EV14 - MODELLING OF HUMAN - TECHNICAL SYSTEMS - NATURE INTERACTIONS

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Table des matières

Objectifs 6
Introduction 7
1. History and Epistemology of Anthropocene Sciences 8
1.1. How does Earth System Sciences (ESS) Evolve ? 8
1.2. What is Anthropocene ? 11
1.3. When does the Anthropocene Start ? 11
1.4. What is the History of the Anthropocene ? 12
1.5. The present situation of the Anthropocene 12
1.6. How do they measure the Anthropocene ? 13
1.6.1. Human activities 13
1.6.2. Earth statement 13
1.7. How do the scholars approach to the Anthropocene ? 14
1.8. What are the measures of the Anthropocene ? 14
1.9. Interpretations of the Anthropocene 15
2. Abiotic ressources 18
2.1. Introduction 18
2.1.1. General caracterizations 18
2.1.2. Médias 20
2.2. Consomption of abiotic resources 20
2.2.1. Main threads of the course 20
2.2.2. Metals 21
2.2.3. Oil 26
2.3. Extraction of abiotic resources 28
2.3.1. Reserves 29
2.3.2. Metals focus 29
2.3.3. Oil focus 32
2.3.4. Medias 34
2.3.5. Impacts of extractive activities 35
2.4. Perspectives of abiotic resources 41
2.4.1. A matter of Stocks 41
2.4.2. A matter of Flow 51
2.5. Bibliography 61
3. Carbon Cycle 65
3.1. Introduction to carbon 65
3.1.1. Why are we talking about carbon? 65
3.1.2. What is the link with the project? 65
3.1.3. What will you learn? 66
3.1.4. What is carbon? 66

3.1.5. Reminder : Earth's Layers 67
3.1.6. Media 68
3.2. Carbon Reservoirs 68
3.2.1. The concept of reservoir 68
3.2.2. Carbon reservoirs 69
3.2.3. Media 72
3.3. Carbon cycle 73
3.3.1. Short cycle 73
3.3.2. Long cycle 80
3.4. Anthropogenic activities and carbon cycle 82
3.4.1. Disruption of the carbon cycle-causes 82
3.4.2. Disruption of the carbon cycle-environmental issues 83
3.4.3. Disruption of the carbon cycle-social issues 87
3.4.4. Conclusion 90
4. Nitrogen Cycle.. 91
4.1. Introduction 91
4.1.1. Why nitrogen is important to life ? 92
4.1.2. Medias 93
4.2. Natural nitrogen cycle 93
4.2.1. Biological fixation 93
4.2.2. Mineralization 94
4.2.3. Assimilation by plants 94
4.2.4. Nitrification 94
4.2.5. Denitrification 95
4.2.6. The role of lightning 95
4.2.7. QCM 96
4.2.8. Medias 96
4.3. Anthropogenic nitrogen cycle 96
4.3.1. Conclusion 98
4.3.2. Medias 99
4.4. Outflows and nitrogen cascade 99
4.4.1. Medias 102
4.5. Environmental Impacts 102
4.5.1. 1. Health impacts 104
4.5.2. Ecosystems 105
4.5.3. Water Pollution 106
4.5.4. Soil pollution 109
4.5.5. Nitrogen as a threat to biodiversity 112
4.5.6. Medias 113
4.6. Bibliography 113

5. Phosphorus 116
5.1. Introduction 116
5.1.1. Why do we talk about phosphorus ? 116
5.1.2. How was phosphorus discovered ? 117
5.1.3. What is phosphorus ? 117
5.1.4. Where is phosphorus ? 118
5.1.5. Why and how humans use phosphorus ? 119
5.2. Phosphorus cycle 120
5.2.1. The cycle 120
5.3. Anthropogenic phosphorus input 121
5.3.1. Why phosphorus became toxic ? 121
5.3.2. Why is it important ? 122
5.3.3. Current phosphorus dependency 123
5.3.4. Prospective of phosphorus demand 124
5.3.5. A new war on phosphorus ? 124
5.3.6. How can we ensure the safety of phosphate supplies? 125
5.3.7. Sustainable management of phosphorus 125
5.4. Bibliography 126
6. Ecology 128
6.1. Introduction 128
6.1.1. What does “nature” mean ? 128
6.1.2. What is ecology ? 128
6.2. Ecosystem, it's structure and functions 129
6.3. Ecosystems, organized entities resulting from the action of ecological factors: the structure of ecosystems 129
6.4. Interactions between the populations of the biocenosis: the interspecific relations 130
6.5. Bibliography 131
7. Humains needs and sustainility........ 133
7.1. What are the needs we are talking about? 133
7.2. Human needs and sustainability 133
7.3. The question which human needs compatible with a Sustainable development (SD) ? 134
7.4. How will its needs make it possible to achieve sustainability ? 134
7.5. How are its needs useful to move towards sustainability ? 135
7.6. Could one lead be to reappropriate the technique to promote the satisfaction of “ lean ”needs and regain one's autonomy ? 137
7.7. And should we give a "value" to nature? 137
7.8. A brief reminder of the values of the sustainable development concept 138
7.9. Reflexivity 138
7.10. Citizen participation 138
8. Digital technological case study........ 139
8.1. Documents 139
8.2. What to do 139

9. Infrastructure case study 141
9.1. Documents 141
9.2. What to do 142
10. TD on waste 144

Objectifs

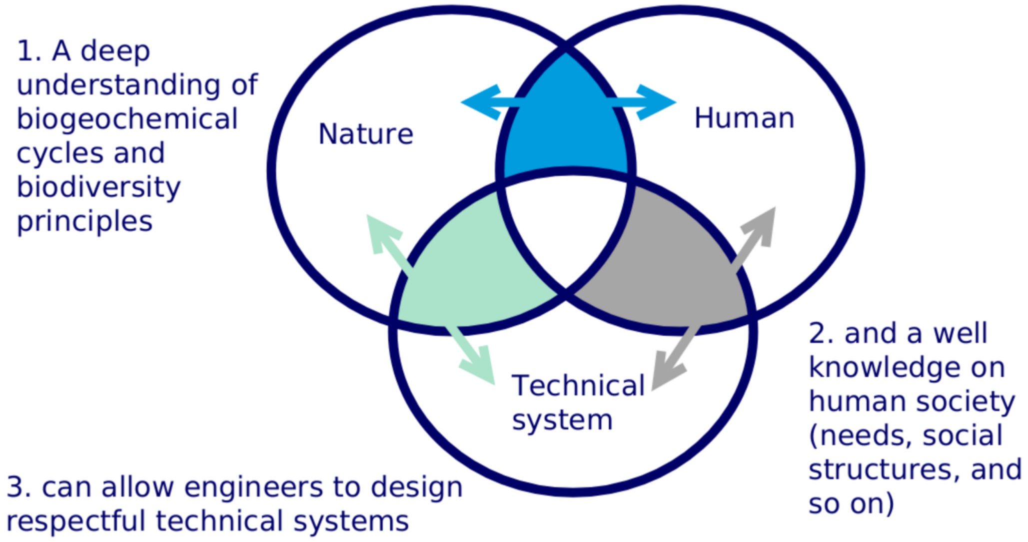
1) Understanding ecosystem functioning and associated Issues
2) Understanding humans organizations and associated issues
3) Being able to model Human - System - Nature interactions

Introduction

The class is in **english** and is organised into 3 blogs :

1. on environmental aspects,
2. on social aspects,
3. on the representation of Human - System - Nature interactions

Why are we studying HSN interactions ?



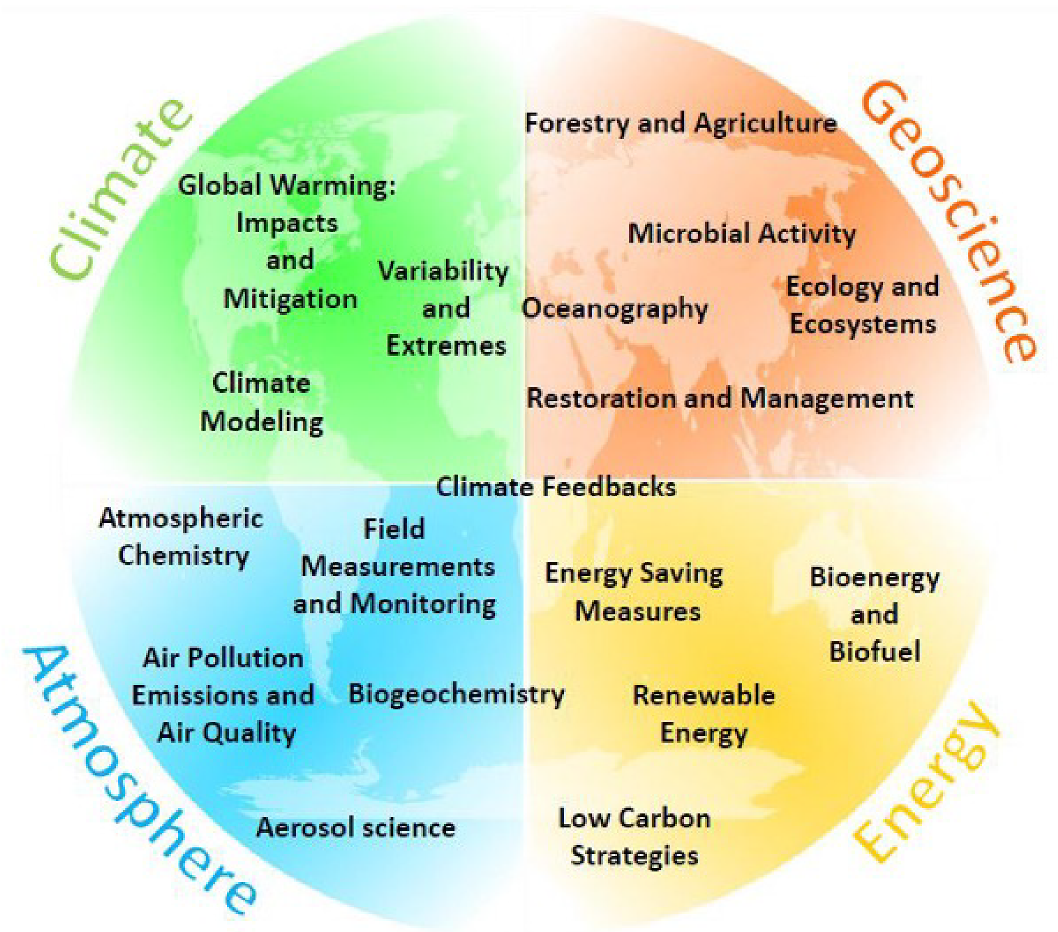
1. History and Epistemology of Anthropocene Sciences

1. To understand the process of accumulating human knowledge about the Earth system .
2. To highlight the importance of the key concepts of the Earth system being proposed and discovered in the process of accumulating knowledge .
3. To realize the importance of looking at the Earth system as a whole, from a multidisciplinary perspective, in order to achieve sustainable development for people and nature today.

