ENVIRONMENTAL FOOTPRINT AND ECO-DESIGN

Loïc LEZZANI

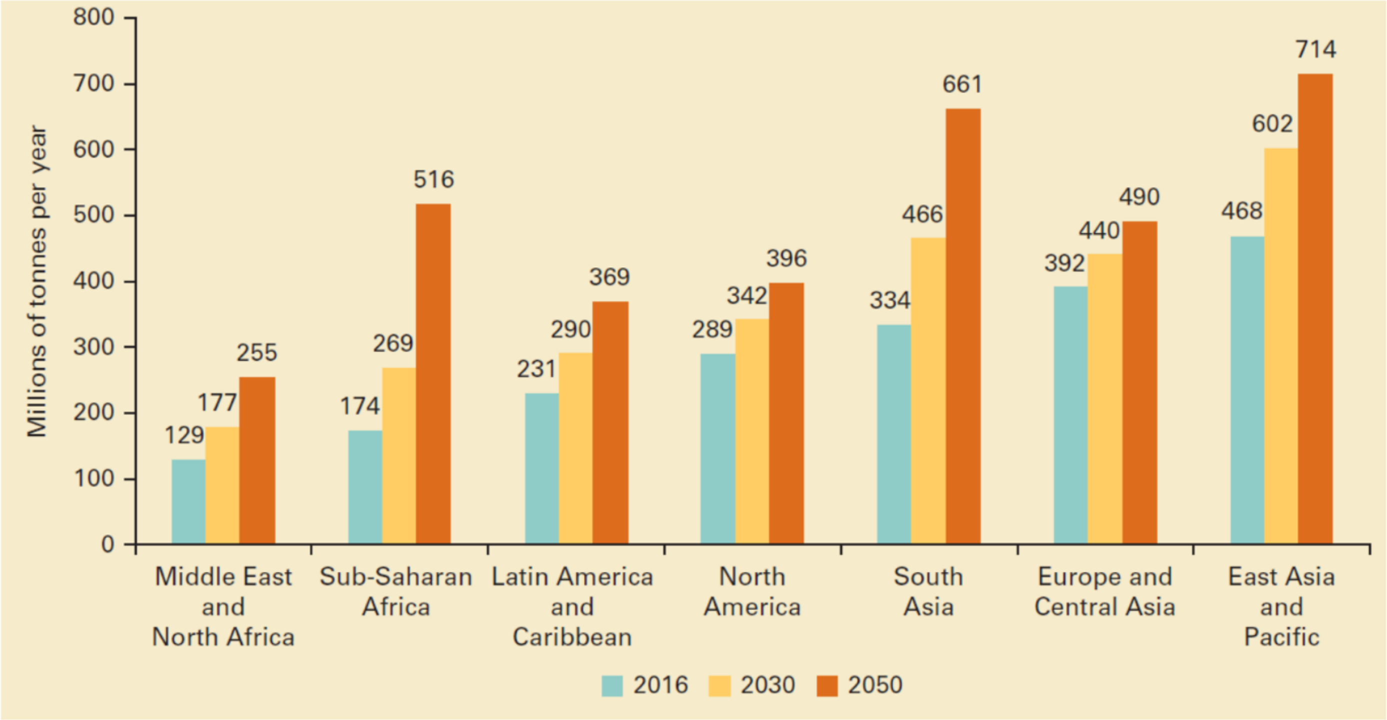
Université Polytechnique des Hauts de France – Valenciennes

Loic.lezzani@uphf.fr

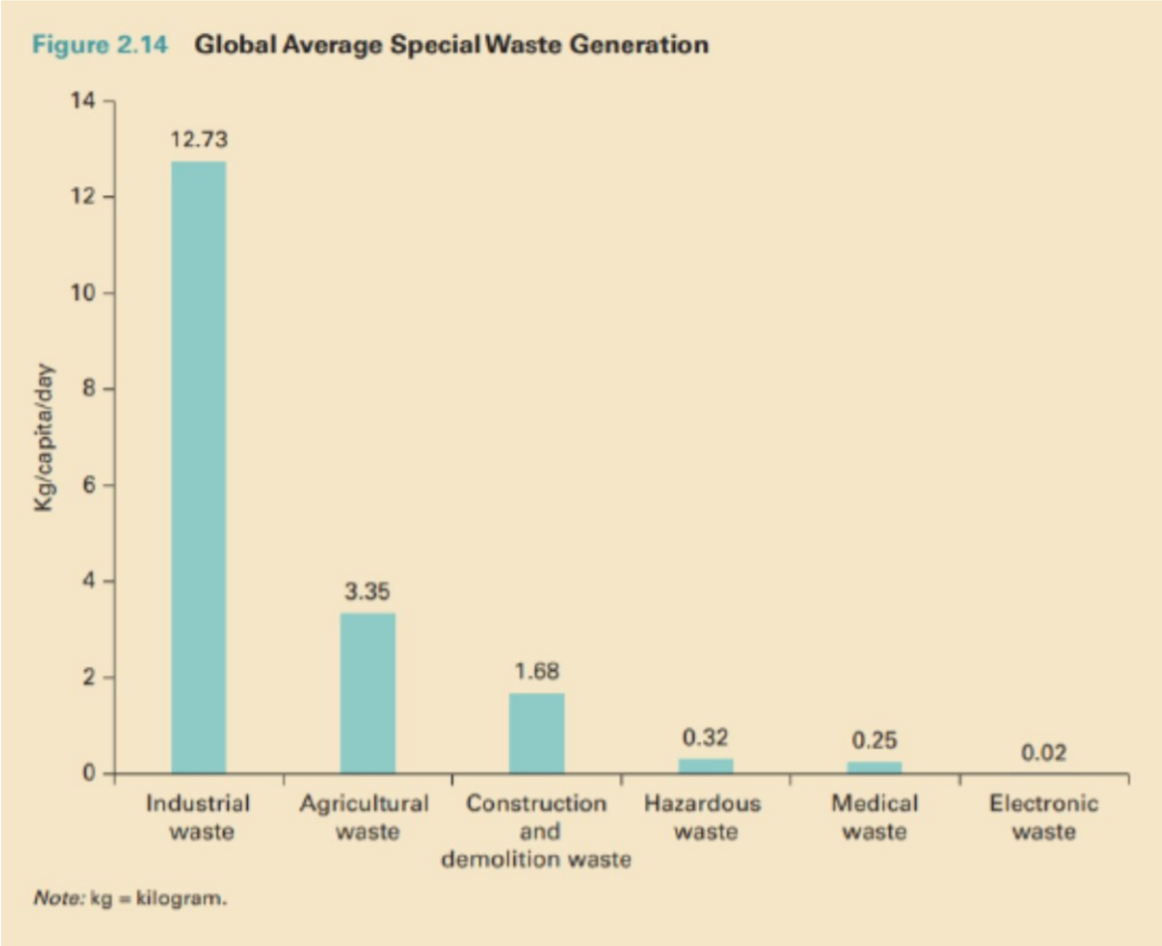
Introduction

- The more we consume, the more waste we generate : due to rapid urbanization, rising living standards, and population growth, the volume of waste is expected to increase by 70%, reaching 3.4 billion tons by 2050, according to the World Bank

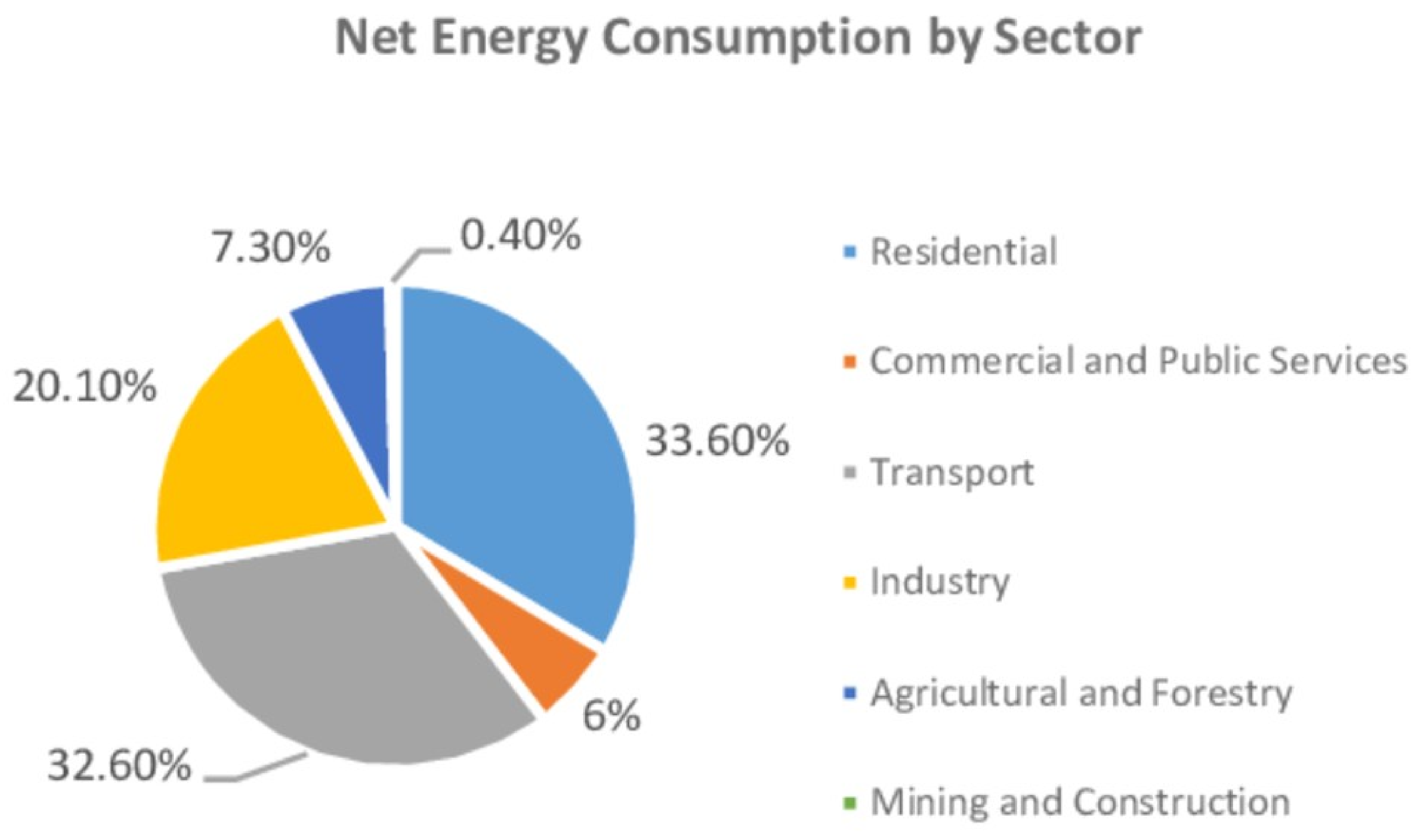
Projected waste generation, by region (millions of tonnes/year)



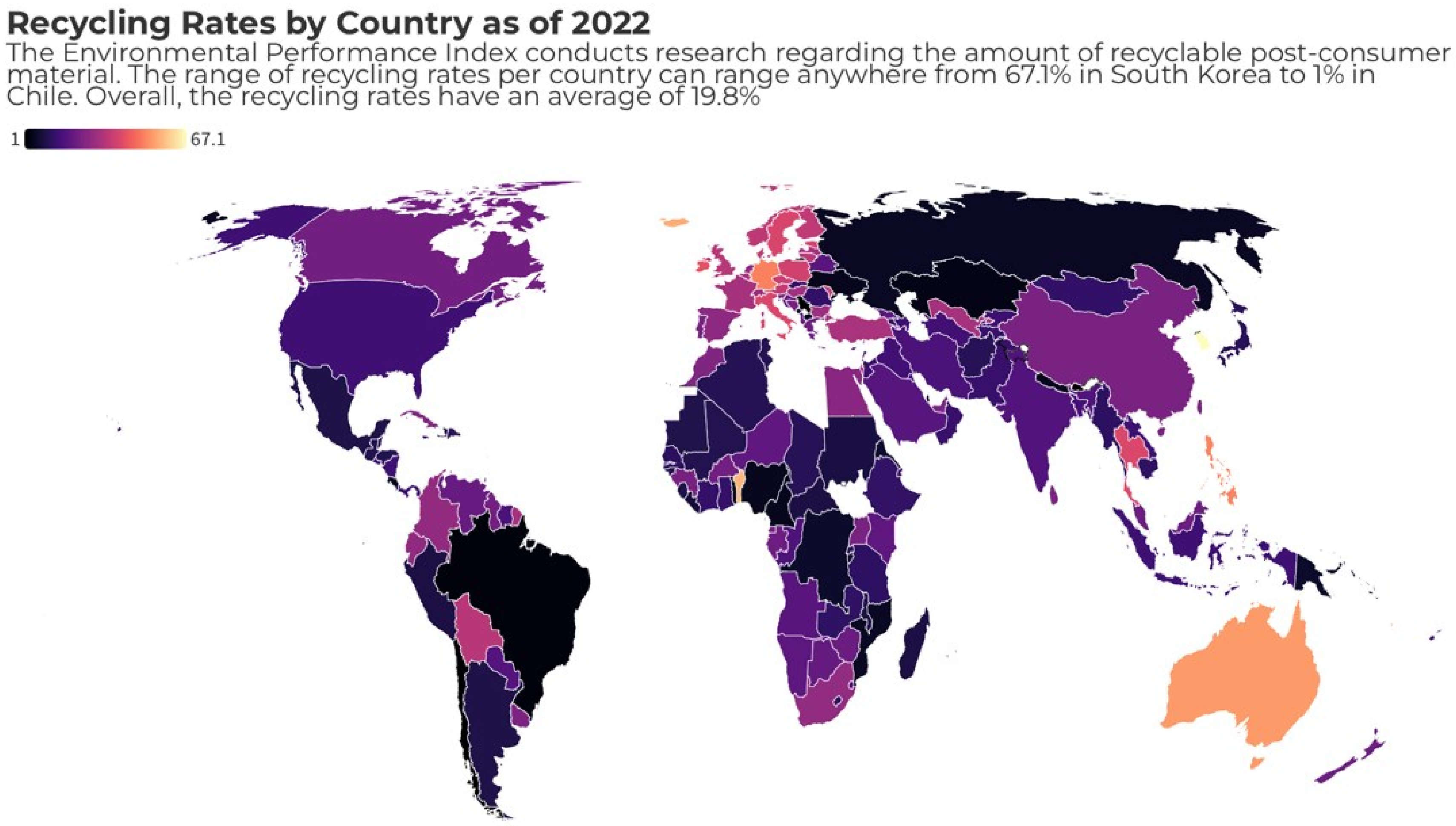
Households are far from being the largest source of waste. The industry generates 18 times more, producing 12.7 kg of waste per day per capita.



