agricultural Institute of Canada. https://doi.org/10.4141/CJAS10034

Humbert, S., Loerincik, Y., Rossi, V., Margni, M., & Jolliet, O. (2009). Life cycle assessment of spray dried soluble coffee and comparison with alternatives (drip filter and capsule espresso). *Journal of Cleaner Production*, *17*(15), 1351–1358. https://doi.org/10.1016/j.jclepro.2009.04.011

Leach, A. M., Galloway, J. N., Bleeker, A., Erisman, J. W., Kohn, R., & Kitzes, J. (2012). A nitrogen footprint model to help consumers understand their role in nitrogen losses to the environment. *Environmental Development*, *1*(1), 40–66. https://doi.org/10.1016/j.envdev.2011.12.005

Leach, A. M., Majidi, A. N., Galloway, J. N., & Greene, A. J. (2013). Toward institutional sustainability: A nitrogen footprint model for a University. *Sustainability*, *6*(4), 211–219. https://doi.org/10.1089/SUS.2013.9852

Lewis, Y., & Cohen, B. (2022). Footprint tools. In *Assessing Progress Towards Sustainability* (pp. 119–135). Elsevier. https://doi.org/10.1016/b978-0-323-85851-9.00014-6

McCourt, S., & MacDonald, G. K. (2021). Provincial nitrogen footprints highlight variability in drivers of reactive nitrogen emissions in Canada. *Environmental Research Letters*, *16*(9), 95007. https://doi.org/10.1088/1748-9326/ac1e3b

Nieder, R., & Benbi, D. K. (2022). Reactive nitrogen compounds and their influence on human health: an overview. In *Reviews on Environmental Health* (Vol. 37, Issue 2, pp. 229–246). De Gruyter Open Ltd. https://doi.org/10.1515/reveh-2021-0021

OECD. (2018). *Human acceleration of the nitrogen cycle : managing risks and uncertainty*.

OurWorldInData.org. (2019). *Number of deaths by risk factor, World, 2019*.

Pelletier, N. (2017). Life cycle assessment of Canadian egg products, with differentiation by hen housing system type. *Journal of Cleaner Production*, *152*, 167–180. https://doi.org/10.1016/j.jclepro.2017.03.050

Point, E., Tyedmers, P., & Naugler, C. (2012). Life cycle environmental impacts of wine production and consumption in Nova Scotia, Canada. *Journal of Cleaner Production*, *27*, 11–20. https://doi.org/10.1016/j.jclepro.2011.12.035

PRé Sustainability B. V. (2020). *SimaPro 9.1.1*. 1–16.

Sala, S., & Cerutti, A. K. (2018). *Development of a weighting approach for the Environmental Footprint*. https://doi.org/10.2760/446145

Sammontana S.p.A. (2022a). *Report Gelato 2021*.

Sammontana S.p.A. (2022b). *Report Pasticceria 2021*.

Sillanpää, M., Hillamo, R., Saarikoski, S., Frey, A., Pennanen, A., Makkonen, U., Spolnik, Z., Van Grieken, R., Braniš, M., Brunekreef, B., Chalbot, M. C., Kuhlbusch, T., Sunyer, J., Kerminen, V. M., Kulmala, M., & Salonen, R. O. (2006). Chemical composition and mass closure of particulate matter at six urban sites in Europe. *Atmospheric Environment*, *40*(SUPPL. 2), 212–223. https://doi.org/10.1016/j.atmosenv.2006.01.063

Singh, S., & Bakshi, B. R. (2015). Footprints of carbon and nitrogen: Revisiting the paradigm and exploring their nexus for decision making. *Ecological Indicators*, *53*, 49–60. https://doi.org/10.1016/j.ecolind.2015.01.001

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., De Vries, W., De Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223). https://doi.org/10.1126/science.1259855

Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M. M. B., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M. (2014). *Climate Change 2013: The physical science basis. contribution of working group I to the fifth assessment report of IPCC the intergovernmental panel on climate change*.

Treyer, K., & Bauer, C. (2016). Life cycle inventories of electricity generation and power supply in version 3 of the ecoinvent database—part I: electricity generation. *International Journal of Life Cycle Assessment*, *21*(9), 1236–1254. https://doi.org/10.1007/s11367-013-0665-2

Vanham, D., Leip, A., Galli, A., Kastner, T., Bruckner, M., Uwizeye, A., van Dijk, K., Ercin, E., Dalin, C., Brandão, M., Bastianoni, S., Fang, K., Leach, A., Chapagain, A., Van der Velde, M., Sala, S., Pant, R., Mancini, L., Monforti-Ferrario, F., … Hoekstra, A. Y. (2019). Environmental footprint family to address local to planetary sustainability and deliver on the SDGs. In *Science of the Total Environment* (Vol. 693). Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2019.133642

Xu, W., Zhang, G., Wang, Y., Tong, S., Zhang, W., Ma, Z., Lin, W., Kuang, Y., Yin, L., & Xu, X. (2021). Aerosol Promotes Peroxyacetyl Nitrate Formation during Winter in the North China Plain. *Environmental Science and Technology*, *55*(6), 3568–3581. https://doi.org/10.1021/acs.est.0c08157

Zampori, L., & Pant, R. (2019). *Suggestions for updating the Product Environmental Footprint (PEF) method. KJ-NA-29682-EN-N (online),KJ-NA-29682-EN-C (print)*. https://doi.org/10.2760/424613 (online),10.2760/265244 (print)

Zhang, Q., Li, Y., Wang, M., Wang, K., Meng, F., Liu, L., Zhao, Y., Ma, L., Zhu, Q., Xu, W., & Zhang, F. (2021). Atmospheric nitrogen deposition: A review of quantification methods and its spatial pattern derived from the global monitoring networks. In *Ecotoxicology and Environmental Safety* (Vol. 216). Academic Press. https://doi.org/10.1016/j.ecoenv.2021.112180

Zhang, X., Ward, B. B., & Sigman, D. M. (2020). Global Nitrogen Cycle: Critical Enzymes, Organisms, and Processes for Nitrogen Budgets and Dynamics. In *Chemical Reviews*

(Vol. 120, Issue 12, pp. 5308–5351). American Chemical Society. https://doi.org/10.1021/acs.chemrev.9b00613

Zuliani, F. (2018). Nitrogen footprint: development and testing of new methodologies for the assessment of environmental impact related to the nitrogen cycle. *PhD Thesis in Industrial Engineering, University of Padova*.

ISO - International Organization for Standardization. 2015. ISO 14001:2015. Environmental Management Systems — Requirements with Guidance for Use.

———. 2006a. ISO 14040:2006. Environmental Management – Life Cycle Assessment – Principles and Framework.

———. 2006b. ISO 14044:2006. Environmental Management – Life Cycle Assessment – Requirements and Guidelines.