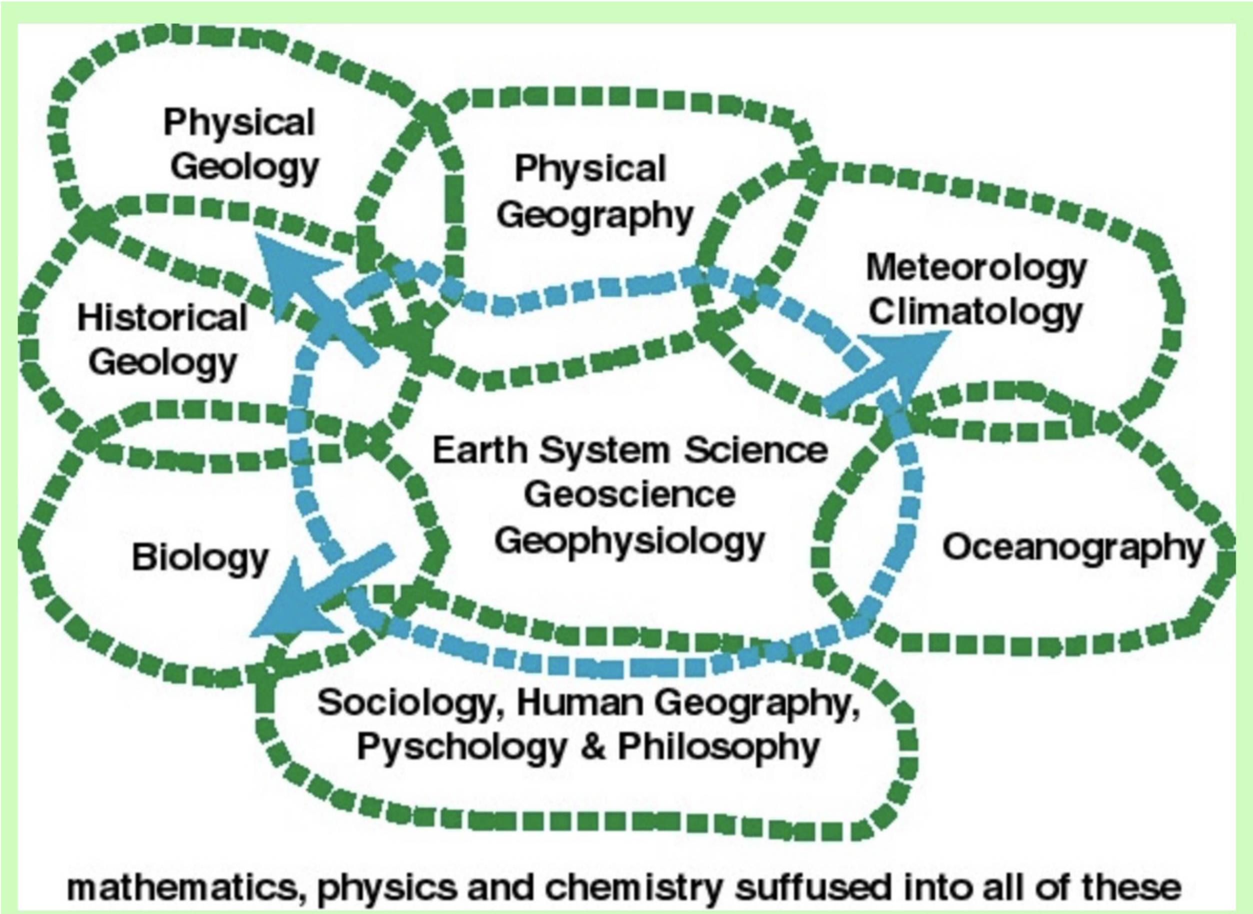
1.1. How does Earth System Sciences (ESS) Evolve ?

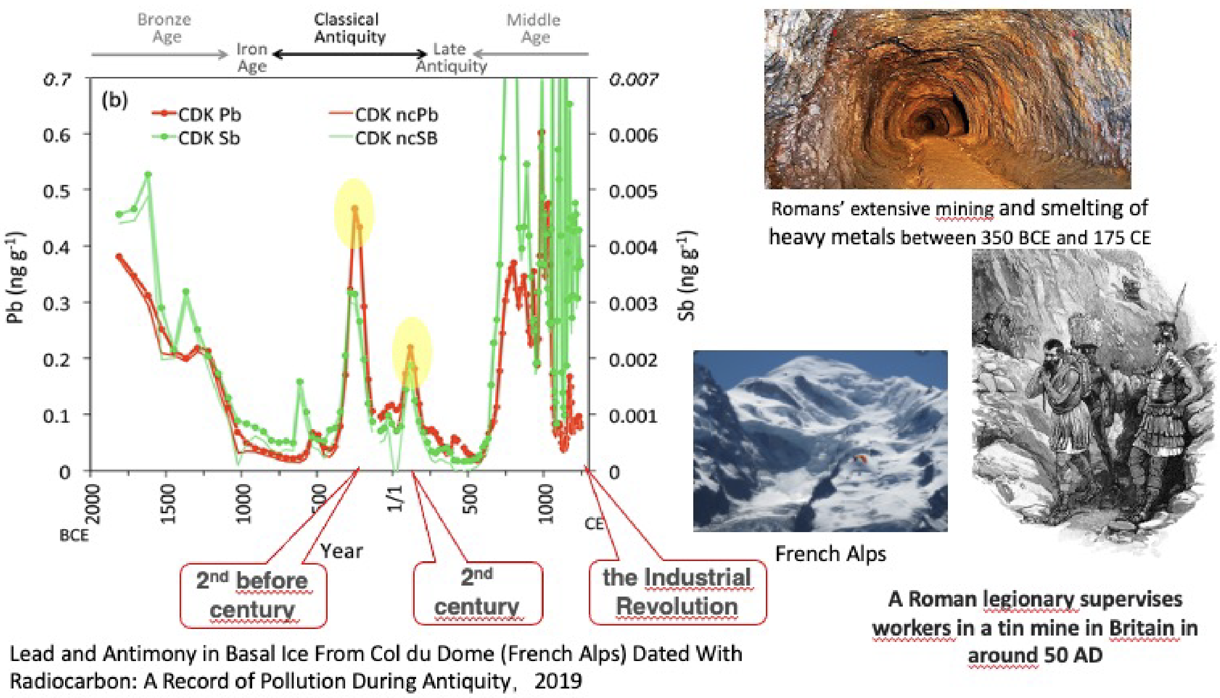
Earth system sciences

- Earth System Science (ESS) is a rapidly emerging **transdisciplinary** endeavour aimed at understanding the structure and functioning of the Earth as a complex, adaptive system. (Will Steffen et. al. 2020)
- Transdisciplinary endeavour



http://www.phd-ess.org/





The development of ESS is the evolution of humans understanding of global change.

History of Earth system sciences

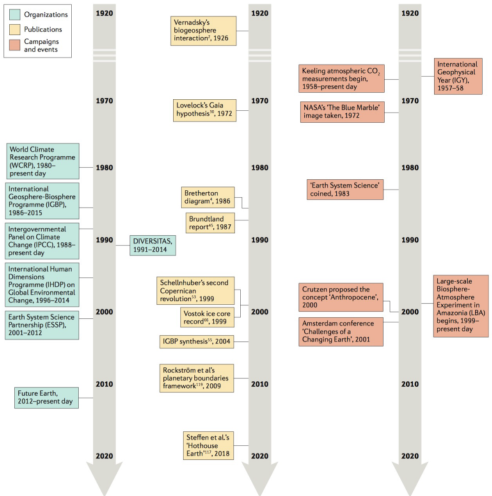
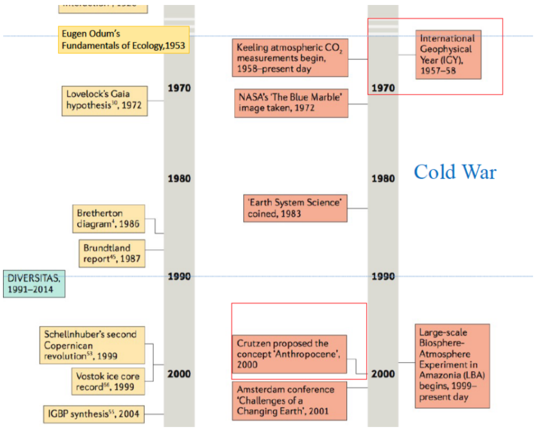


Fig. 1 | **Timeline illustrating the development of Earth System Science from the mid-20th century.** The figure shows the key organizations, events and concepts that have helped to define and develop Earth System Science.