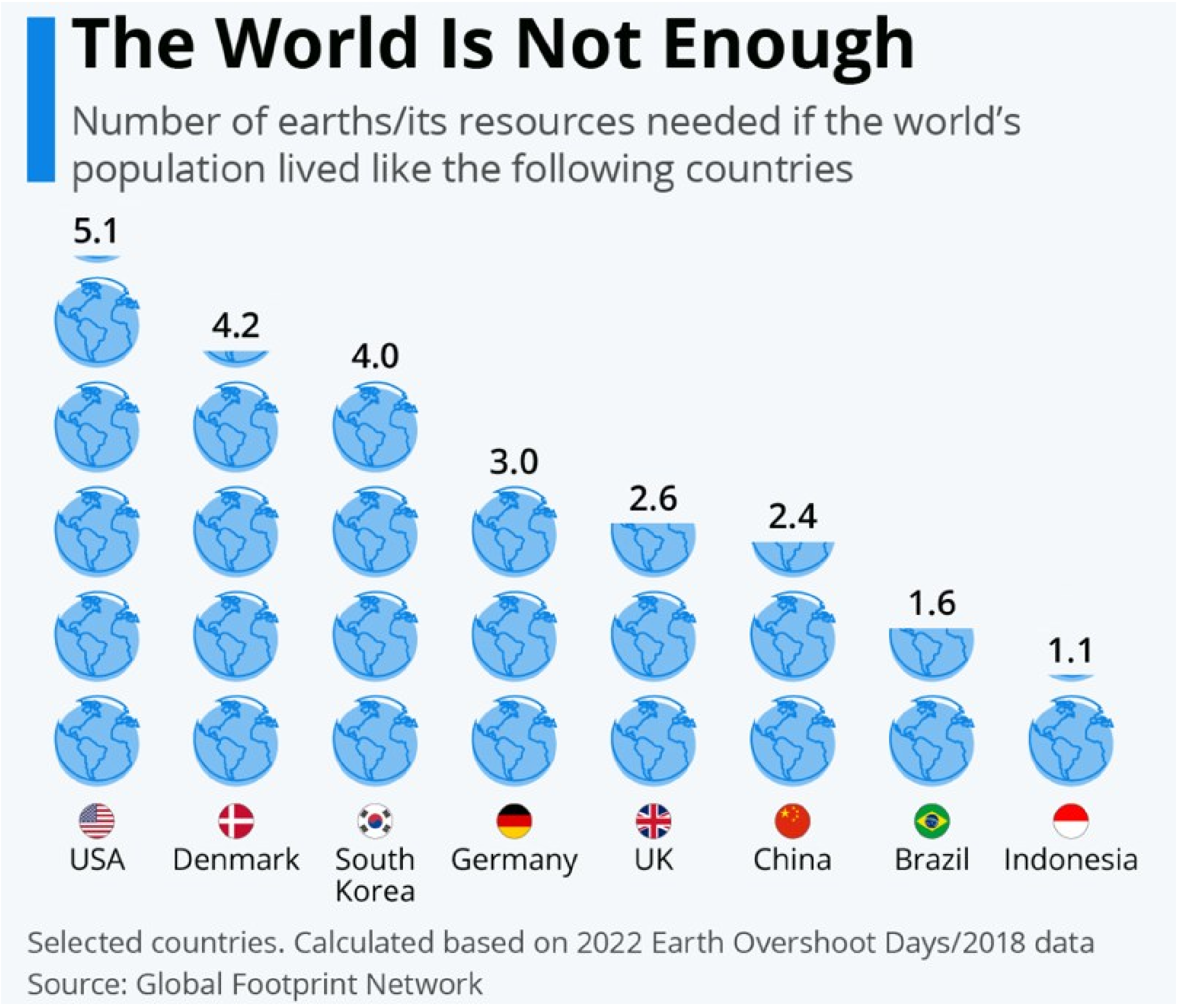
A recent study commissioned by the European Commission, called EIPRO, targets three sectors particularly impacting household consumption :

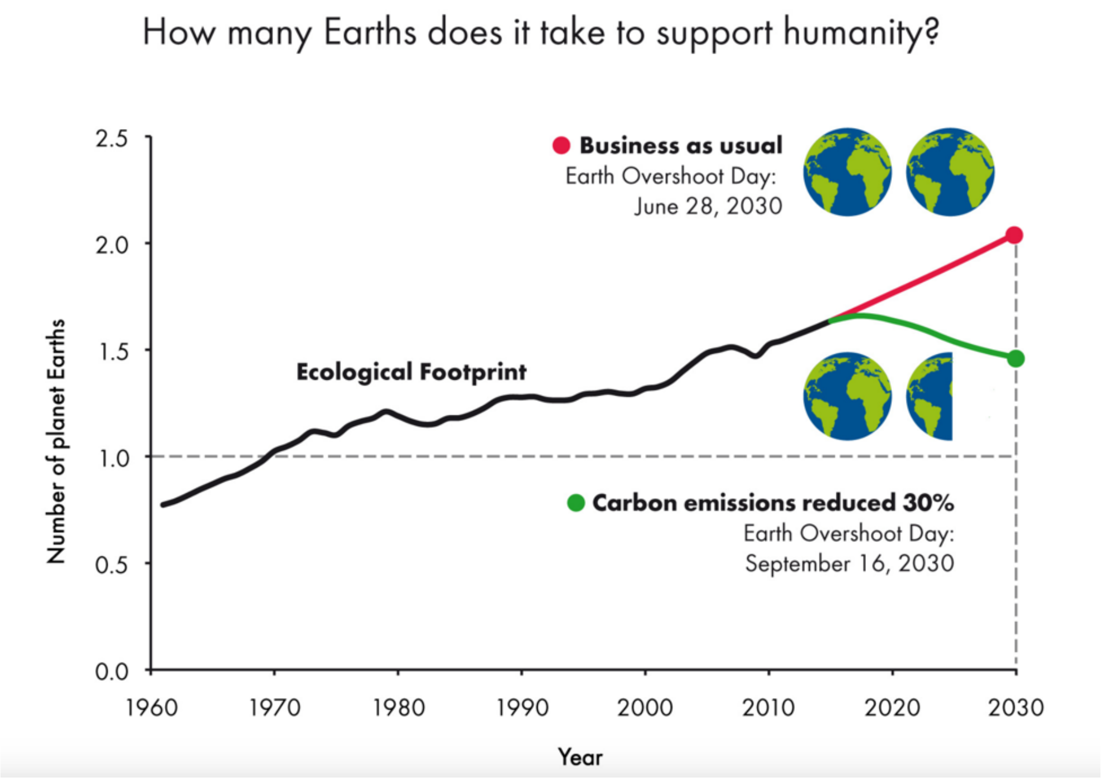


Waste recycling is generally still too low :

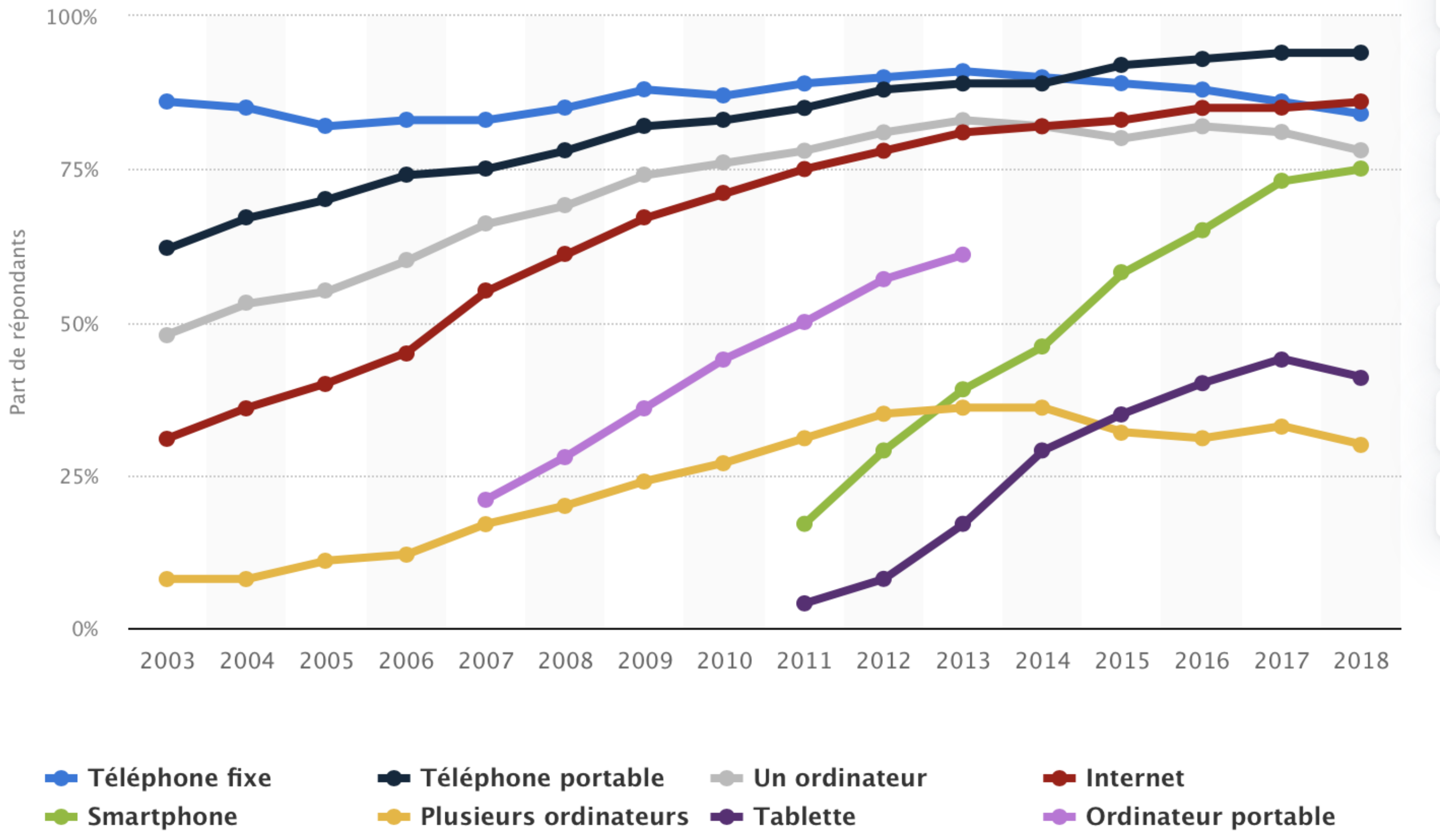


The evolution of our ecological footprint in terms of planetary equivalents! We are already consuming too much, meaning above the productive capacities of our Earth :





Our propensity to consume is the evolution of our spending on ICT. Over 18 years, we have increased our spending on ICT by nearly 40%, resulting in a total volume multiplied by 10

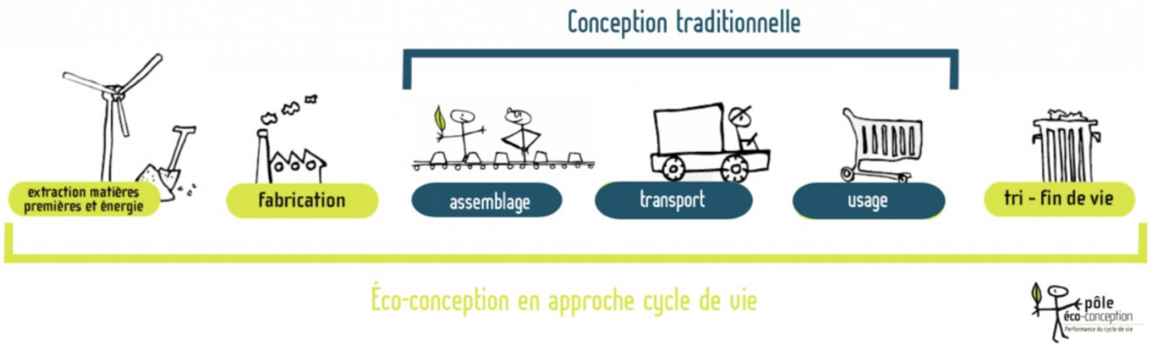


HISTORY OF ECO-DESIGN

- 1968, the awareness of environmental issues : the Club of Rome was created, a consortium of scientists, economists, and industrialists, mainly from the European automotive industry .
- The first environmental assessment was commissioned in 1969 to academics at the Midwest Research Institute by the Coca-Cola Company, with the aim of comparing the life cycles of returnable glass bottles to seven other types of containers, including disposable plastic and metal containers
- In **1972**, this awareness was modeled by MIT researchers commissioned by the Club of Rome to produce a report on the limits to growth (in a finite world).
- It is perhaps **here that the beginnings of the eco-designer profession**, combining design and environmental assessment, are drawn: environmental assessment should push the designer to rethink the production and consumption system and to do everything possible to ensure that the sustainability conditions of the system are applicable and applied.

ECO-DESIGN - Introduction

- There is no product or service with "zero environmental impact.
- To avoid or reduce the environmental impacts, action must be taken at the source, which is during the product's design phase.
- The recent nature of this discipline means its scientific foundations are still developing. In this context, eco-design approaches remain relatively unknown to many companies.
- Another challenge : implementing eco-design within the company's strategy, that is, beyond the descriptive aspect of the results, reaching the managerial framework (in the Anglo-Saxon world, this is referred to as "life cycle management")

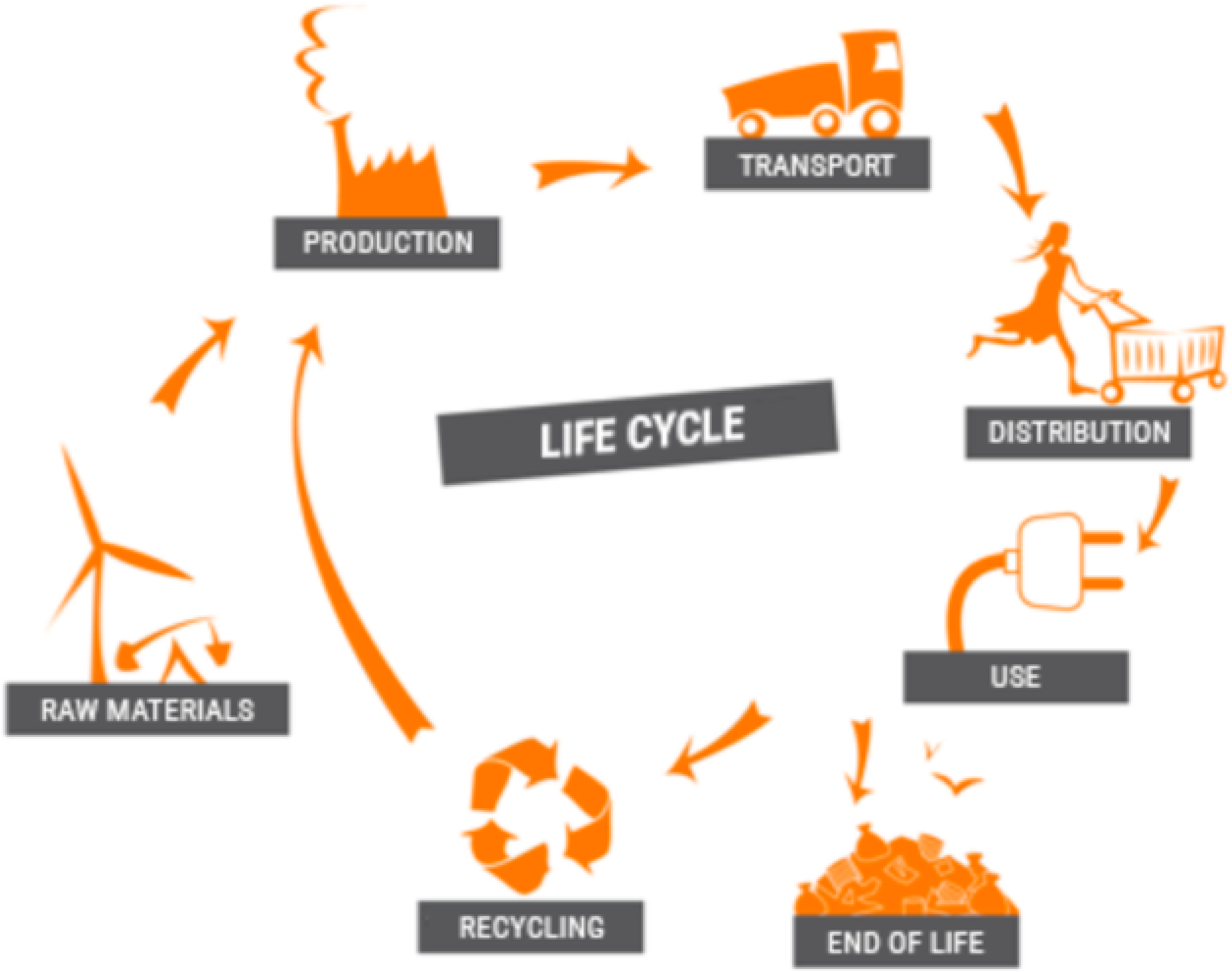


Definition

- Eco-design, by definition, is a **process of continuous and innovative improvement for companies**. It allows for the consideration of reducing environmental impacts at each stage of a product's or service's lifecycle.