- Vernadsky 'The Biosphere'



- International Geophysical year
- Eugene Odum , Father of Modern Ecology
- Gaïa Hypothesis
- The Bretherton Diagram

The wisdom accumulated in this process has introduced new concepts and theories that have altered our understanding of the Earth System, particularly the disproportionate role of humanity as a driver of change.

One of the most influential concept is that of the Anthropocene.

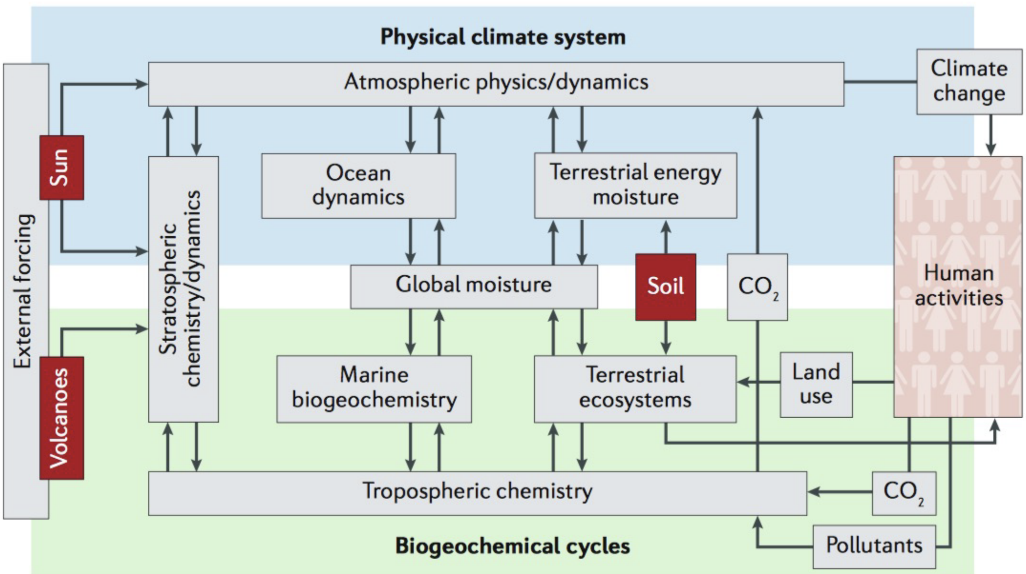


Fig. 2 | **The NASA Bretherton diagram of the Earth System.** The classical, simplified depiction of the Earth System and its interactions. The focus is on the interactions between the geosphere and the biosphere, with human forcings represented as an outside force affecting the geosphere–biosphere system. Reproduced with permission of National Academies Press from NASA (1986) Earth System Science Overview. A program for global change. Prepared by the Earth System Sciences Committee, NASA Advisory Council. 48pp. (REF.[4]), permission conveyed through Copyright Clearance Center, Inc.

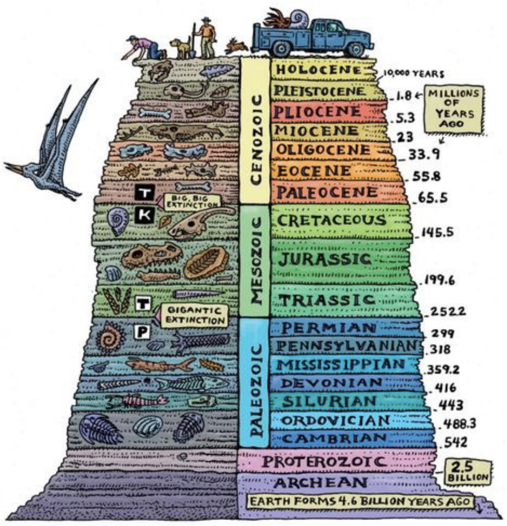
One result from NASA ESSC is The Bretherton diagram, which epitomized the rapidly growing field of ESS through its visualization of the interacting physical, chemical and biological processes that connect components of the Earth System and through the recognition that **human activities were a significant driving force** for change in the system.

1.2. What is Anthropocene ?

Définition Anthropocene

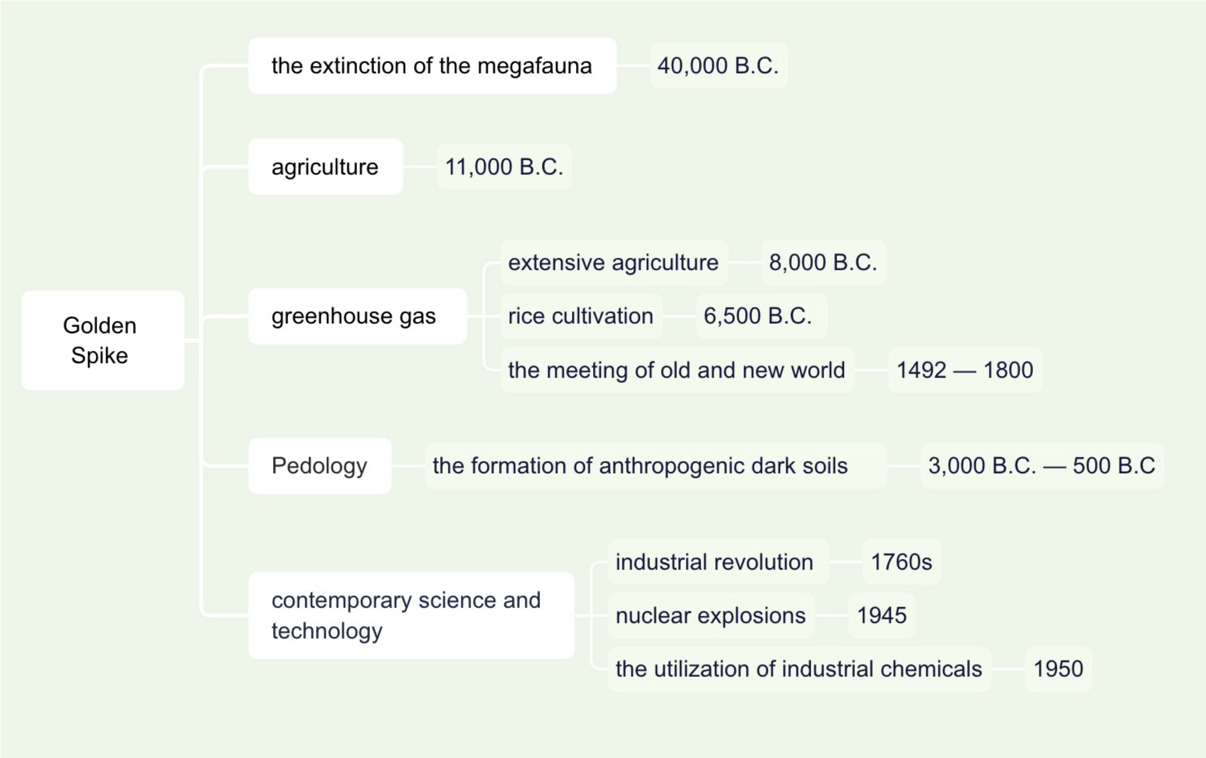
> The **Anthropocene** is a concept that designates a state of the planet in which key natural systems are coupled with social systems at a global level, thus influencing Earth system as a whole, thereby turning the human species into a global geophysical force that put the future habitability of the Earth into question (Steffen et al., 2007).

1.3. When does the Anthropocene Start ?



The **Anthropocene** is a proposed new geological epoch dating from the commencement of significant human impact on the Earth system.

- Crutzen, Nature, 2002



- Gemenne et al., 2019.12 Atlas de l'Anthropocène

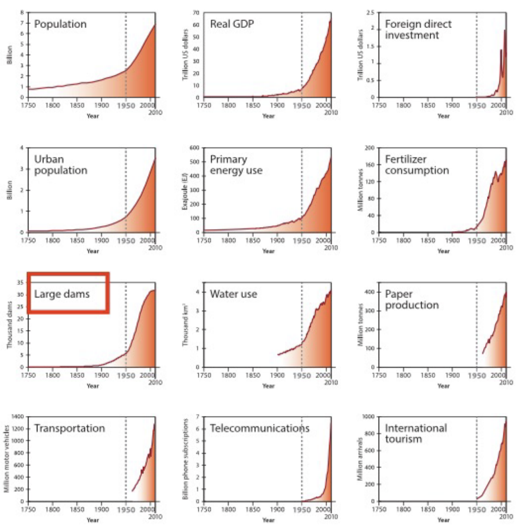
1.4. What is the History of the Anthropocene ?

Wayne Hayes, 2014

1.5. The present situation of the Anthropocene

1.6. How do they measure the Anthropocene ?

1.6.1. Human activities



Socio-economic trends - 12 indicators

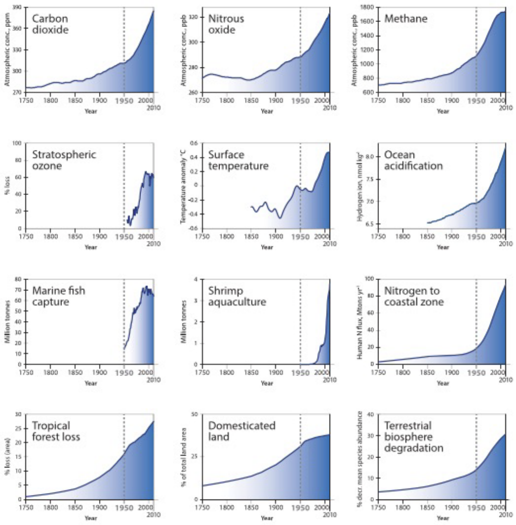
Figure 1. Trends from 1750 to 2010 in globally aggregated indicators for socio-economic development.