Eco-design :

- Is a **preventive approach** that occurs upstream of decisions. It allows for the prevention or reduction of environmental impacts at the source.
- Is a **multi-criteria approach** that considers impacts in numerous areas : raw materials, energy, water, air, soil, biodiversity, climate, human health, etc.
- Is a **circular approach** that takes into account all stages of the life cycle (manufacturing, distribution, use, final recovery).
- To implement eco-design, it is not enough to focus on a single environmental issue or one stage of the life cycle. One must **voluntarily integrate all environmental impacts throughout the entire life cycle of the product.**


PRODUCTION
TRANSPORT
DISTRIBUTION
LIFE CYCLE
USE
RAW MATERIALS
RECYCLING
END OF LIFE

The eco-designer of a product or service ensures to :

- Choose renewable, recycled, and/or recyclable materials.
- Select materials that do not come from threatened ecosystems.
- Opt for materials that are safe for the environment and human health.
- Choose materials that, during extraction, have not caused environmental degradation.
- Select materials that do not generate hazardous waste.
- Opt for materials that have traveled short distances during transportation or have been transported by more environmentally friendly means (ship or train).
- Choose manufacturing processes that consume few resources (energy, water, raw materials) and do not cause polluting emissions (including smoke, dust, and waste).
- Design products that generate little, to no pollution and waste and consume minimal energy and resources during use.
- Create high-quality products that have a long lifespan and are easy to use, maintain, upgrade, repair, reuse, recycle, or remanufacture.
- Improve the logistics of transporting finished products to minimize fuel consumption.
- Reduce manufacturing waste to a minimum and handle it appropriately.

Environmental Management System

There are various environmental management tools, with the most well-known being ISO 14001 and EMAS :

- ISO 14001: This is an international standard created by companies through the International Organization for Standardization based in Geneva. Organizations that have implemented ISO 14001 commit to complying with legislation and following the principle of continuous improvement in their environmental performance.
- EMAS (Eco-Management and Audit Scheme) : This is a more stringent European regulation than the ISO 14001 system. Organizations that have committed to implementing EMAS must comply with all the requirements of the regulation (including compliance with environmental legislation) and must demonstrate results.

Who is Involved ?

- All companies that can directly or indirectly influence the design or improvement of products are involved in eco-design. It is an approach that highlights the value of innovation and the creativity of the staff. It presents a new opportunity for differentiation and a future competitiveness factor.

- Engaging in any eco-design initiative requires strong commitment from the hierarchy. Indeed, it modifies—enhances—the usual practices of market research, competitive intelligence, design choices, supplier selection, product communication, etc.

Before generalizing an Eco-Design approach, the Company should be aware of or at least familiar with :

— Quality and environmental management (ISO 9000 and ISO 14000 standards) ;

— Product development processes within a cross-functional "project team" framework ;

— Multi-criteria performance evaluation methods for projects ;

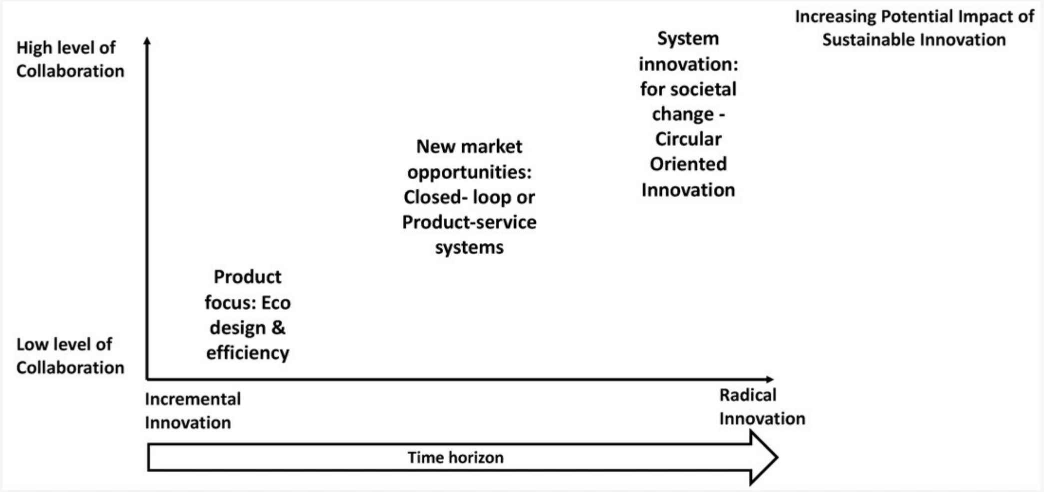
— Functional analysis and industrial design, disciplines that allow for considering a wide range of requirements during product development.

Advantages and Benefits of Eco-Design

Engaging in an eco-design approach allows a company to :

- Reduce its environmental impact.
- Better manage risks and costs associated with the product lifecycle.
- Anticipate customer expectations and meet the growing demand for environmentally friendly products and services.
- Make the environment a new factor for dynamism and creativity in the processes of product creation and design.
- Improve its image and differentiate itself in the market.
- Achieve economic gains.
- Anticipate increasingly stringent requirements set by governments and the market.

Figure 1. Evolution of sustainable oriented innovation and collaboration (adapting and integrating [10,39]).



Advantages and Benefits of Eco-Design

For the consumer : Benefit from eco-designed products : products that meet needs and are durable. Preserve or improve living conditions. Save money when using products.

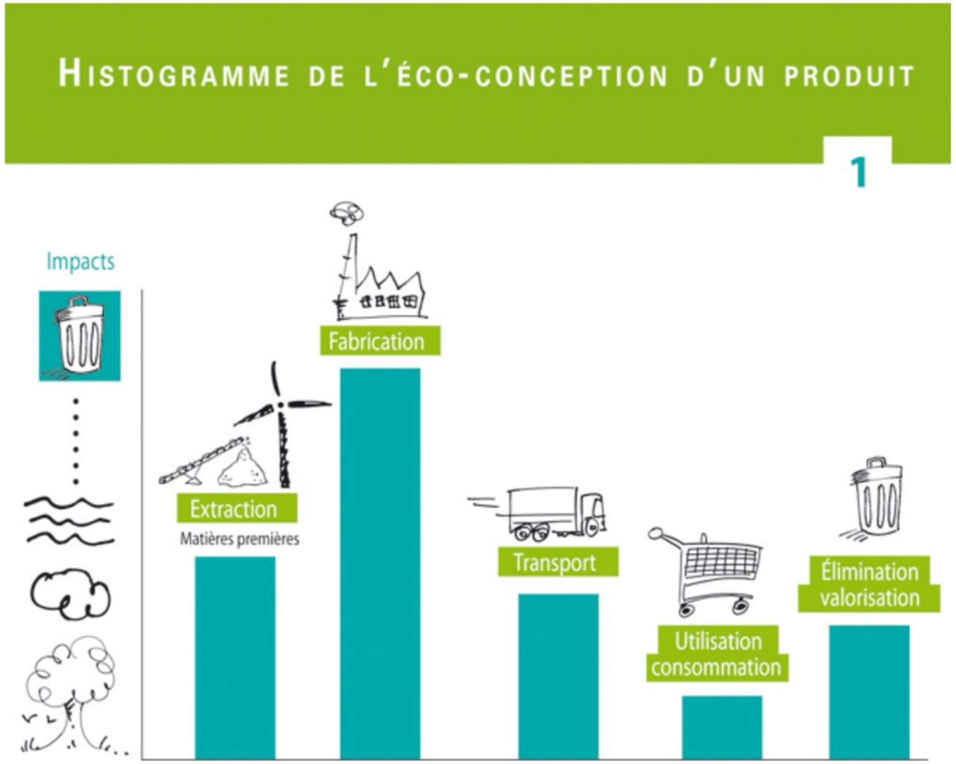
For the community : Achieve energy savings. Reduce waste treatment costs. Lower costs associated with pollution and risks. Manage natural resources sustainably over the long term.

Pollution Transfers

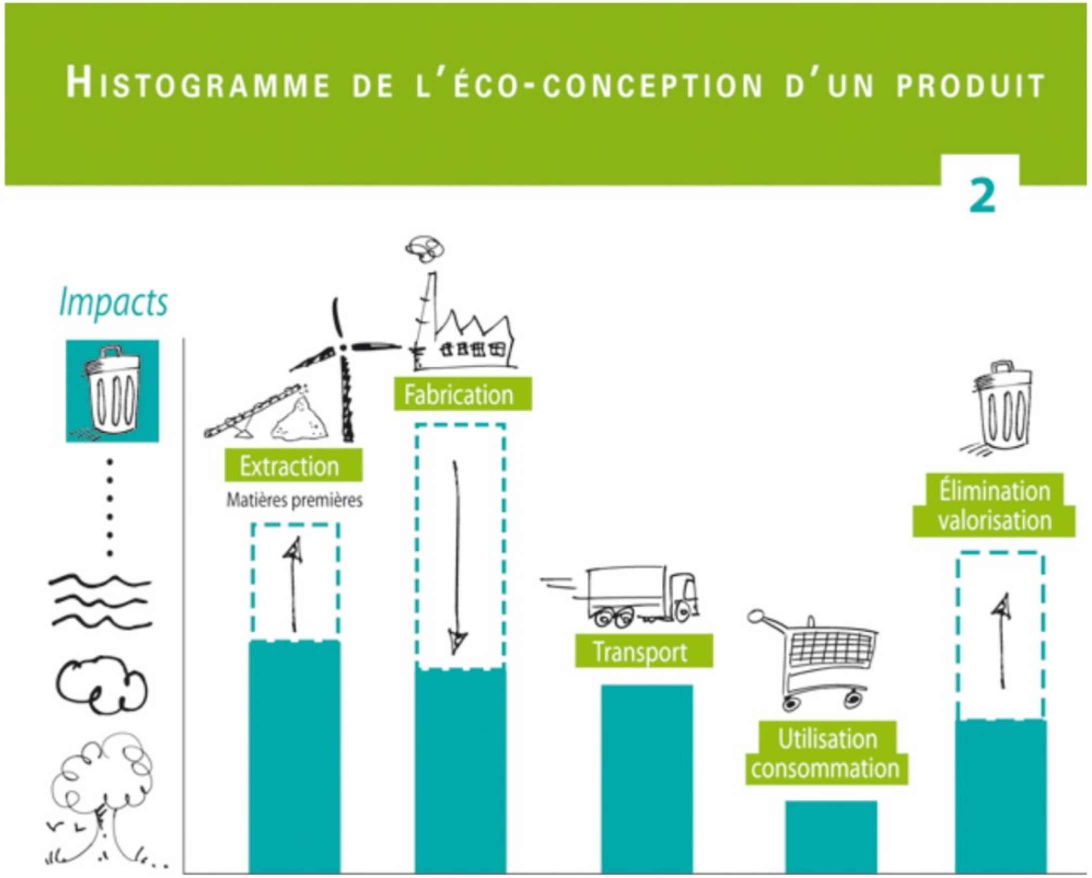
- Beware of Pollution Transfers It is essential to remember that any modification of a product's characteristics in one specific area has repercussions on the entire product. When a designer modifies one or another aspect of a product's life cycle to reduce its impact, they must ensure that the proposed change does not strengthen or create other impacts.

<u>Example of Pollution Transfer :</u>

Version 1: In this version, it is noted that the manufacturing phase presents the most significant issues :



Version 2 : If the product is redesigned by substituting one material or substance with another to reduce pollution from the processes, the environmental performance of the production site will indeed be improved. However, if a rare material or substance that is difficult to recycle at the end of its life is chosen, the overall environmental effect could be as bad as, or even worse than, the initial solution :



IMPACTS
Carbon Footprint

Before delving into the multi-criteria approach specific to eco-design and life cycle assessments, we will discuss a method increasingly known to the general public : the Carbon Footprint.

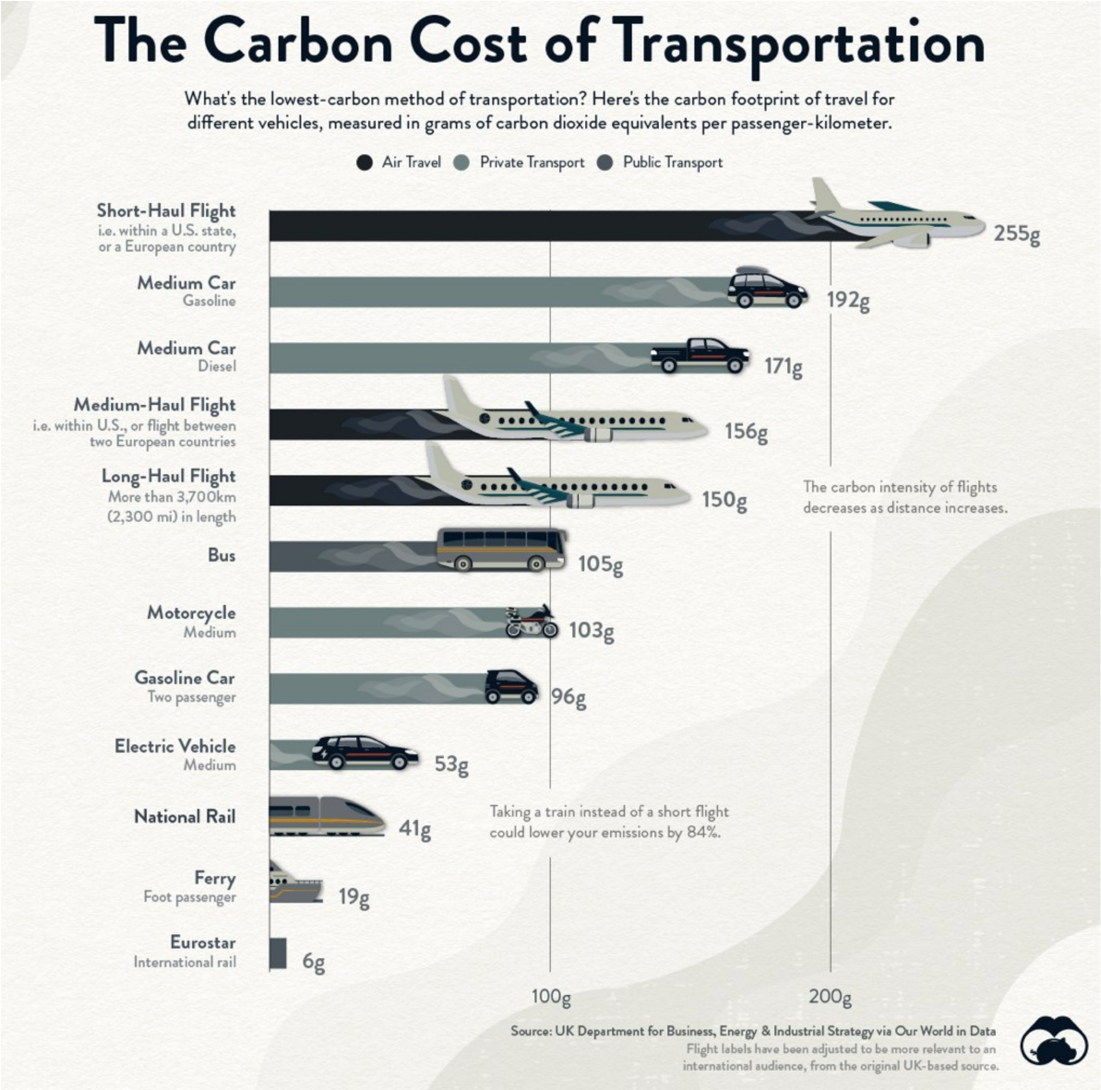
- The carbon footprint is an indicator that aims to measure the impact of an activity on the environment, particularly the **greenhouse gas emissions** related to that activity.
- This impact is generally expressed in carbon dioxide equivalent or CO2e. Why ? For simplicity and standardization, all greenhouse gases are measured against a single standard referenced to **CO2**.