(Will Steffen et. al 2015)

The Earth System indicators, in general, continued their long-term, post-industrial rise, although a few, such as atmospheric methane concentration and stratospheric ozone loss, showed a slowing or apparent stabilisation over the past decade. The post-1950 acceleration in the Earth System indicators remains clear.

From the perspective temporality, only beyond the mid-20th century is there clear evidence for fundamental shifts in the state and functioning of the Earth System that are beyond the range of variability of the Holocene and driven by human activities.

1.6.2. Earth statement

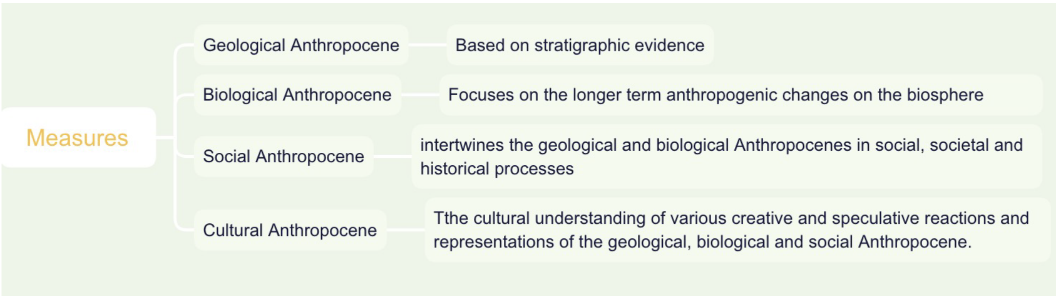


Earth system trends - 12 indicators

Generally, the dominant feature of the socioeconomic trends is that the economic activity of the human enterprise continues to grow at a rapid rate, especially after 1950s.

Figure 3. Trends from 1750 to 2010 in indicators for the structure and functioning of the Earth System.

1.7. How do the scholars approach to the Anthropocene ?



The social Anthropocene is a socioenvironmental approach in which the evolution of human–nature relations are investigated within the context of past, present and future social structures. The perspective produces knowledge on how the changes in biosphere are connected to both world-systemic as well as national and regional social hierarchies, power and economic structures or political interests.

Culture : the set of values, ideas, beliefs and practices that are functioning on all areas of human life.

T Toivanen, et al., 2017

1.8. What are the measures of the Anthropocene ?

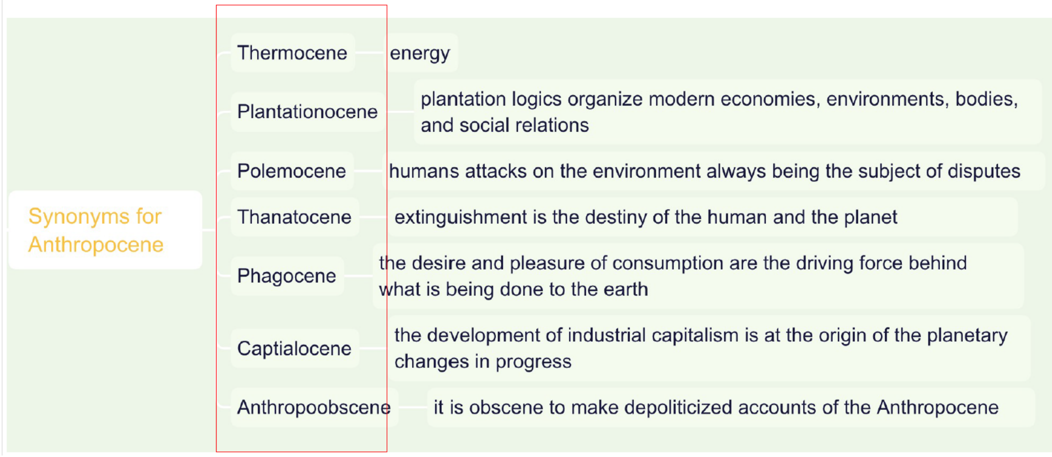
Social Anthropocene =>

- Can identify, problematize and popularize the economic, political and ideological barriers that stand in front of sustainable pathways.
- Can contribute to innovate, establish and rearrange the institutional arrangements that structure the economy, social life and environmental relations.

Social Anthropocene et cultural Anthropocene =>

- Create more discerning models for understanding human involvement in the Earth's processes (and the Earth's involvement in human processes);
- Point to the diverse social and cultural phenomena resistant to modelling and develop alternative methods to research such phenomena. (repressed or denied beliefs and ideological commitments, narratives of individual or collective identity or destiny, ideas about rights and responsibilities, and other forms of individual and collective thought that underlie human action)

1.9. Interpretations of the Anthropocene



Bonneuil and Fressoz, 2016 The Shock of the Anthropocene : The Earth, History and Us.

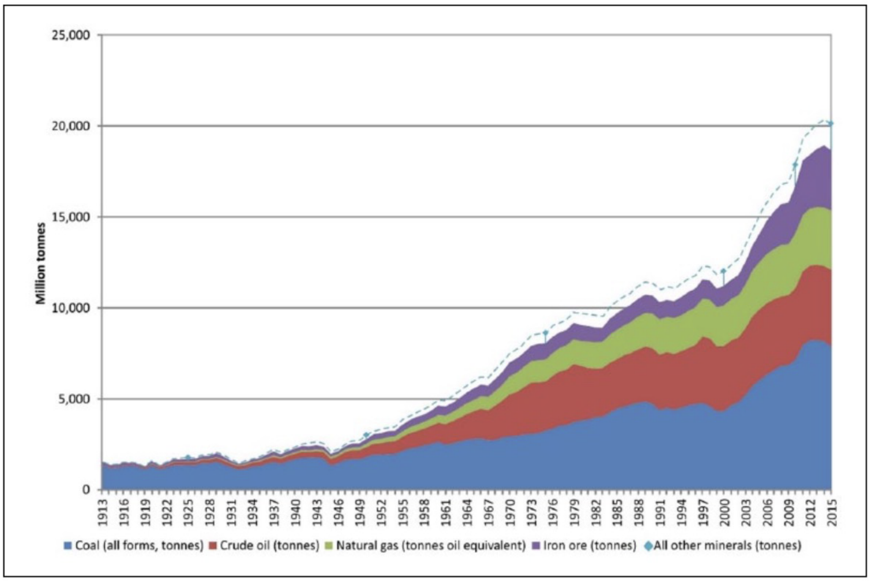


Figure 1. World production of coal, crude oil, natural gas and iron ore, with all other minerals (except for construction aggregates) interpolated between key year intervals.

(Anthony H Cooper et. al 2018)

- By 2015, the most significant by mass of world production are coal 39%, oil 21%, and natural gas 16% ;
- Over time, the production amounts of coal, crude oil, and nature gas has been increasing.
- Where was the energy transition?

Thermocene

- Bonneuil and Fressoz contest that the truth of the seeming energy transition in the history of energy is successive **additions** of new sources of primary. It is the confusion between relative (the use of coal decreased in relation to oil) and absolute (the consumption of coal remains continually grew), between local and global that creates this illusion.
- Energy transitions “follow neither an internal logic of technical progress, nor a logic of scarcity and substitution, nor even a logic that was simply economic, and history of energy is above all one of political, military and ideological choices that involve with strategic interests and objectives of certain social groups”.

Plantationocene

- Estimates suggest that 75 million acres of land worldwide have been sold or leased in the past decade to foreign investors for large-scale oil palm, rubber, and other agricultural concessions.
- The plantation, as Sidney observed, was a “synthesis of field and factory,” an agro-industrial system of enterprise integral to the historic rise and growth of capitalism.

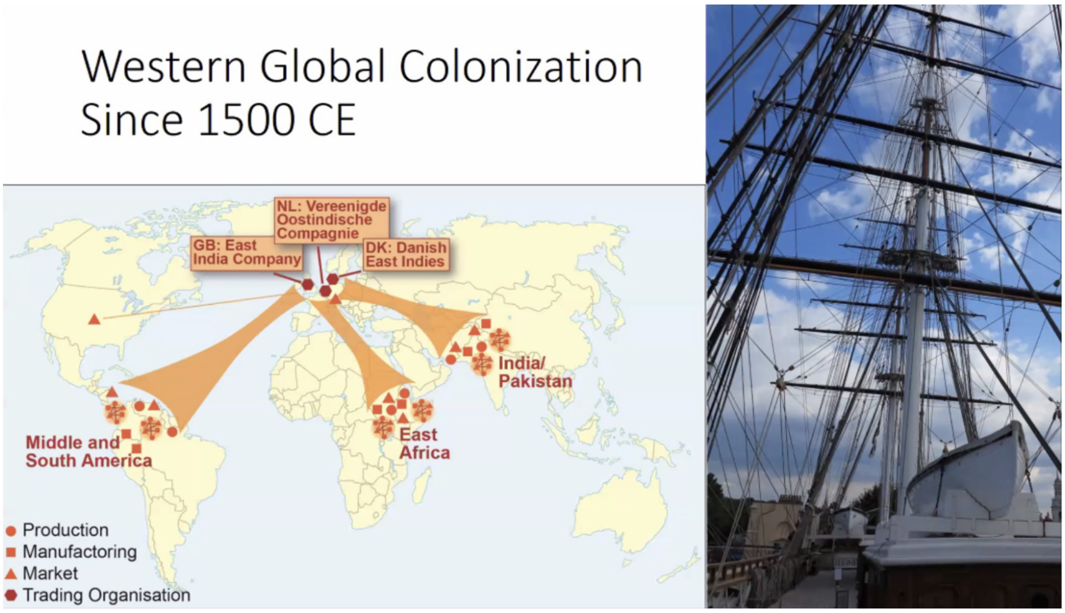
Rubber seedlings await planting on a concession granted to Firestone

Tire & Rubber Company by the Liberian government in 1926. Firestone’s

99 year lease for up to one million acres of land in Liberia paved the

way for the current wave of land concessions to foreign investors in

Liberia. Photo by Gregg Mitman.



Rüdiger Glaser, 2021

Polemocene

- It re-evaluates criticisms of anthropocenic action since the dawn of industrialisation.
- It is a history of socioecological struggles and challenges to the damages of industrialism, where people defend the forest, its rights of usage and the planet, people question machines and mass production, people are opposite to innovations. Bonneuil and Fressoz

use this 'cene to emphasize a long history of political struggle motivated by social justice and "environmentalism of the poor". Despite of this resistance, they failed to prevent industrialism's expansion from the Industrial Revolution through the Cold War to today.

Thanatocene

- It is the natural history of destruction. a teleological view that, extinguishment is the destiny of the human and the planet that is now in the stage of intense destruction, which owes to the global mobilizations of the Second World War.
- As the twentieth century progressed, wars became both deadlier and more frequent. Troops were supported, and to a certain degree replaced, by extraordinarily powerful machines, technological and logistic systems. War machines that required growing quantities of raw materials and energy had an unprecedentedly heavy impact on the environment.
- The contemporary aircraft industry is likewise a product of the Second World War, both technologically (aluminium, radar, jet engines) and institutionally. The Second World War thus prepared the technological and legal framework for mass-consumption society.

Phagocene

- This interpretation revolves around consumerism. Consumerism is a social and economic order that encourages people to acquire goods and services in ever-increasing quantities. With the advent of the Industrial Revolution, the supply of goods outstrips consumer demand, as a result of mass production led to overproduction, so manufacturers turned to planned advertising to manipulate consumer spending.

Captialocene

- From the perspective of captialocene. The last three centuries have been characterized by an extraordinary accumulation of capital: despite destructive wars, this grew by a factor of 134 between 1700 and 2008. The dynamic of capital accumulation gave rise to a 'second nature' made up of roads, plantations, railways, mines, pipelines, wells, power stations, futures markets and container ships, financial positions and banks that structure flows of matter, energy, goods and capital on a world scale. It is this profit-oriented technostructure that swung the Earth system into the Anthropocene. The change in geological regime is the act of the 'age of capital', rather than simply the 'age of man' as the dominant narratives claim.

Anthropoobscene

- One view from Anthropo-obscene is that it is impotant to make depoliticized accounts of the Anthropocene. This concept could be listed on top 10 most difficult terminology in Anthropocene. It is a reflection of the reflection on the Anthropocene. The debate on the Anthropoobscene tries to figure out whether the interpretation of Anthropocene is associated with politics. For example, scholar Erik Swyngedouw attempts to defense that the matter of ecology is fundamentally de-politicised. And he clams that the "political" cannot and should not be grounded on the eventual truth of the Anthropocene.

• *Gemenne et al., 2019.12 Atlas de l'Anthropocène*

• *Sophie Sapp Moore 2019, 1 Plantation Legacies*

2. Abiotic ressources

2.1. Introduction

Définition « Abiotic ressources » [1]

- Firstly, ***biotic resources*** refers to ressources coming from living things, or more precisely, organic matter. Ex: animals, plants.
- Consequently, **abiotic resources** refers to all ressources but biotic ones. So, it encompasses minerals, but also air, water, sunlight, etc.
- Fossil fuels can be classified either as biotic or abiotic resources, depending on the timescale considered. Indeed they're coming from living things, resulting of bio-geo-chemical cycles, but were definitvely formed milllion years ago. In EV14, we'll consider them as abiotic.

But what even are « resources »? [1]

- Surprisingly, it is not often explicitly defined, even in major texts. Ex: ISO 14040 norm (giving framework for all Life-cycle analysis), or the classical 1983 report of the United Nations.
- Analysis of varied definitions highlights some converging points: a resource is considered as such if :
  - It has an value or utility (from material properties for an industrial process to cultural valorization of precious stones)
  - For a certain subject (generally considered: the humans)

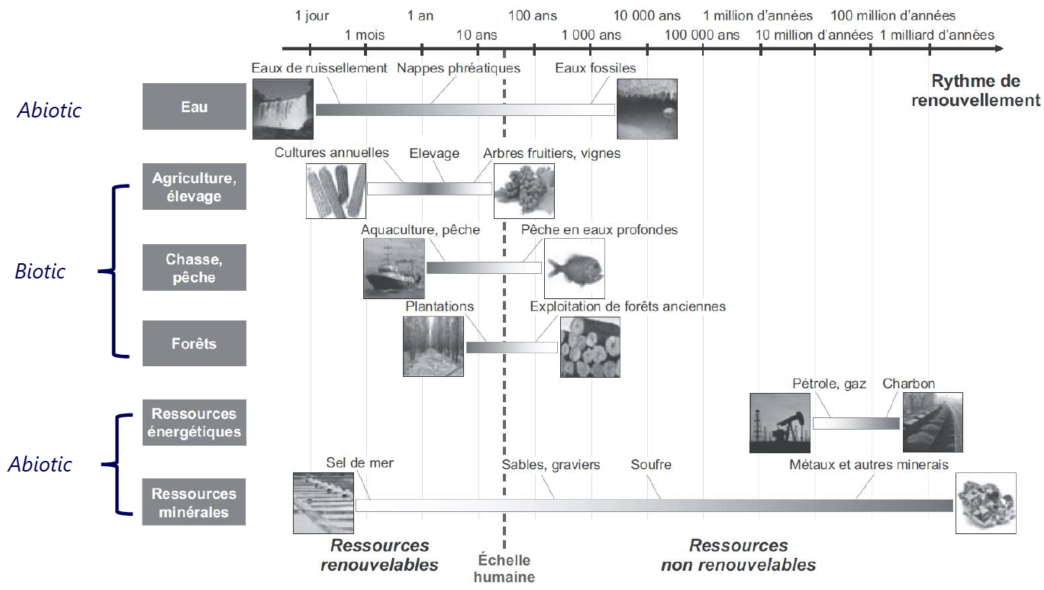
[1] BEYLOT, A. et al, 2020. DOI 10.1016/j.resconrec.2020.104748

2.1.1. General caracterizations

a)The renewable/non-renewable polarity [2]

- Renewable when the stock reconstitutes itself at a « sufficiently quick rate ». Usual threshold: timespan of a human life.
- Non-renewable when they constitute themselves on a long period of time, way longer than a human life. Their use is always a depletion in available stocks.

Extracted from [3]



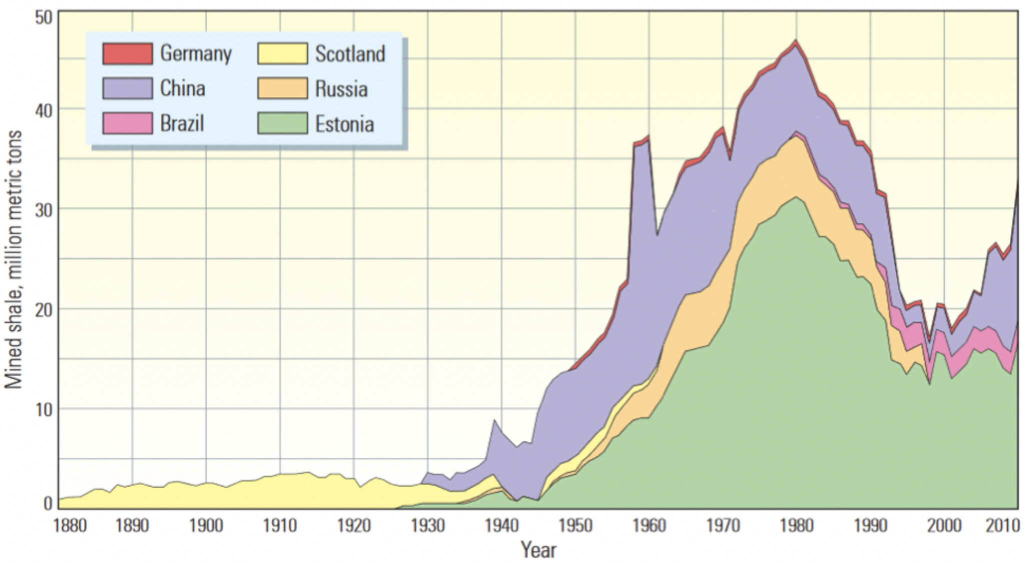
[2] Resource, 2020. *Wikipedia*[online].

[3] BIHOUIX, P., GUILLEBON, B., 2010. *Quel futur pour les métaux.*

b)The availability/non-availabilitypolarity

- Available when concentration and position let them be technically AND economically usable by humans.
- More or less available according to the variation of these dimensions. Ex: Oil shale in the XXth, depending on stocks' concentrations and competition with conventional crude oil. [4]and [5]

Extracted from [6]



^ More than a century of commercial oil shale mining. Tonnage of mined shale rose dramatically in the 1970s when oil prices were also rising; it peaked in 1980, but declined as oil prices made shale oil noncompetitive. Several countries continue to mine oil shale as a source of heat, electricity, liquid fuel and chemical feedstock. Since 1999, mined shale tonnage has started to increase again.