Here is the complete list of greenhouse gases (GHGs) whose emissions must be considered :

Compound	Pre-industrial concentration (ppmv*)	Concentration in 2019 (ppmv)	Atmospheric lifetime (years)	Main human activity source	GWP**
Carbon dioxide (CO_2)	280	411	variable	Fossil fuels, cement production, land use change	1
Methane (CH_4)	0.715	1.877	12	Fossil fuels, rice paddies, waste dumps, livestock	28
Nitrous oxide (N_2O)	0.27	0.332	121	Fertilizers, combustion industrial processes	265
HFC 23 (CHF_3)	0	0.000024***	222	Electronics, refrigerants	12,400
HFC 134a (CF_3CH_2F)	0	0.000062***	13	Refrigerants	1,300
HFC 152a (CH_3CHF_2)	0	0.0000064***	1.5	Industrial processes	138
Perfluoromethane (CF_4)	0.00004	0.000079***	50,000	Aluminum production	6,630
Perfluoroethane (C_2F_6)	0	0.0000041***	10,000	Aluminum production	11,100
Sulphur hexafluoride (SF_6)	0	0.0000073***	3,200	Electrical insulation	23,500

*ppmv = parts per million by volume, **GWP = 100-year global warming potential, ***Concentration in 2011
Water vapor not included in table, see bullet.

Example : Carbon footprint of transportation. The carbon footprint of transportation represents the largest part of our average carbon footprint



How to calculate your carbon footprint ?

Physical ratios Wherever possible, emissions of CO_2 are estimated based on a physical emission factor (GHG = GreenHouse Gas) :

Amount of GHG = Quantity Consumed x Physical Emission Factor

Here, the quantity consumed is expressed in the unit of the product (liters of gasoline, square meters of area, kilograms of pineapple, etc).

The physical emission factor specifies the amount of CO_2 emitted per consumed unit. For example, ferry travel - one of the most polluting modes of transportation - emits an average of 5 kg of CO_2 (emission factor) per km (quantity consumed).

How to calculate your carbon footprint ?

Monetary ratios : monetary emission factor, expressed in kgCO2e / k€ excluding taxes, allows estimating the CO2 content of a product/service based on its price.

- **Amount of GHG = Price x Monetary Emission Factor**

Online calculators :

Several calculators are available and freely accessible on the internet, mainly offered by associations such as the GoodPlanet Foundation, the MicMac tool (supported by Avenir Climatique)…

https://www.goodplanet.org/fr/calculateurs-carbone/
https://www.footprintcalculator.org/home/fr

The example of the A380 : from an industrial good to the impact of a service

How to calculate the emissions of a passenger on an A380 flight ?

Quick methodological overview, also derived from the Carbon Footprint

- Define the scope : a passenger flight.
- Establish calculation algorithms. As airplanes emit not only CO2, the authors of the Carbon Footprint method have attributed, a factor of 2 to more accurately account for the "climate change impact of airplanes.
- Here is the formula used thereafter :

$$\begin{array}{c}\text{Émissions}\\ \text{par passager}\\ \text{classe économique}\end{array} = \frac{2 \times \begin{array}{c}\text{Quantité totale}\\ \text{de carburant}\end{array} \times \begin{array}{c}\text{Facteur d'émission}\\ \text{du kérosène}\end{array}}{\begin{array}{c}\text{Nombre total}\\ \text{de sièges « équivalent}\\ \text{classe économique »}\end{array} \times \begin{array}{c}\text{Distance totale}\\ \text{parcourue}\end{array} \times \begin{array}{c}\text{Taux}\\ \text{de remplissage}\\ \text{moyen}\end{array}}$$

The example of the A380 : from an industrial good to the impact of a service

- Since emissions must be attributed to the passenger, understanding the 'composition' of the aircraft is also an important prerequisite for performing the calculation :

Avion	Quantité maximale de carburant (litres)	Rayon d'action (km)	Nombre de sièges				
			Classe économique	Classe Affaires	1 re classe	Total	Total équivalent classe économique
A380	310 000	14 816	439	96	20	555	733

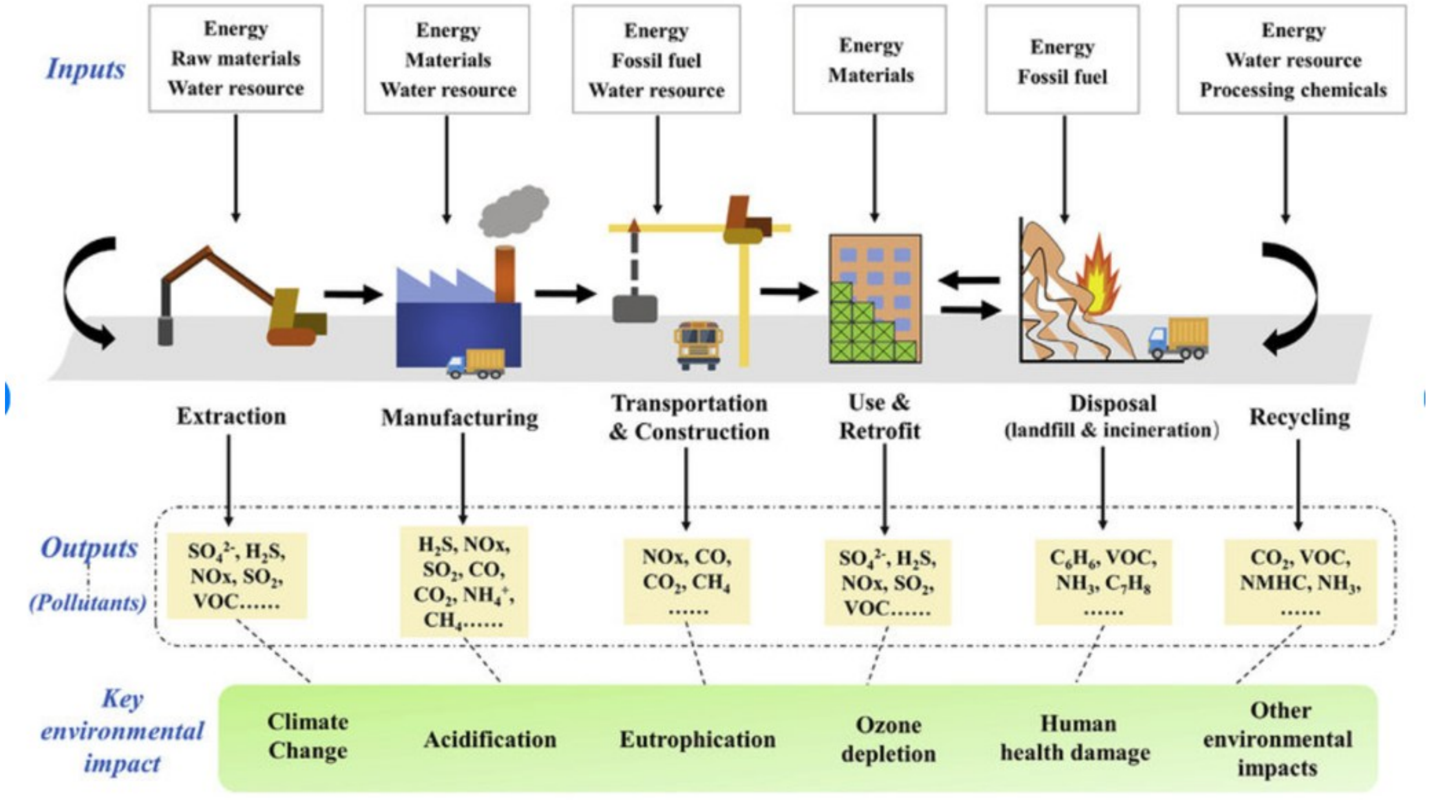
The example of the A380 : from an industrial good to the impact of a service

Two main variables : the average occupancy rate for commercial flights and the space occupied by different classes. A380 emissions per type of passenger in the assumption of an average occupancy rate of 75% and weighting factors for Business and First class seats ranging from 88 to 250%

	Classe économique	Classe Affaires	1^{re} classe	Total	Moyenne sièges
Nombre de sièges	439	96	20	555	
g CO_2/passager/km	59	138	207		78

The others impacts

Simple topics such as the question, for example, of the least polluting fuel mode, demonstrate to us daily, and despite its justified predominance, that **the sole consideration of CO2 equivalent is not sufficient to fully describe the environmental impact** of a product, let alone to praise the ecological performance of a solution



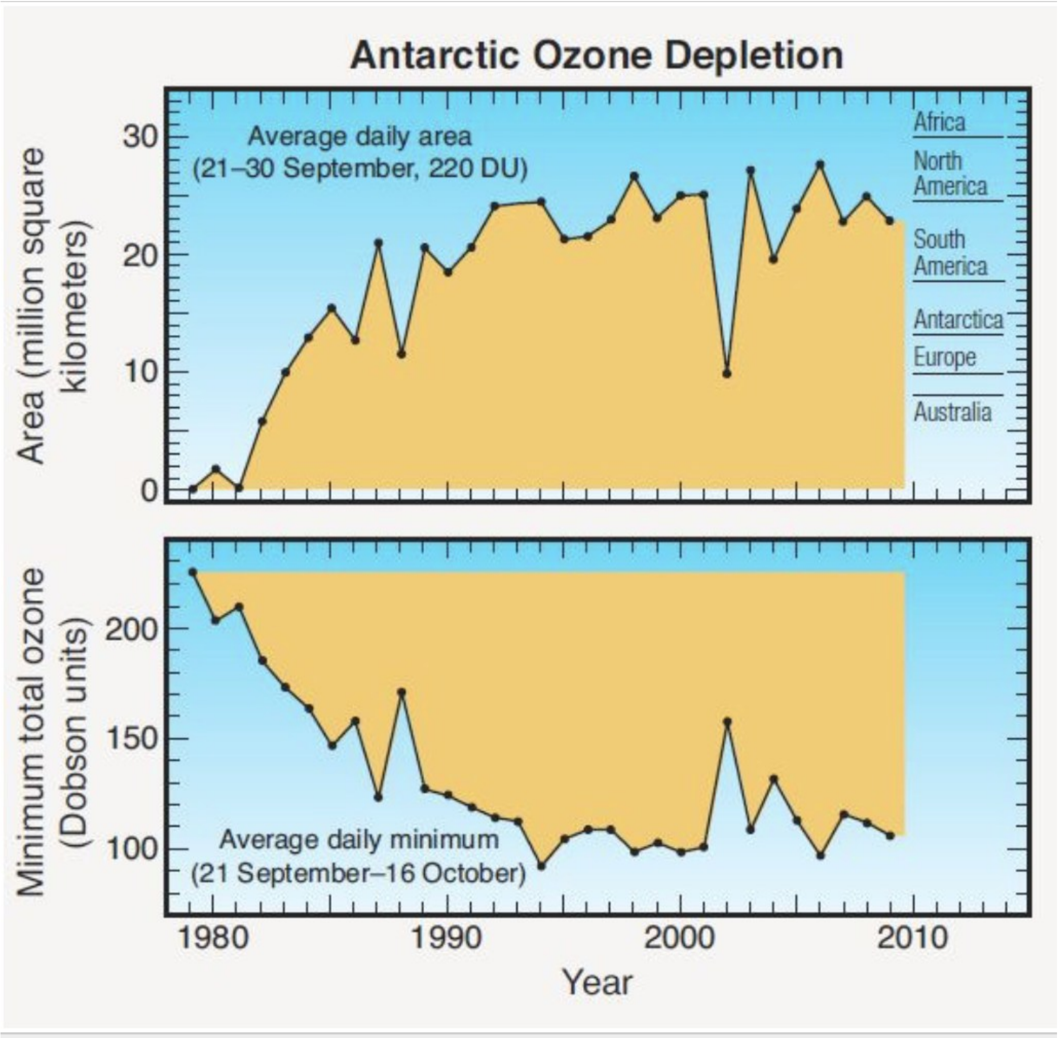
Numerous studies on consumption have been conducted, resulting in a variety of calculation systems. The most recent method synthesizes approaches that have long been opposed : **the "midpoint" and "endpoint"** approaches.

In summary, the process involves collecting data on the consumption of resources (materials and energy) and the pollutants (inputs and outputs) emitted into the environment by the products studied (and linked to the emission factors of their components).