[4] History of the oil shale industry, 2020. Wikipedia [online].

[5] Allix et al., 2010. Coaxing Oil from Shale. Oilfield Review [online]. 2011.
[6] BP, 2020. BP Statistical Review of World Energy. [online]. 2020

2.1.2. Médias

https://pod.utt.fr/video/3943-ev14-abiotic-resources-1-intro/

2.2. Consumption of abiotic resources

- Main threads of the course : Metals and Oil
- Metals
  - Brief global history
  - Contemporary trends
- Oil :
  - Brief global history
  - Contemporary trends
- Sociotechnical perspective (Tutorial work)

2.2.1. Main threads of the course

The mineral resource example: Metals

- Why metals? On the 118 known atoms, most of them are metals :[3]
  - 85 metals
  - 6 metalloids
  - 17 non metals
  - 10 non determined
- General properties :
  - electrical & thermal conductors
  - mechanical ductility
- Geological forms: oxides (common) > sulfides (less common) > natives (uncommon)

The energetical resource example: Oil

- Currently, most used source in main primary energy consomption :
  - Oil (33,1%)
  - Coal (27%)
  - Natural gas (24,2%) [6]
- Regroup varied forms of derived fuels (petrol, shale oil) and secondary resources

- General properties: gives a lot of secondary resources when refined, good energy density, easy and convenient to transport and to use as energy vector in varied contexts

2.2.2. Metals

a)Metals global history

A very brief summary [3]

- Contrary to first intuition: native metals were the first to be used. Although uncommon (often mixed) they were ealily recognizable:
  - Copper (at least 8000 BC, and melted since 4000 BC), Gold and Silver (4000 BC)
  - Alloys starting in 2500 BC with Bronze (Tin & Copper)
  - Furnaces since at least 1000 BC let reduce oxides (notably, Iron oxide) and developp experiments on alloys (Steel = Iron + Carbon)
  - Lead, Antimony, Mercury used pure or in allows during Antiquity
- This tiny number of metals has constituted the main uses until the XIXth century and structured economical and geopolitical relationships between populations
  - Besides native platinum in Peru, other metals like Nickel, Zinc, Cobalt have been identified by chemistry and metallurgy (beginning of XVIIIth). And then: Manganese, Molybdenum, Tungsten, Titanium (end of the XVIIIth).
  - Electrolysis in XIXth allows to separate most elements in pure form, but weak rate of use until the XXth century.

b)Contemporary trends

i)Continuous growth in use of base metals

Extracted from [7]

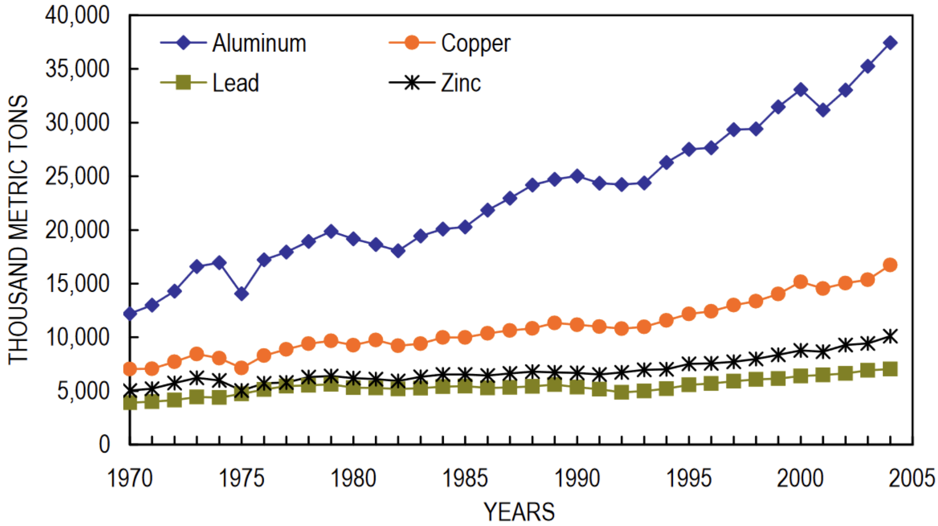


Figure 3. Global aluminum, copper, lead, and zinc consumption.

- Heterogeneous rise of world consumption for base metals: by a factor from ***1,5*** (Lead) to ***3*** (Alumunium)

Extracted from [7]

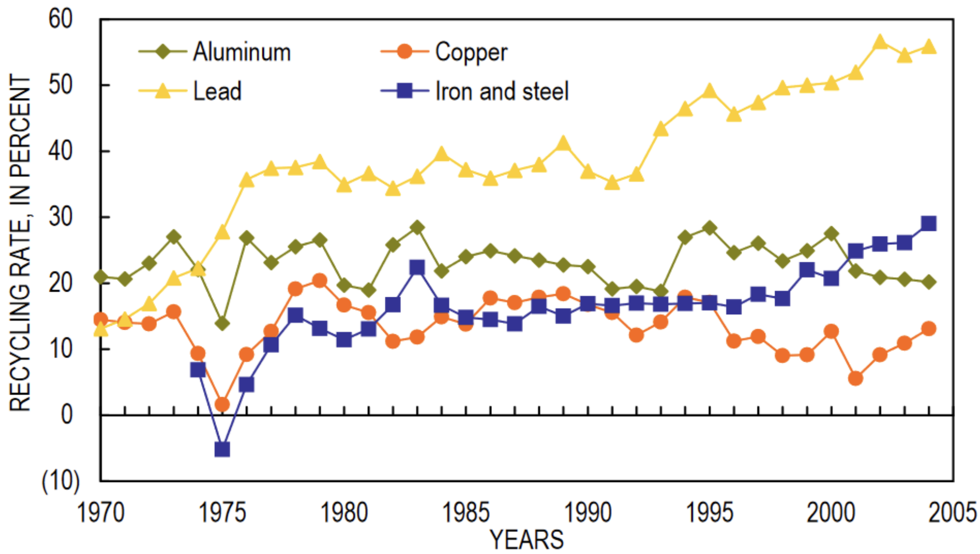


Figure 24. Graph illustrating calculated world metals recycling rates.

- Recycling rates not progressing as much

[7] ROGISH, D.G., and MATOS, G.R., 2008, The global flows of metals and minerals: USGS Open-File Report 2008–1355

ii)Countries high disparities

Extracted from [7]

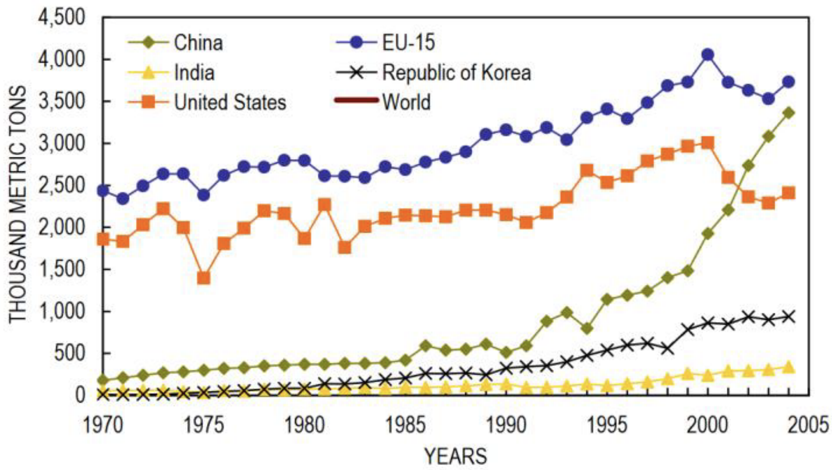


Figure 11. Copper consumption by country.

Extracted from [7]

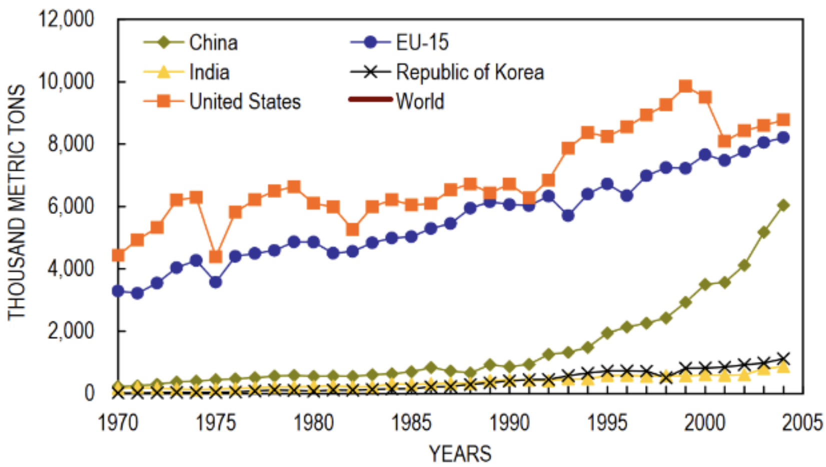


Figure 12. Aluminum consumption by country.

Extracted from [7]

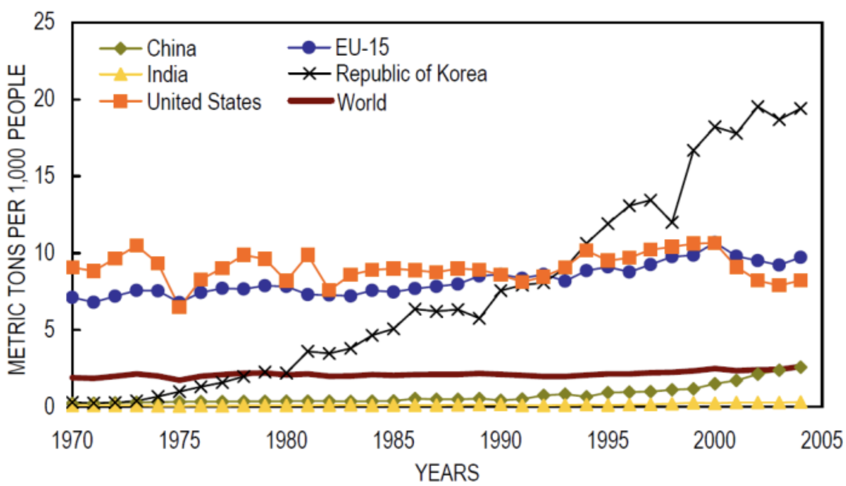


Figure 15. Copper consumption per capita by country.