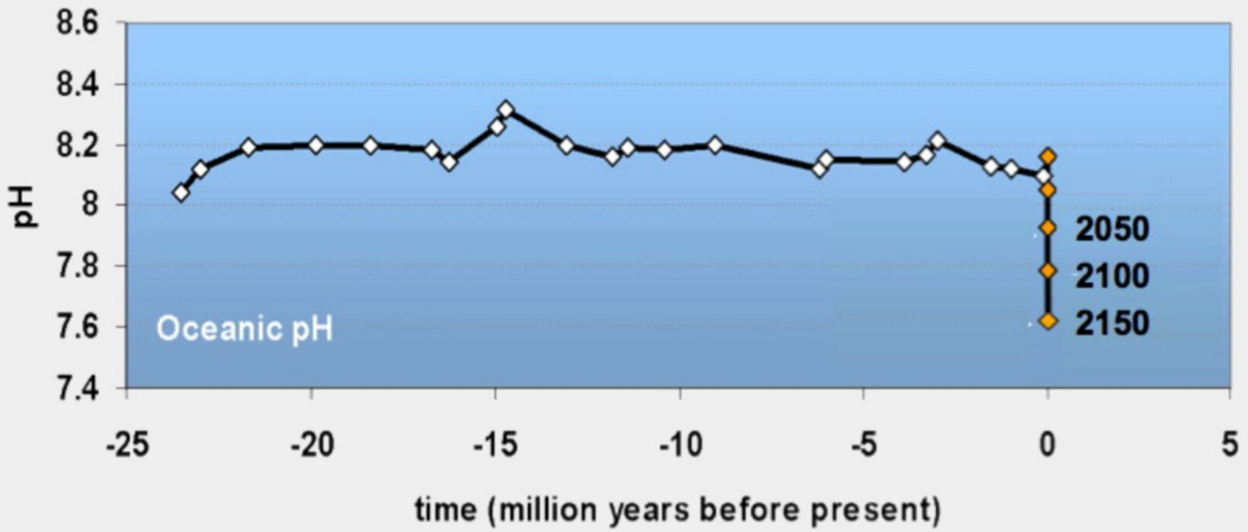
This data is then consolidated into a first **set of indicators** (**18** in total, including climate change), which can ultimately be summarized into 3 consolidated indicators regarding the degradation of human health, ecosystem diversity, and resource availability. Below are the indicators considered :

Environmental Indicator	Acronym	Unit
Global Warming	GWP	kg CO_2 eq
Stratospheric Ozone Depletion	ODP	kg CFC-11 eq
Ionising radiation.	IRP	kBq Co-60 eq
Ozone formation, Human health	HOFP	kg NOx eq
Fine particulate matter formation	PMFP	kg PM2.5 eq
Ozone formation, Terrestrial ecosystems	EOFP	kg NOx eq
Terrestrial acidification	TAP	kg SO_2 eq
Freshwater eutrophication	FEP	kg P eq
Marine eutrophication	MEP	kg N eq
Terrestrial ecotoxicity	TETP	kg 1,4-DCB
Freshwater ecotoxicity	FETP	kg 1,4-DCB
Marine ecotoxicity	METP	kg 1,4-DCB
Human carcinogenic toxicity	HTPc	kg 1,4-DCB
Human non-carcinogenic toxicity	HTPnc	kg 1,4-DCB
Land use	LOP	m^2a crop eq
Mineral resource scarcity	SOP	kg Cu eq
Fossil resource scarcity	FFP	kg oil eq
Water consumption	WCP	m^3

Ozone Layer Depletion : The Ozone Depletion Potential (ODP) of a chemical compound is the relative theoretical degradation that this compound causes to the ozone layer by destroying ozone in the upper atmosphere.



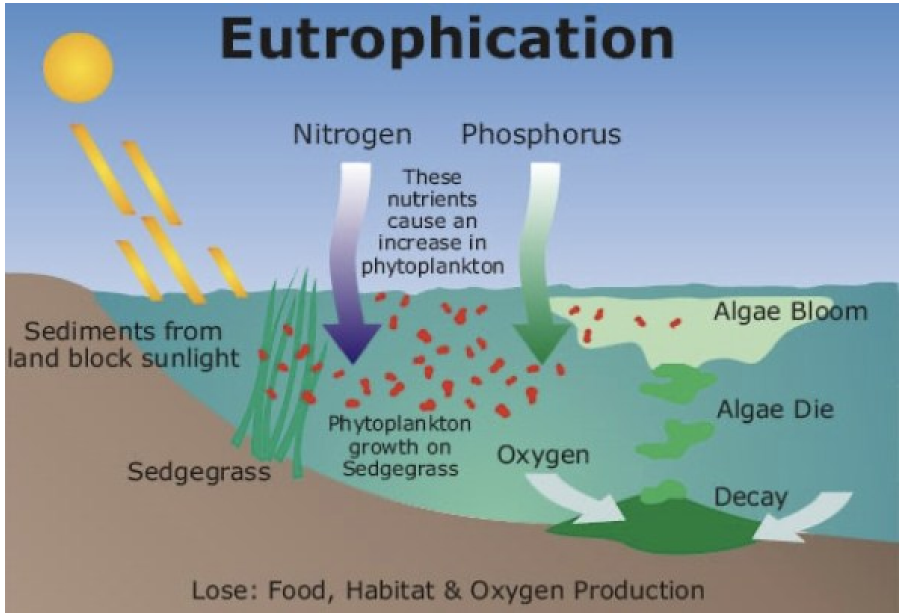
Terrestrial Acidification : An increase in the acidity of soil, water bodies, or air due to human activities. This phenomenon can alter chemical and biological balances and severely affect ecosystems. The increase in air acidity is mainly due to emissions of SO2, NOx, and HCl, which oxidize to form acids like HNO3 and H2SO4.



Evolution possible du pH océanique à l'avenir, et comparaison avec les valeurs passées sur les 25 derniers millions d'années.

Source Pearson et al., Atmospheric carbon dioxide concentrations over the past 60 million years. Nature, 2000, cité in Turley et al. DEFRA 2006

Eutrophication : The impact of eutrophication on water bodies (EUT) represents the alteration and degradation of an aquatic environment due to an excessive influx of nutrients, particularly nitrogen and phosphorus.
The increased nutrient levels promote the proliferation of algae, disrupting biological balances and leading to the death of aquatic fauna and flora.



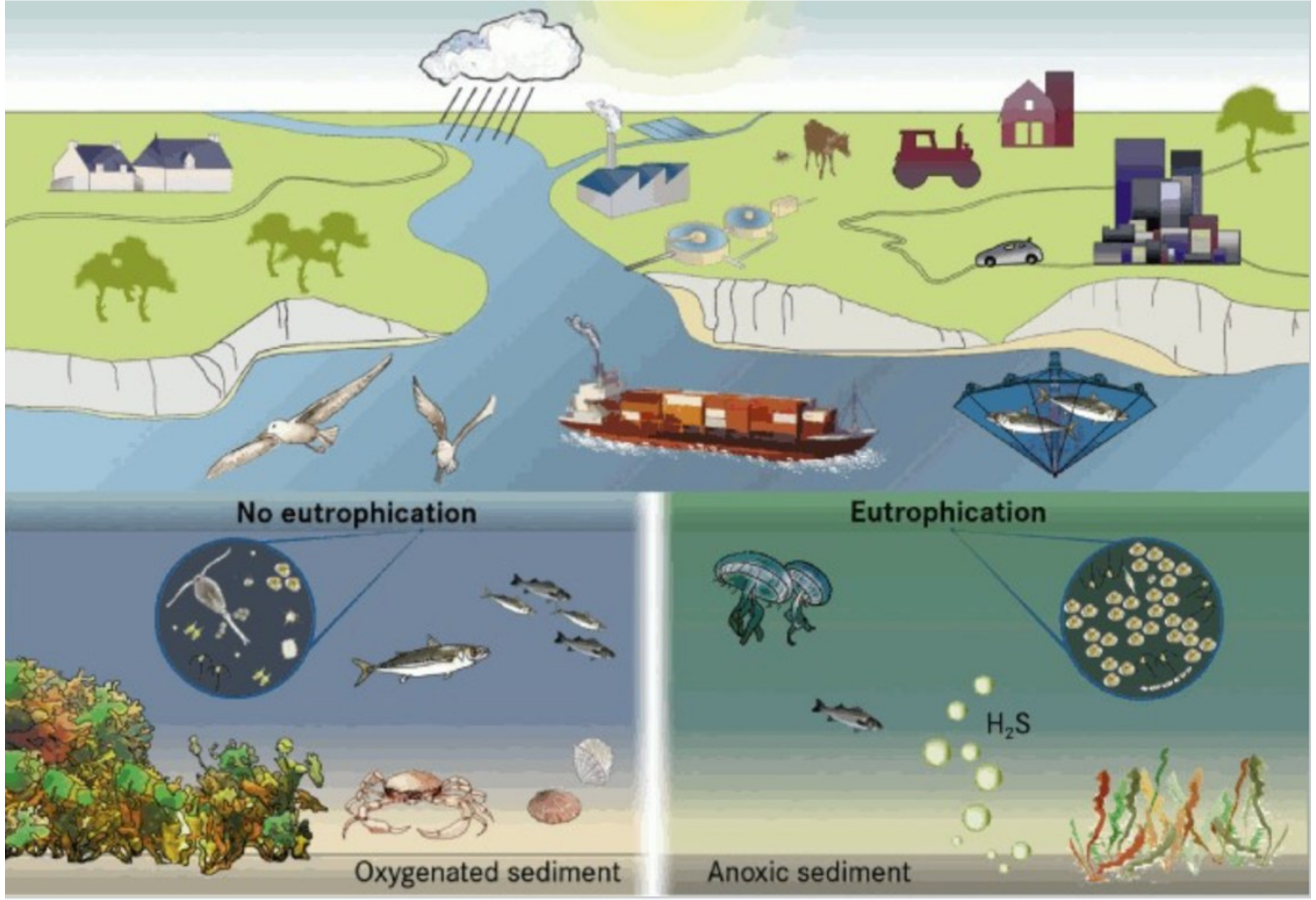
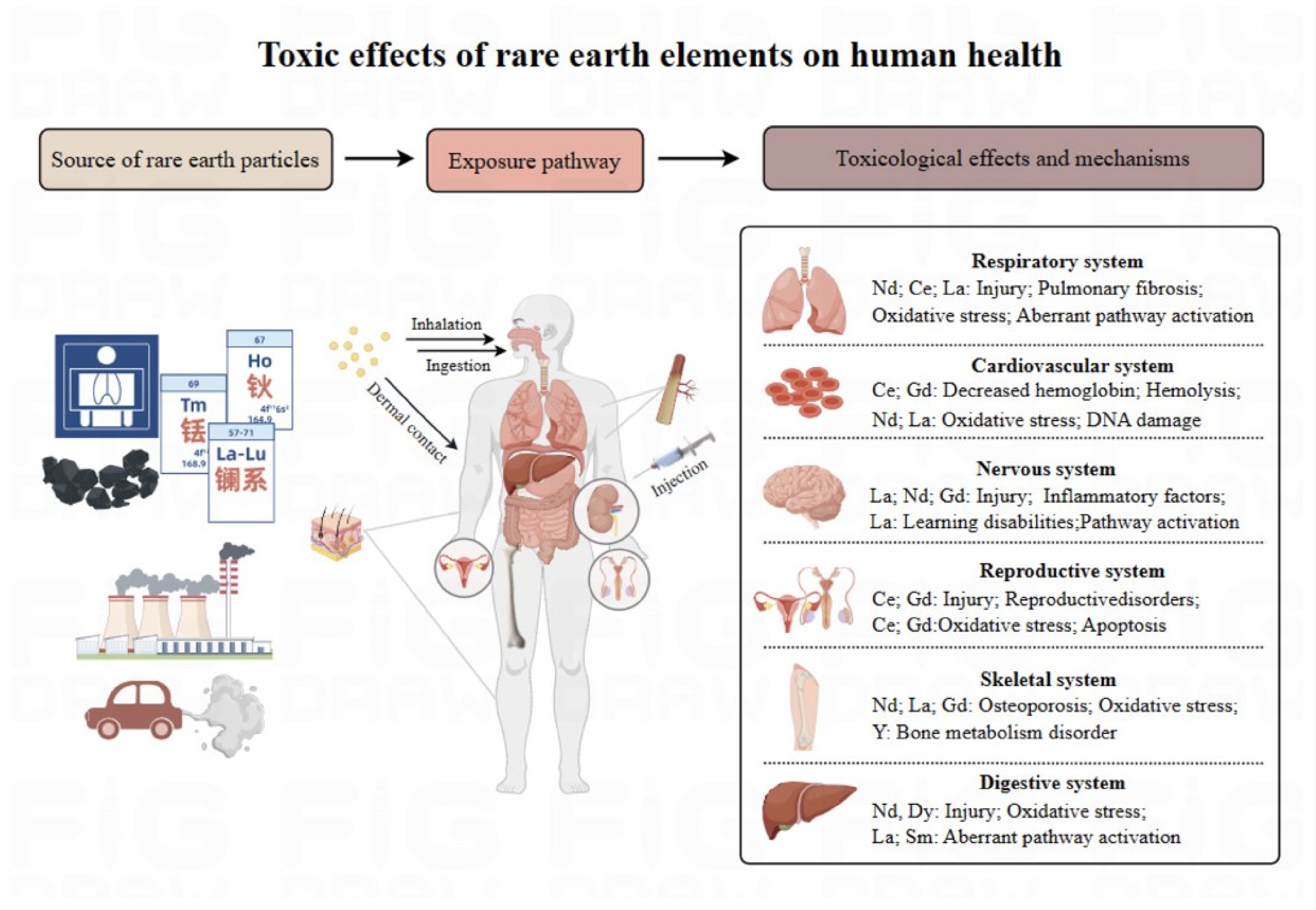


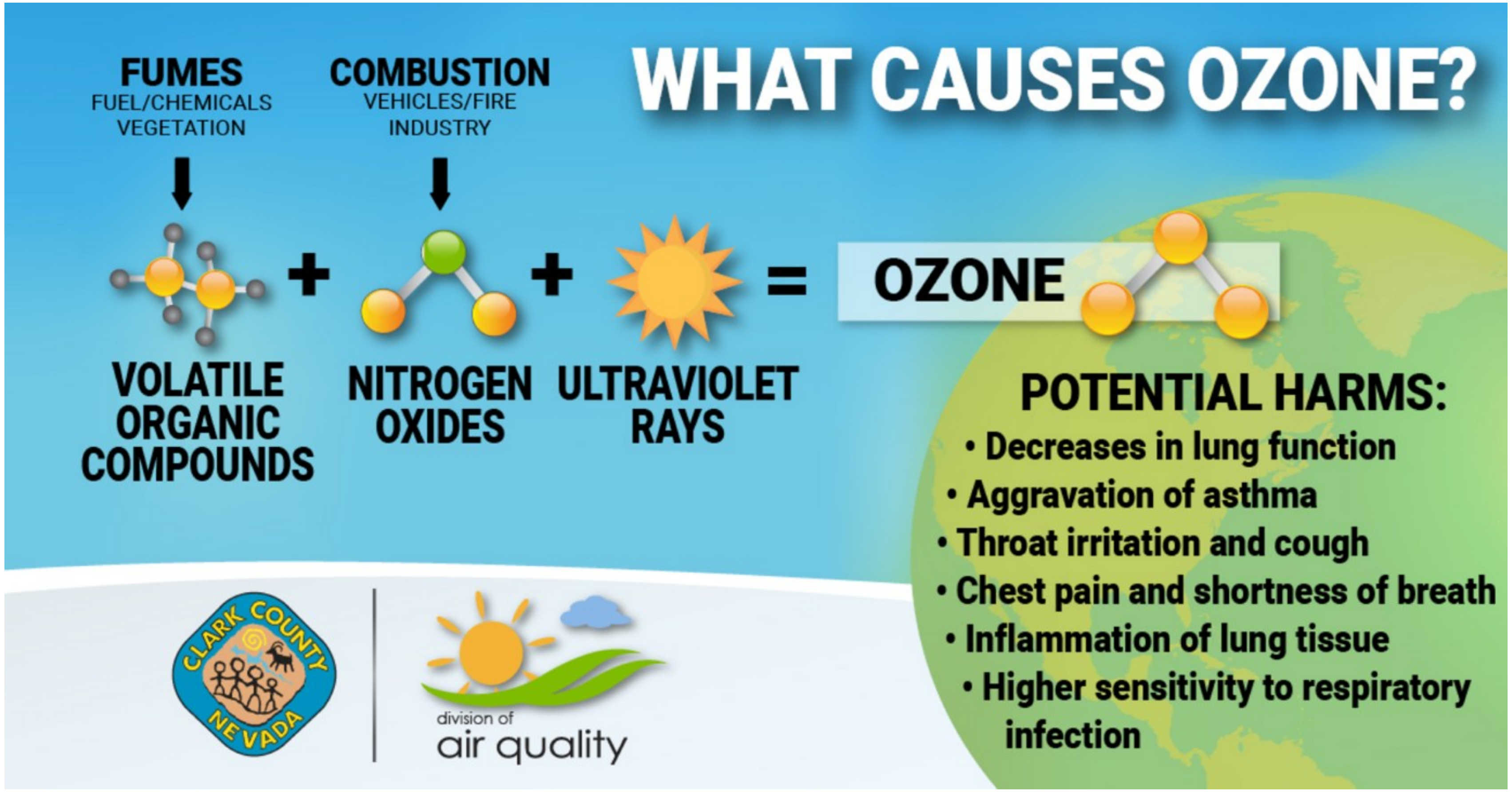
Fig.2. Sources of nutrient input to the marine environment and simplified schemes showing eutrophication effects arising from nutrient enrichment [7].