Extracted from [7]

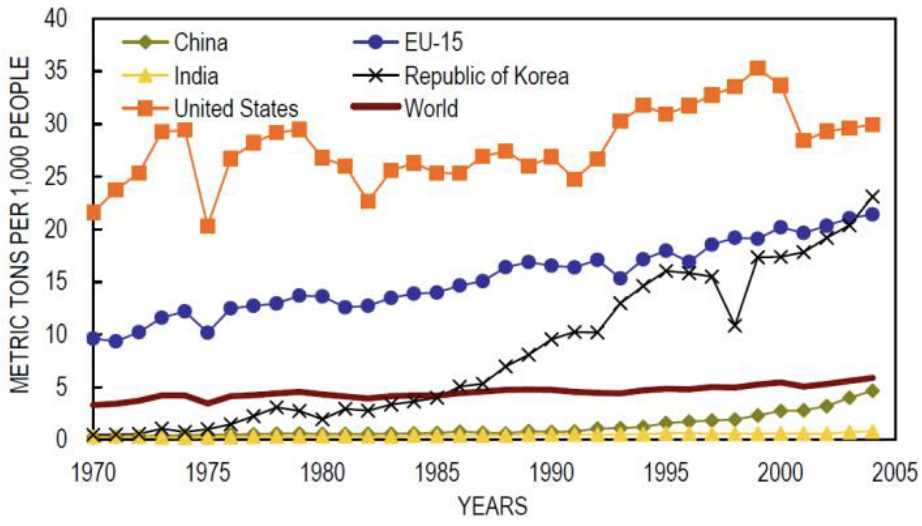
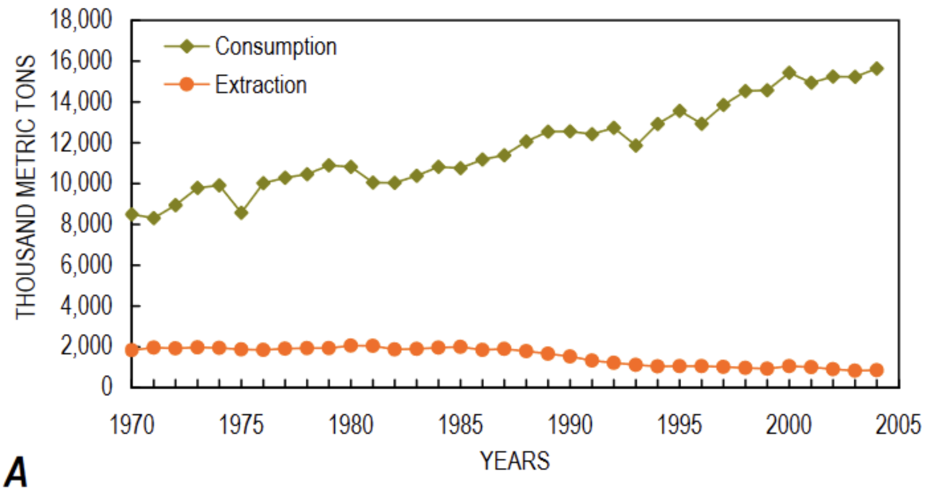
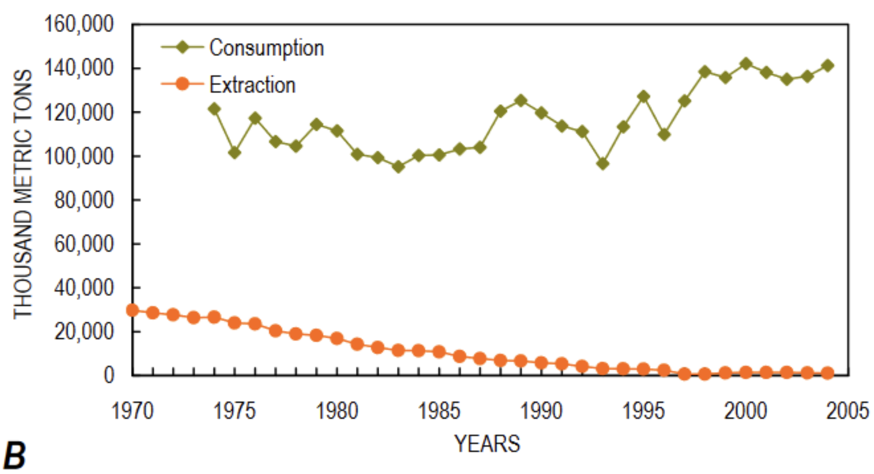


Figure 16. Aluminum consumption per capita by country.

iii)Global Extraction/Consomption pattern



A



B

Figure 18. Consumption and extraction in the European Union group of 15 countries (EU-15). A, Base metals. B, Iron and steel.

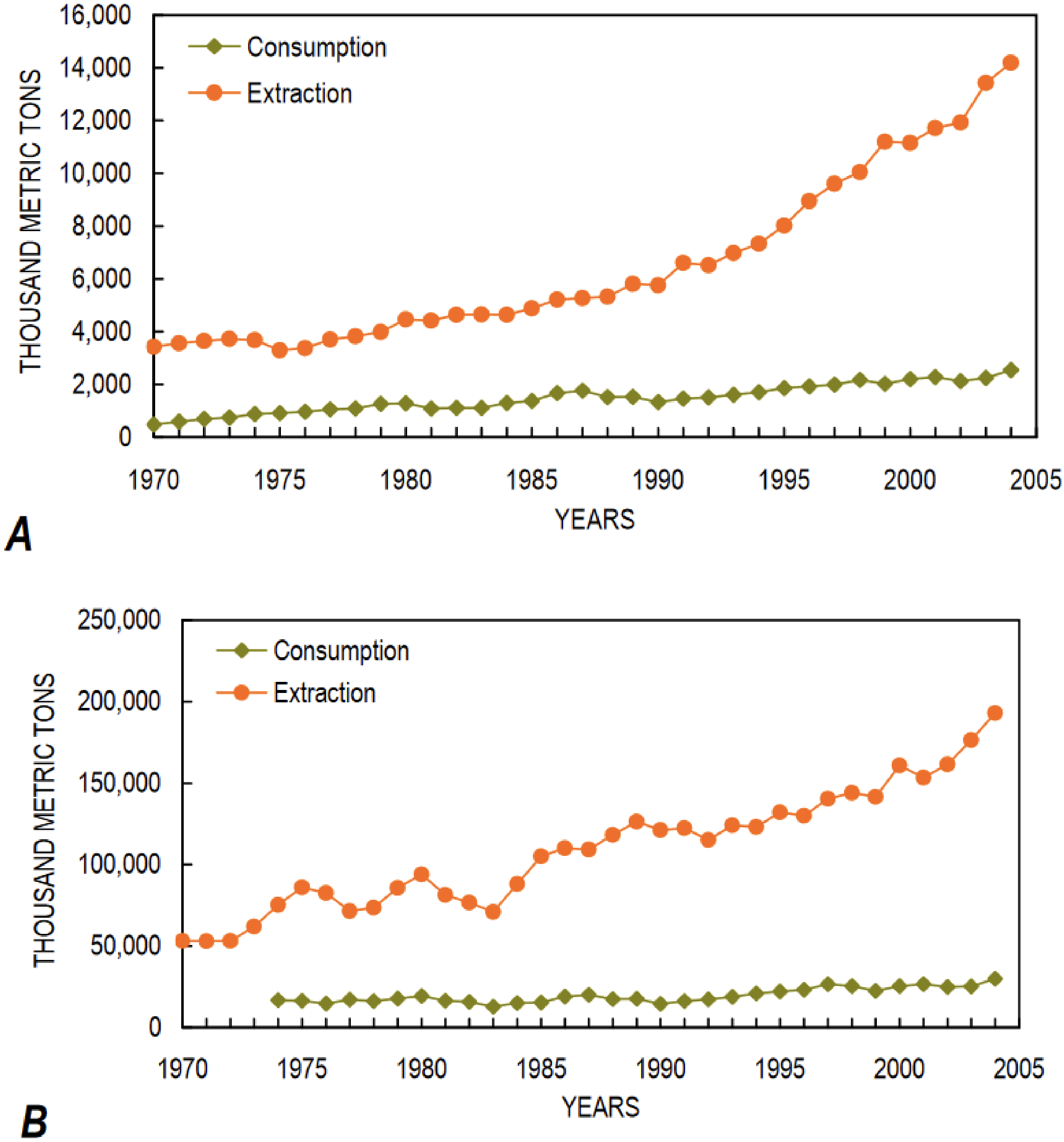
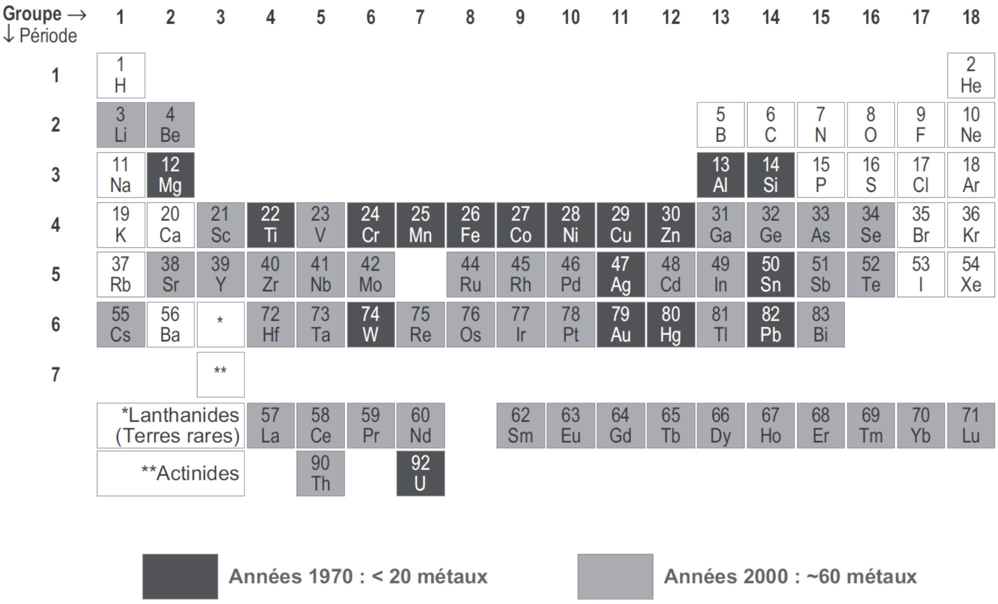