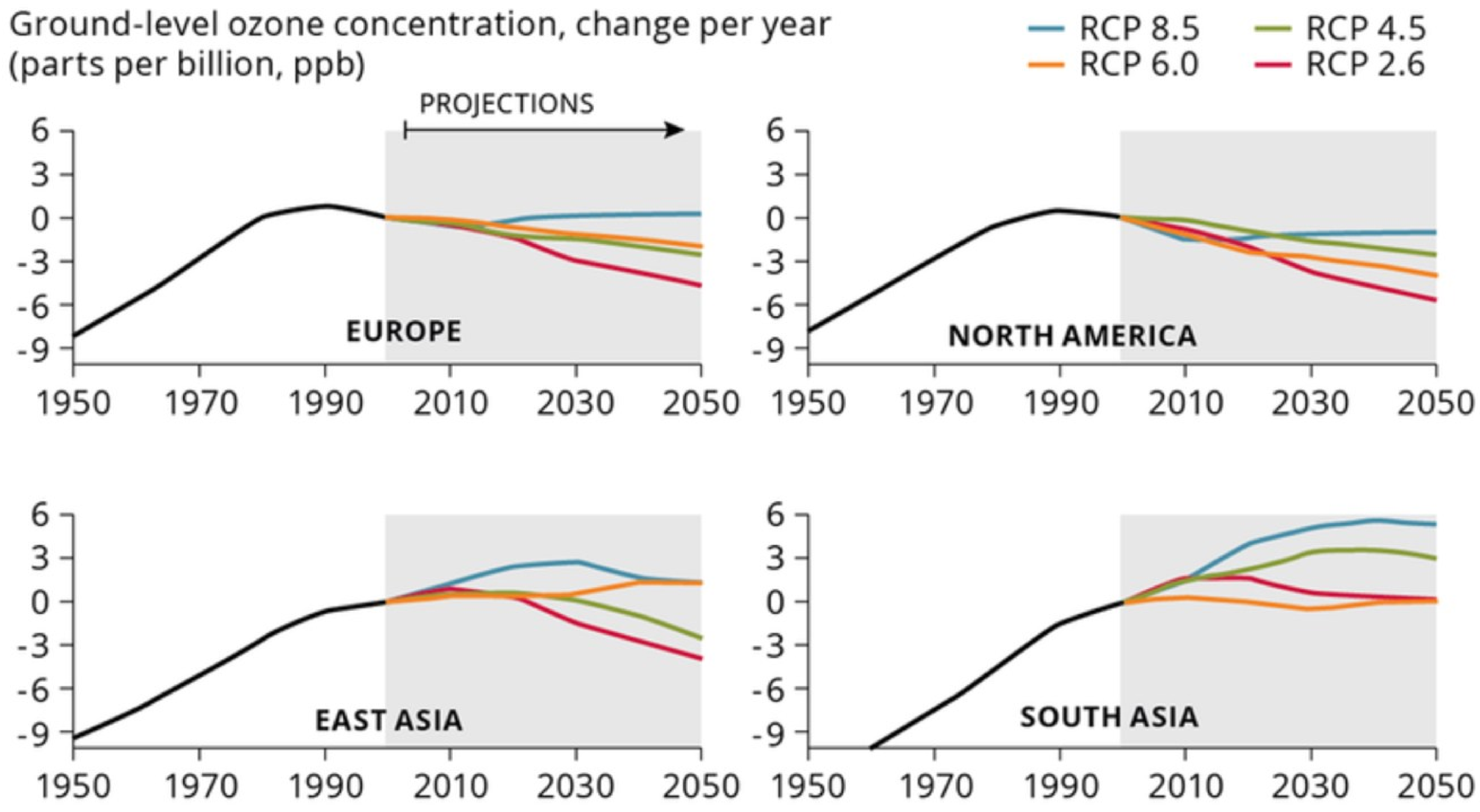
Human Toxicity : Human toxicity refers to the inherent capacity of a chemical substance to produce harmful effects in a living organism, making it a toxic substance.
Some need to be absorbed in large quantities to cause poisoning, while others can be harmful even in small doses.

Figure 1. Toxic effects of rare earth elements on human health.



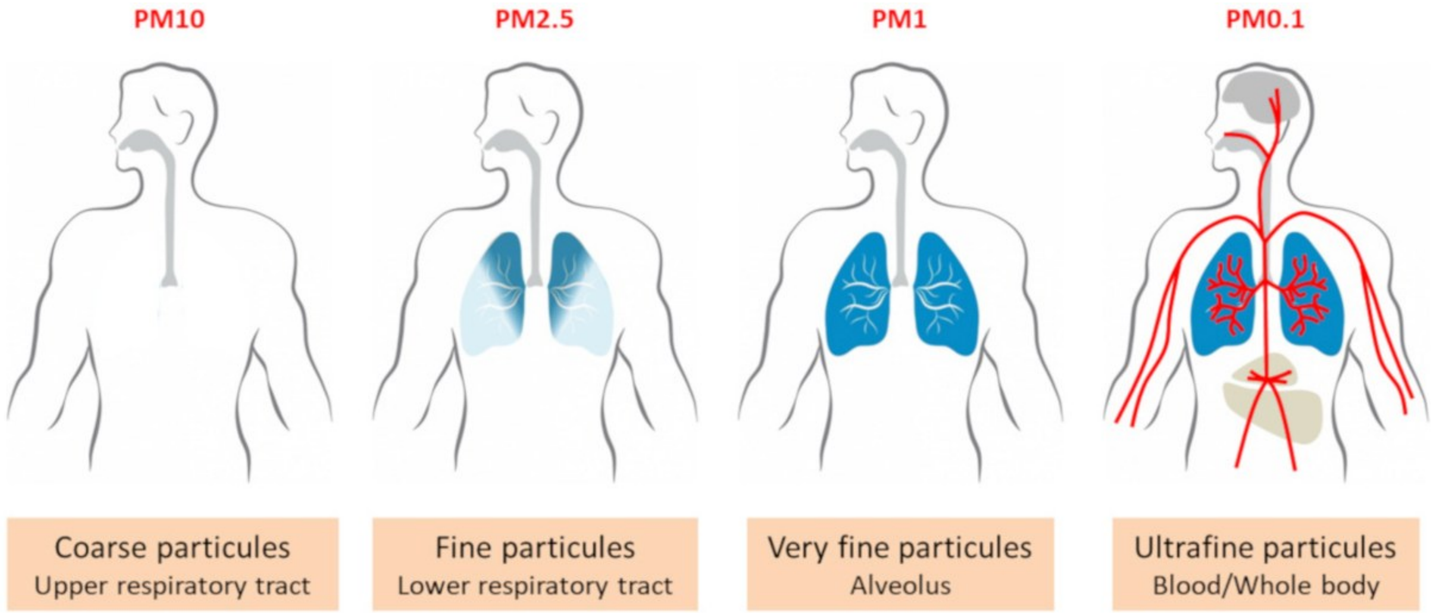
Photochemical Oxidants : Photochemical pollution, also known as photochemical oxidant pollution, is a complex set of phenomena leading to the formation of ozone (O_3) and other oxidizing compounds

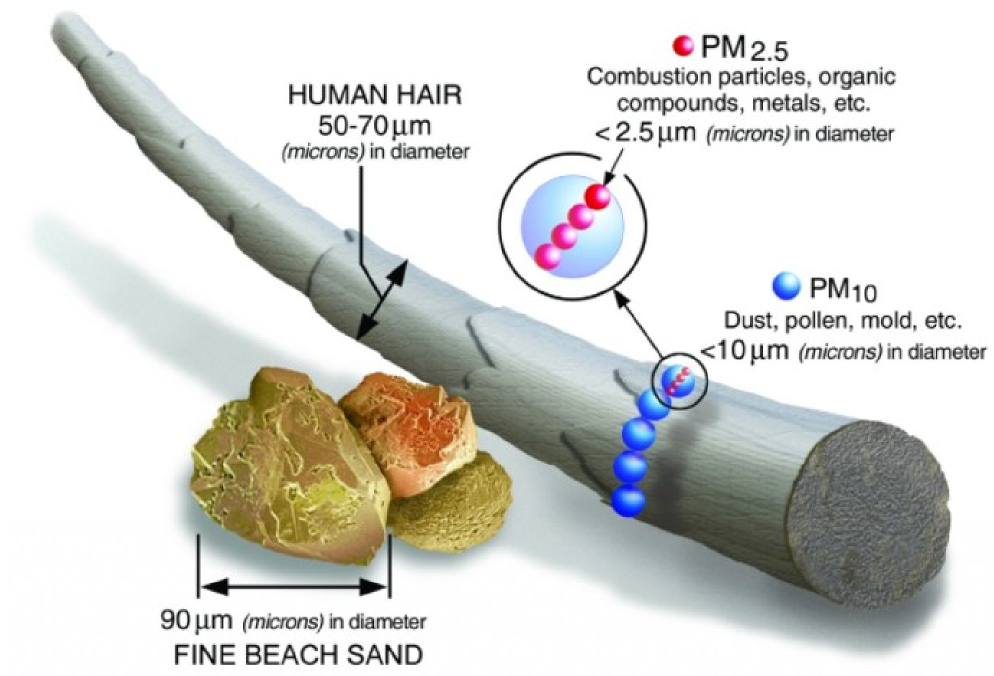




Ground-level ozone concentration, change per year
(parts per billion, ppb)
RCP 8.5
RCP 4.5
RCP 6.0
RCP 2.6
PROJECTIONS
EUROPE
NORTH AMERICA
EAST ASIA
SOUTH ASIA
6
3
0
-3
-6
-9
1950
1970
1990
2010
2030
2050

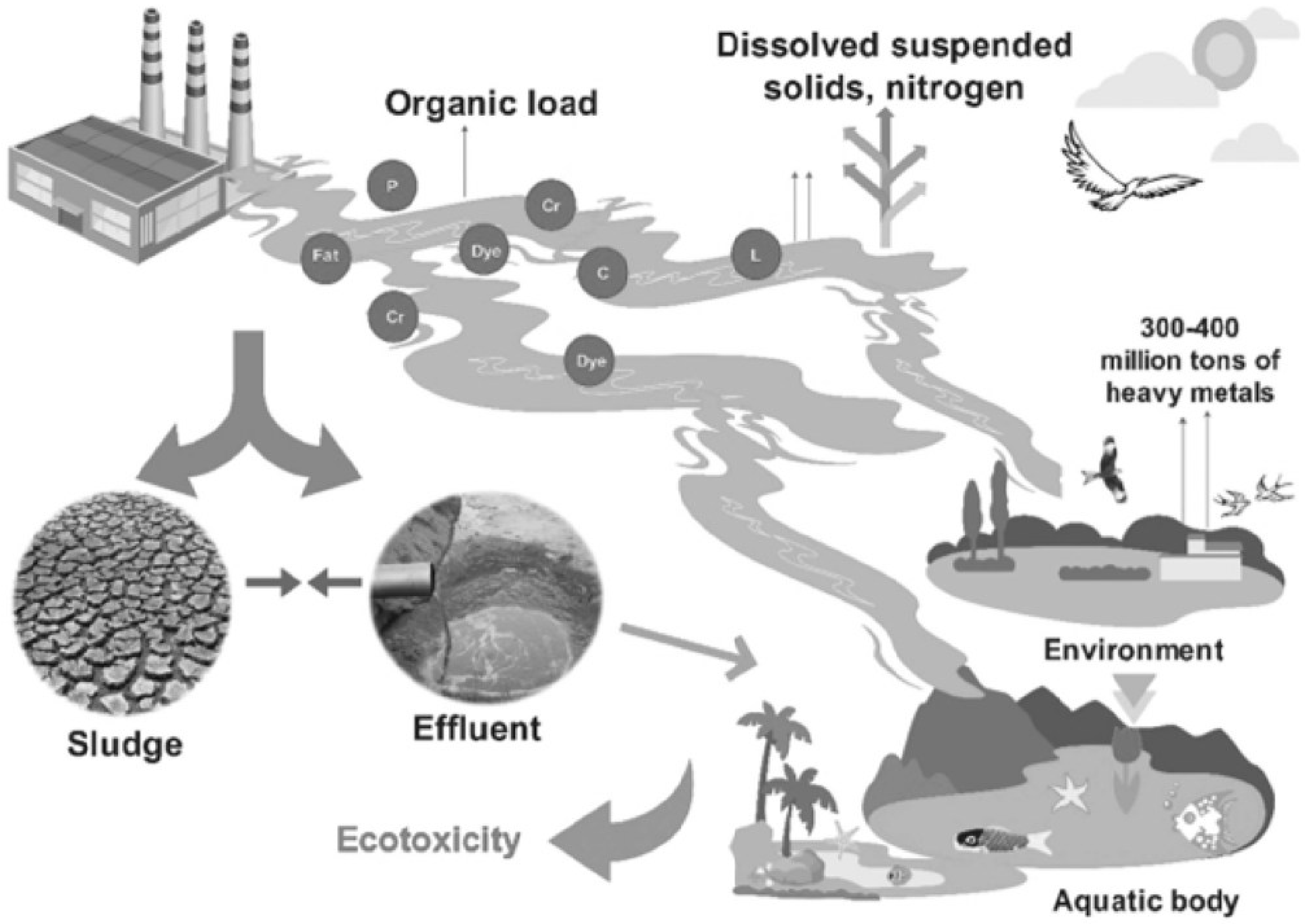
Formation of particles : Particles are formed by a change in the state of matter, by chemical reactions between substances in the gaseous state, by evaporation at high temperatures followed by condensation.
The size spectrum of these particles ranges from a few nanometers to a few tenths of microns.



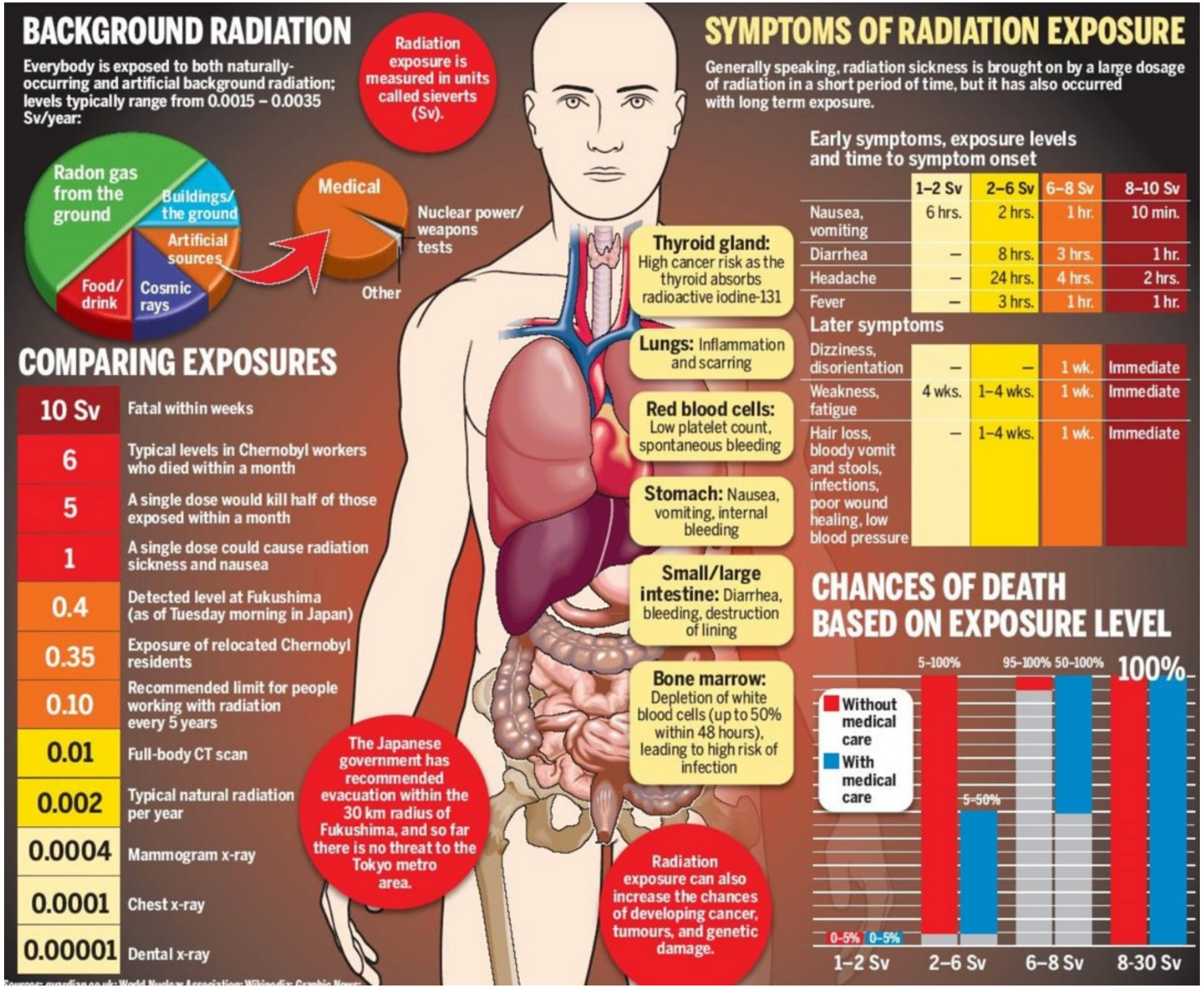


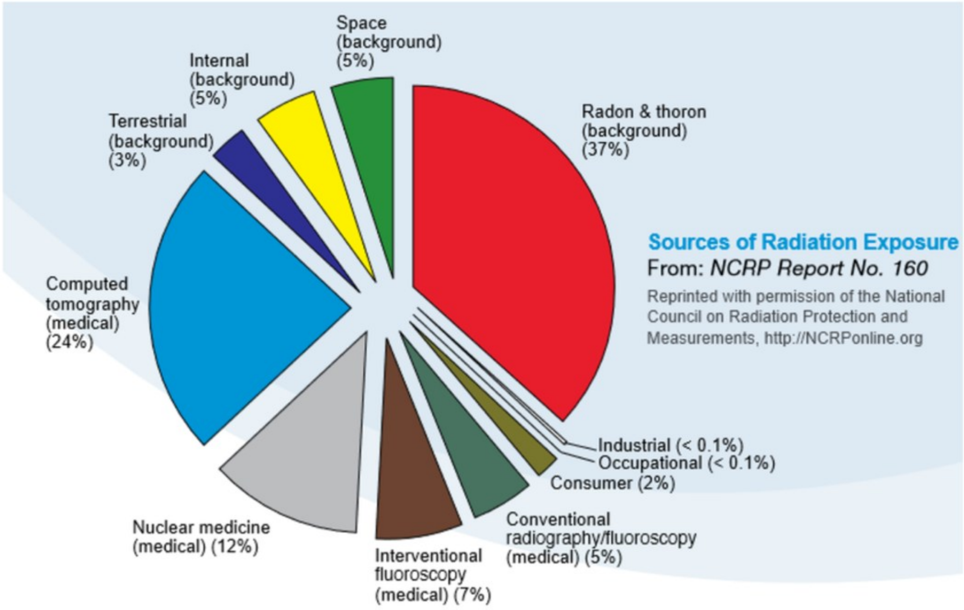
Size comparisons for PM particles

Ecotoxicity : the set of ecological hazards caused by a product, an industry, etc.



Ionizing radiation : Particle or energetic radiation capable of transferring its energy to irradiated matter, ionizing it.

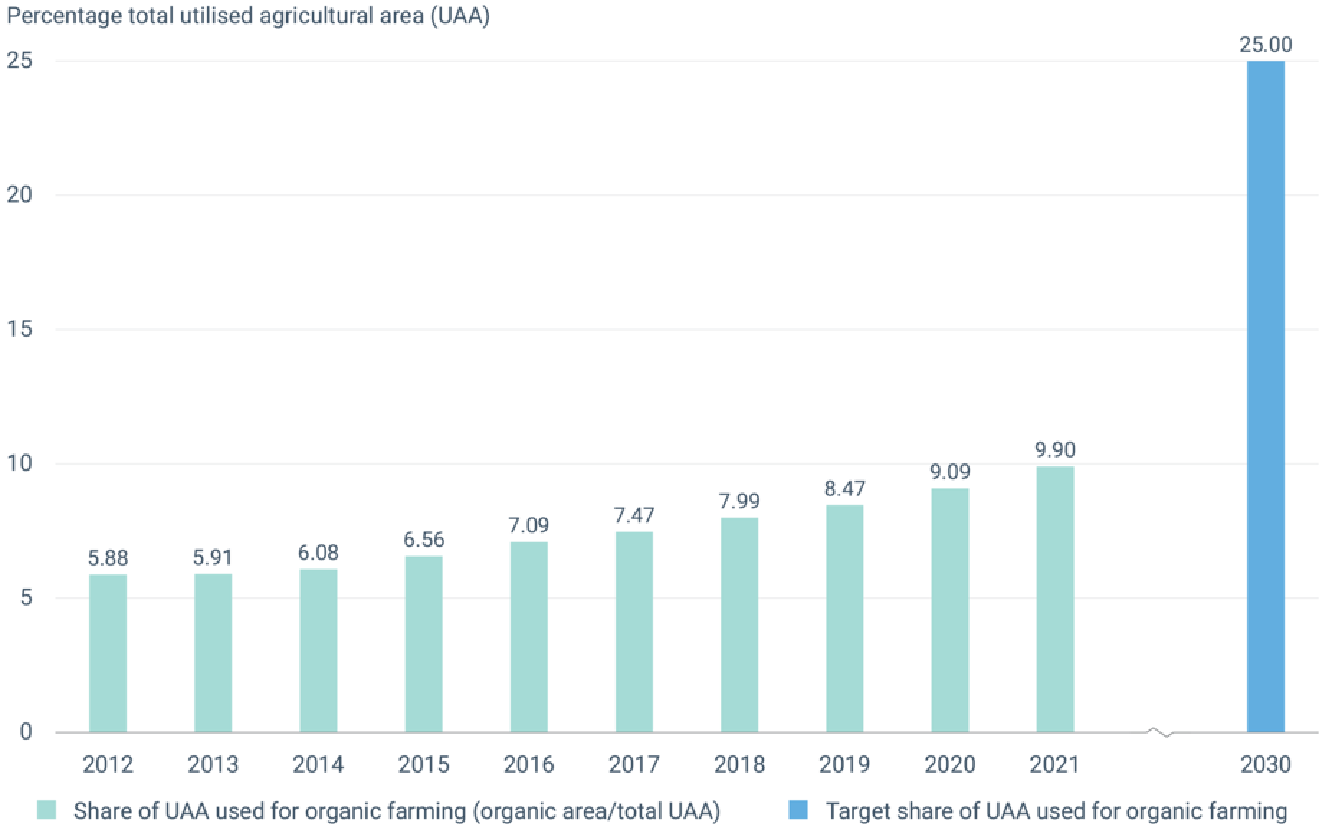




Average annual exposure to ionizing radiation of the United States population [3].

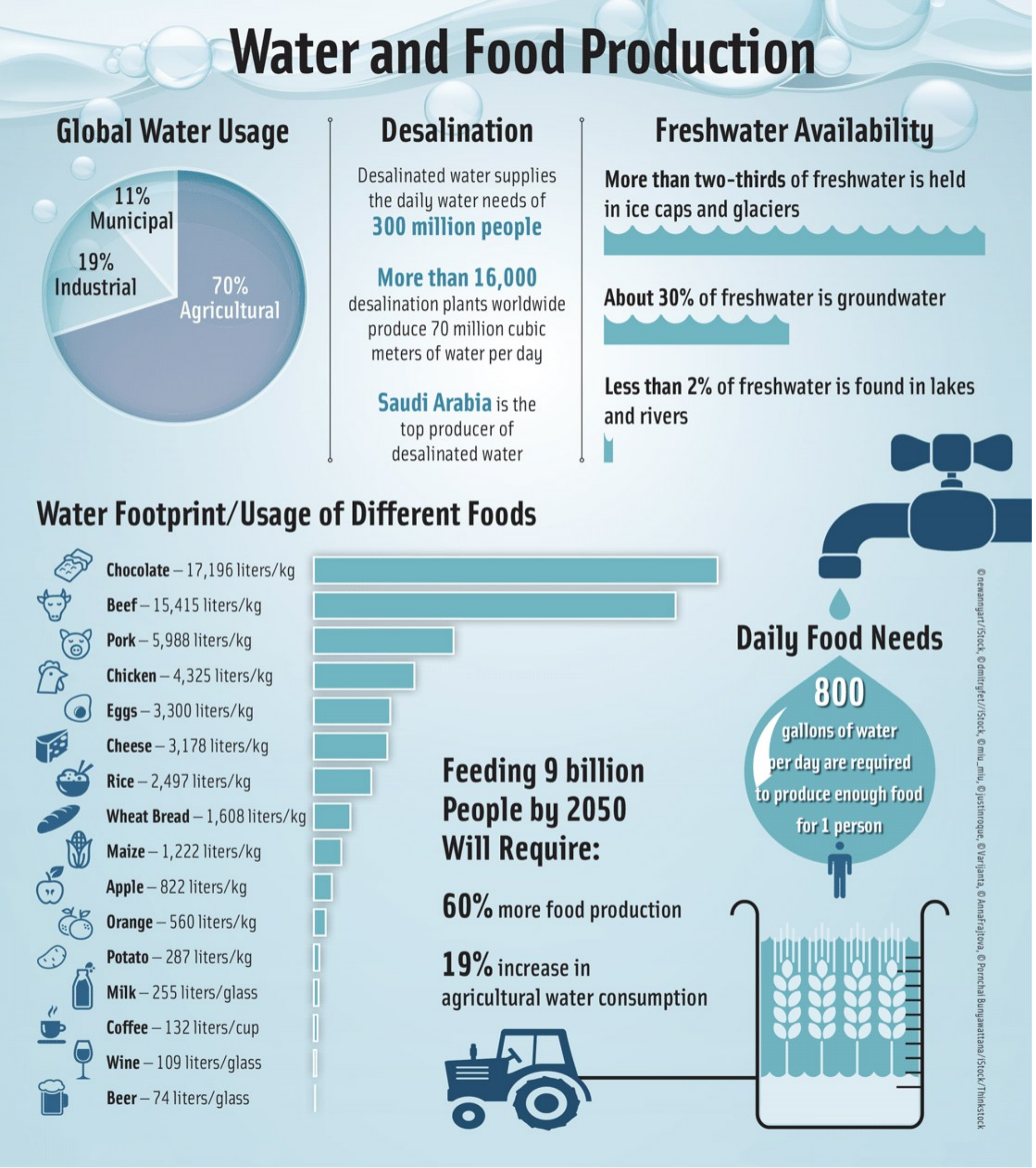
Use of Agricultural Land : Agricultural lands are a rare and non-renewable resource. They serve multiple functions, including the production of food and renewable energy, the preservation of biodiversity, the maintenance of living environments and landscapes, and protection against natural hazards.

Figure 1. Share of the utilised agricultural area used for organic farming in the EU-27 over the period 2012-2021

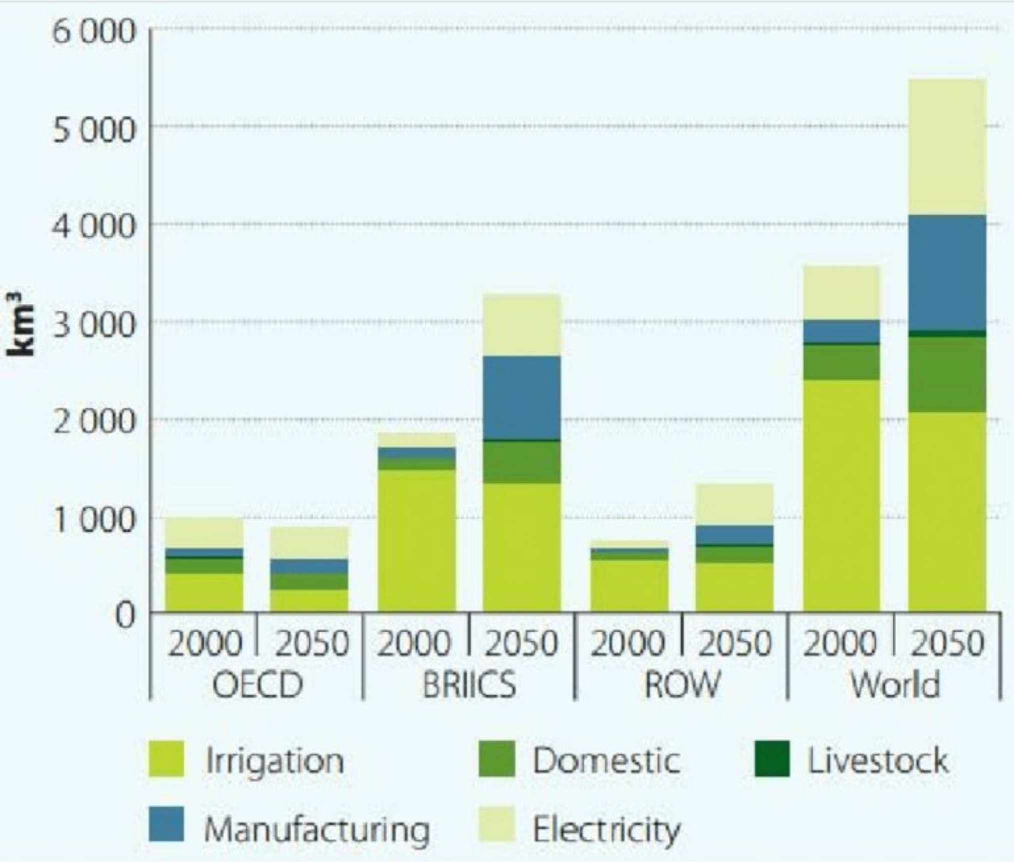


Water Resource Depletion Water : Renewable but Vulnerable. Since the beginning of the 20th century, global freshwater consumption has increased.

- Over the past thirty years, available water quantities have decreased (from an average of 12,900 m^3 to 6,800 m^3 per person per year).
- Non-potable water is the leading cause of mortality worldwide, killing ten times more people than wars.
- Exploitation of non-renewable groundwater reserves has tripled in 40 years and currently.
- 6.1 billion people had access to drinking water in 2010, exceeding the international target of reaching 88% of the global population by 2015. However, 2.5 billion people still lack access to adequate sanitation facilities.
- Soils are also experiencing intense erosion, threatening global agriculture.
- In some regions, soils are being eroded 100 times faster than they can regenerate.

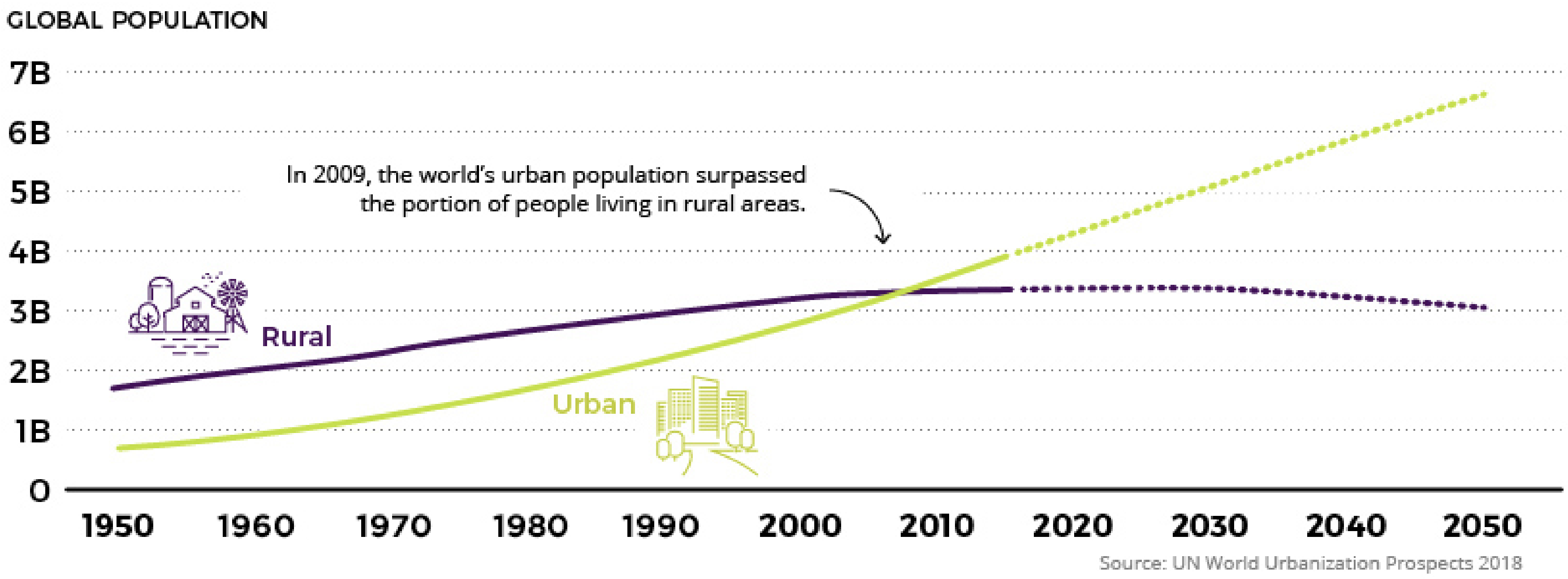


Sources: UN, FAO, GE Water Technologies, Water Footprint Network. © newannyart/ iStock, © dmitryfet//iStock, © miu_miu, © justinroque, © Varijanta, © AnnaFrajtova, © Pornchai

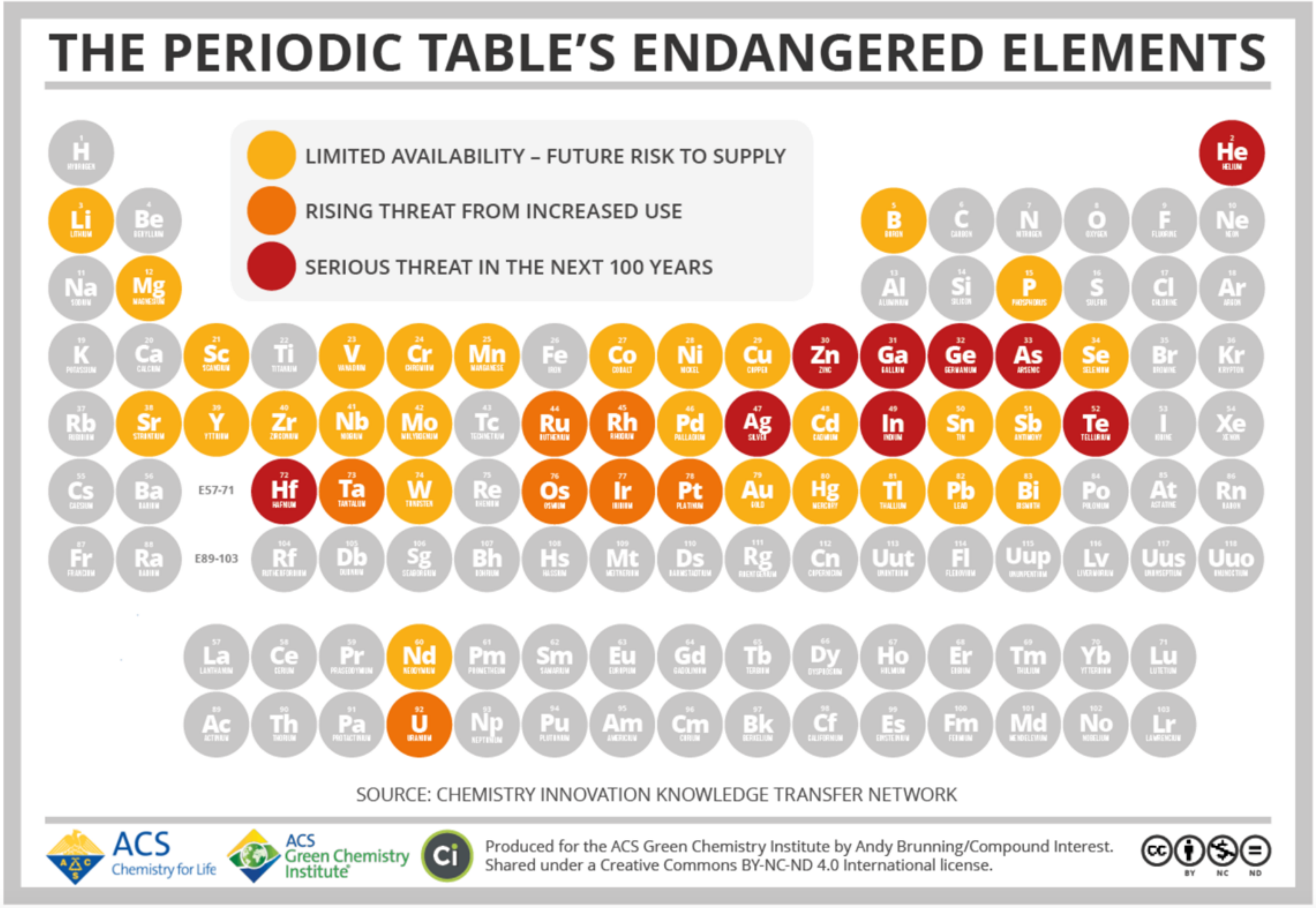


Global water demands in 2000 and 2050 (see online version for colours)

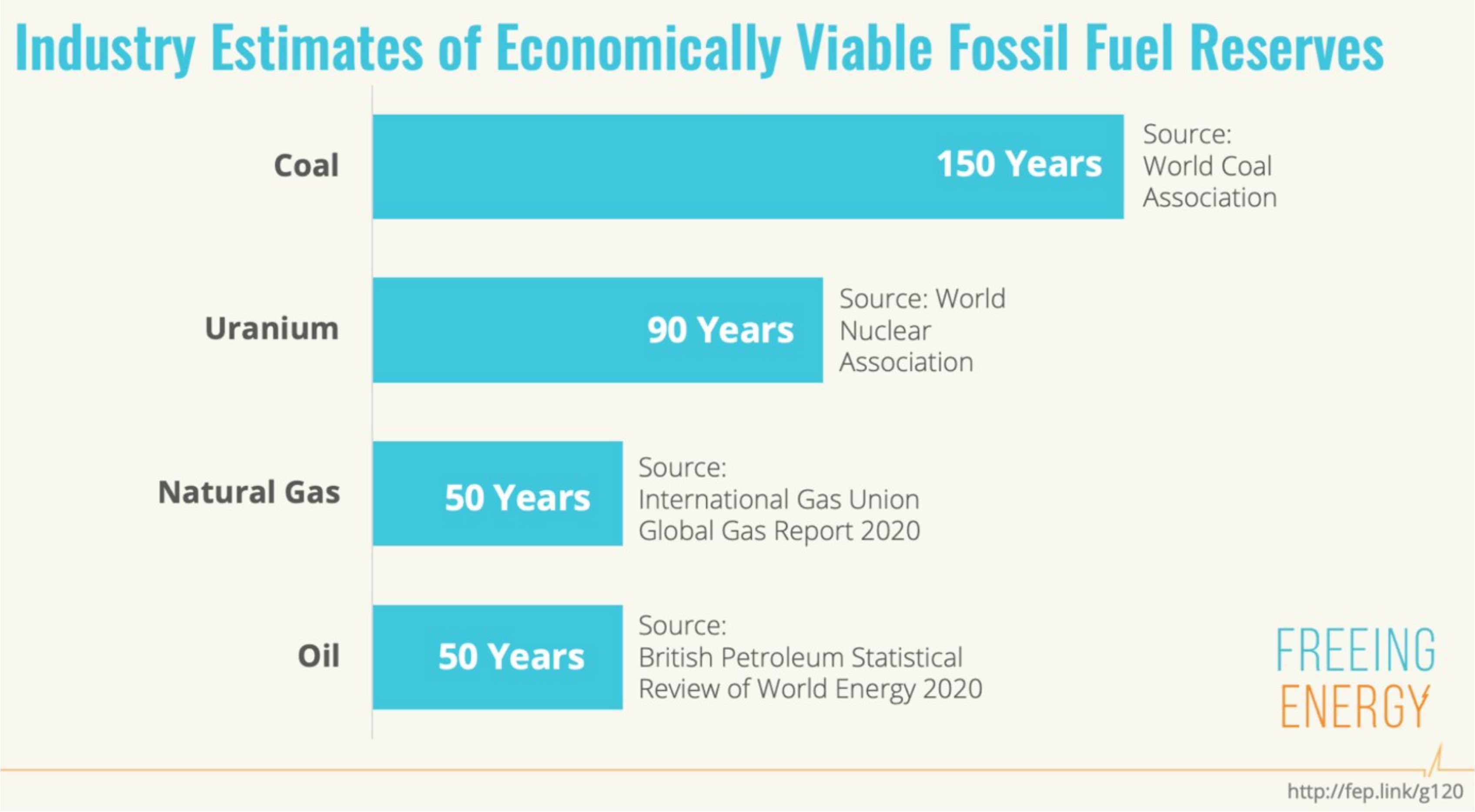
Urban Land Use : Urban areas are expanding rapidly, impacting various aspects of the environment and society.



Depletion of mineral resources : Mineral resource depletion rather focuses on how conditions evolve during exploitation, how the ore grade decreases, and how the industry reacts, for example.



Depletion of fossil fuels : The exhaustion of fossil fuel resources is a drawback of fossil energy. Fossil energy resources were produced millions of years ago and are limited in quantity, making them non-renewable on a human time scale, which can be problematic given human dependence on this energy.



Environmental Declarations

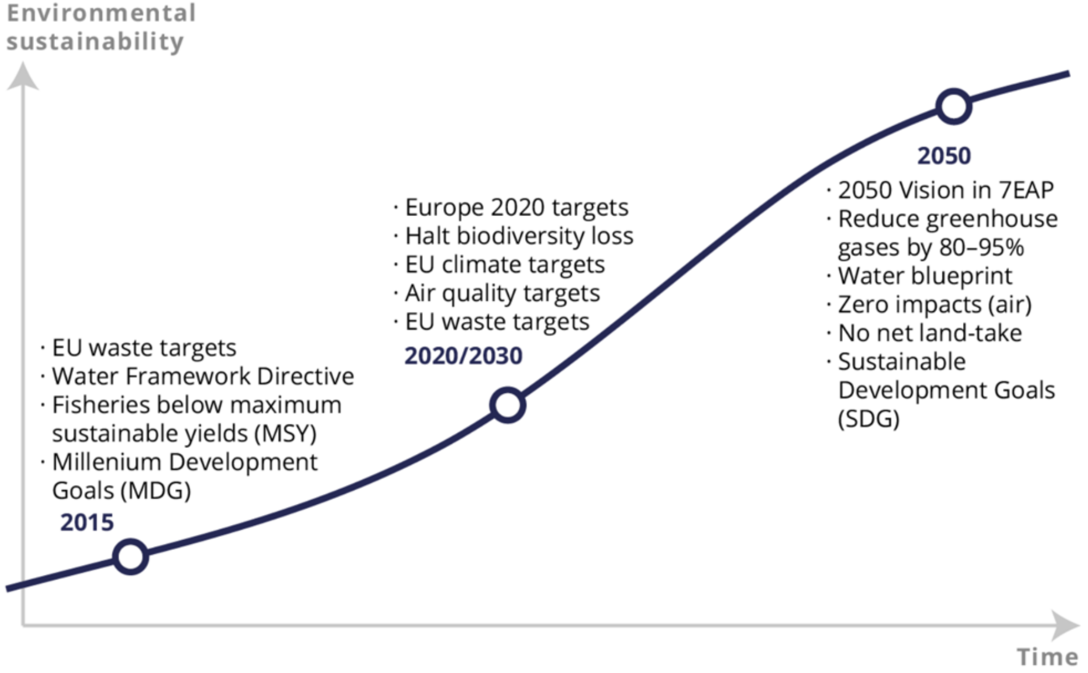
Three forms of environmental declarations are regulated by the family of ISO 14020 standards, which deals with environmental labeling of products, along with communication about the environmental aspects of products and services :

EU Ecolabel www.ecolabel.eu www.ecolabel.eu	ISO 14024 Environmental labels and declarations (Type I environmental labelling)
www.recycle-more.co.uk	ISO 14021 Self-declared environmental claims (Type II environmental labelling)
EPD® www.environdec.com	ISO 14025 Environmental labels and declarations (Type III environmental declarations)

Environmental Regulation in Europe

The EU has developed a comprehensive framework of environmental legislation covering various aspects such as air and water quality, waste management, biodiversity conservation, and climate change mitigation.

Figure 1.1 Long-term transition/intermediate targets related to environmental policy



2015	Thematic policies, timelines and deadlines
2020/2030	Comprehensive policies (Europe 2020, 7th Environment Action Programme), or specific target
2050	Long-term visions and targets with a societal transition perspective

Source: EEA, 2014m.