Figure 20. Consumption and extraction in South America. A, Base metals. B, Iron and steel.

iv)Growing variety of metals for expanding specific uses

Adapted from [3]



c)Medias

https://pod.utt.fr/video/3944-ev14-abiotic-resources-2-metals/

2.2.3. Oil

a)Oil global history

A very brief summary [8]

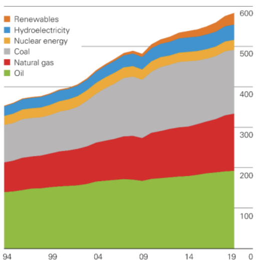
- Oil has been used for a long time in varied forms
    - Used as fuel as back as 400 BC in China
    - Used for lighting or in the asphalt form for construction as back as 2000 BC in Babylon
    - Crude oil already distilled by Persian chemist in 9th century to obtain tar, used for streets' paving
    - Distillation arrive in Europe in 12th century through Islamic Spain
- The mid19th –early20th turning point [9]
    - First industrial oil well and oil refinery around 1850
    - Consomption stayed low (5% of world energy in 1910), as oil as not that interesting at first, compared to wind or animals for transport, solar& coal were largely dominant for thermal power, etc.
    - Complex and crossing technical but mostly political phenomena let oil grew in varied uses, to represent more than60% of world energy as soon as 1970

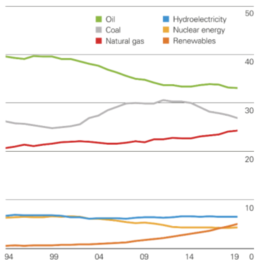
[8] Petroleum, 2020. *Wikipedia*[online].

[9] BONNEUIL, C., FRESSOZ, J-B, 2016. *The Shock of the Anthropocene. The Earth, History and Us*.

b)Contemporary trends

i)No primary energy transition



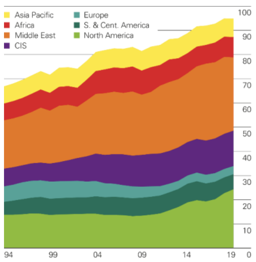


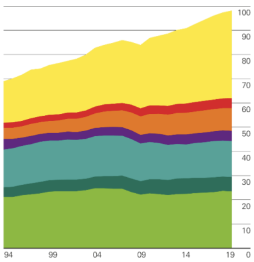
- Oil's share in primary energy is steadily decreasing for more than30 years, but:
  - Oilisstillthe dominant energyvector
  - In absolute quantity, it is not declining at all, as for all energy vectors!

Extracted from [6]

[6] BP, 2020. BP Statistical Review of World Energy. [online].

ii)Three main profiles

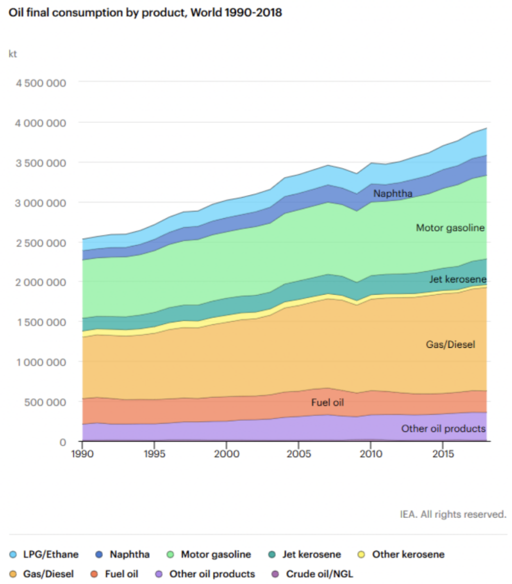


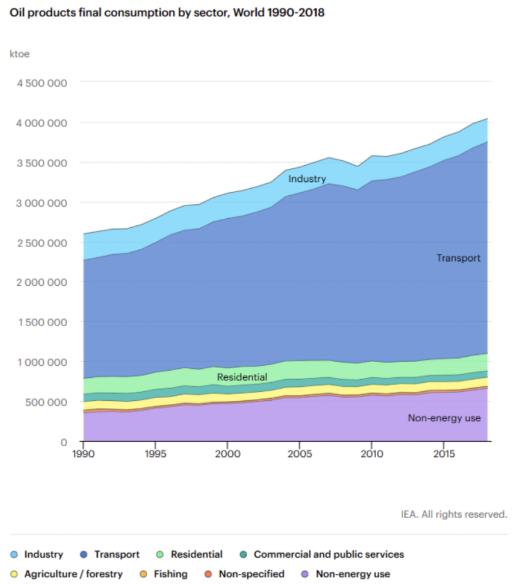


- High ratio of Production/Consomption
- Low ratio of Production/Consomption
- Ratio of Production/Consomption near 1

Extracted from [6]

iii)Consistency of uses





c)Medias

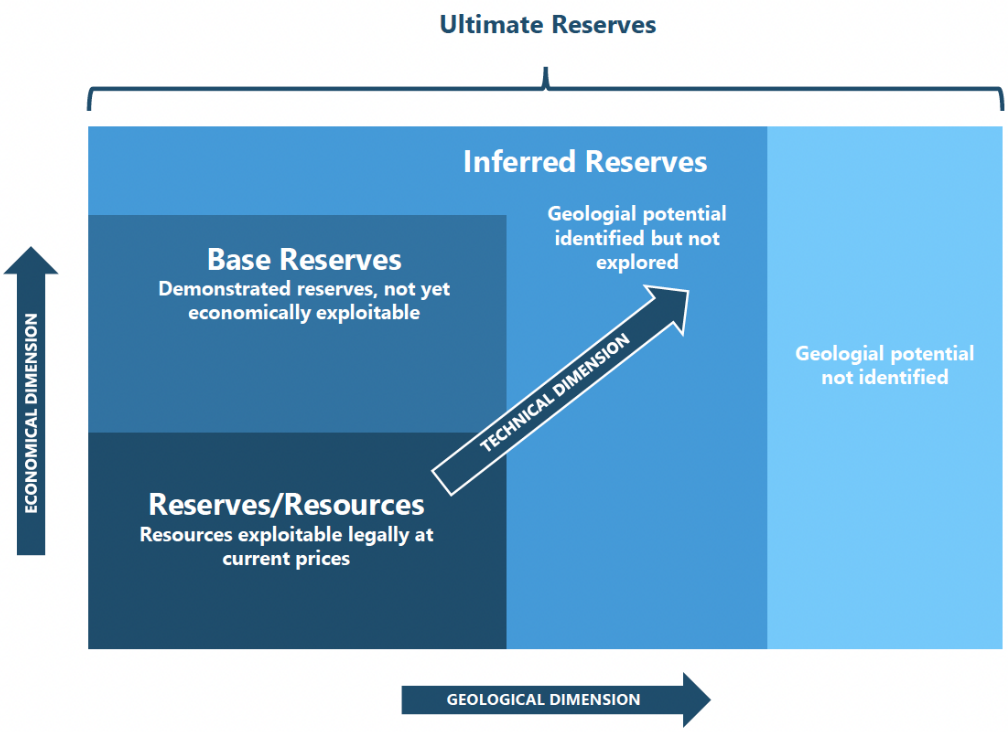
https://pod.utt.fr/video/3945-ev14-abiotic-resources-3-oil/

2.3. Extraction of abiotic resources

- Reserves
  - Definitions
  - Metals focus
    - Concentrations
    - Mineralogical wall
  - Oil focus
    - Assessing reserves
    - Caution in interpretation
- Impacts of extractive activities
  - Growing interdependancies
    - Energy footprint of minerals
    - Material footprint of energy
  - Environmental focus
    - Other abiotic resources: water & air quality
    - Biotic resources: wildlife and land
  - Socio-economical focus
    - Contrasted local realities
    - Global frictions…
    - Rootedin historical inequalities

2.3.1. Reserves

Définition



Adaptated from [3]

[3] BIHOUIX, P., GUILLEBON, B. ,2010. *Quel futur pour les métaux?*

[11] USGS, 2014. *Estimate of Undiscovered Copper Resources of the World*[online]. Fact Sheet.

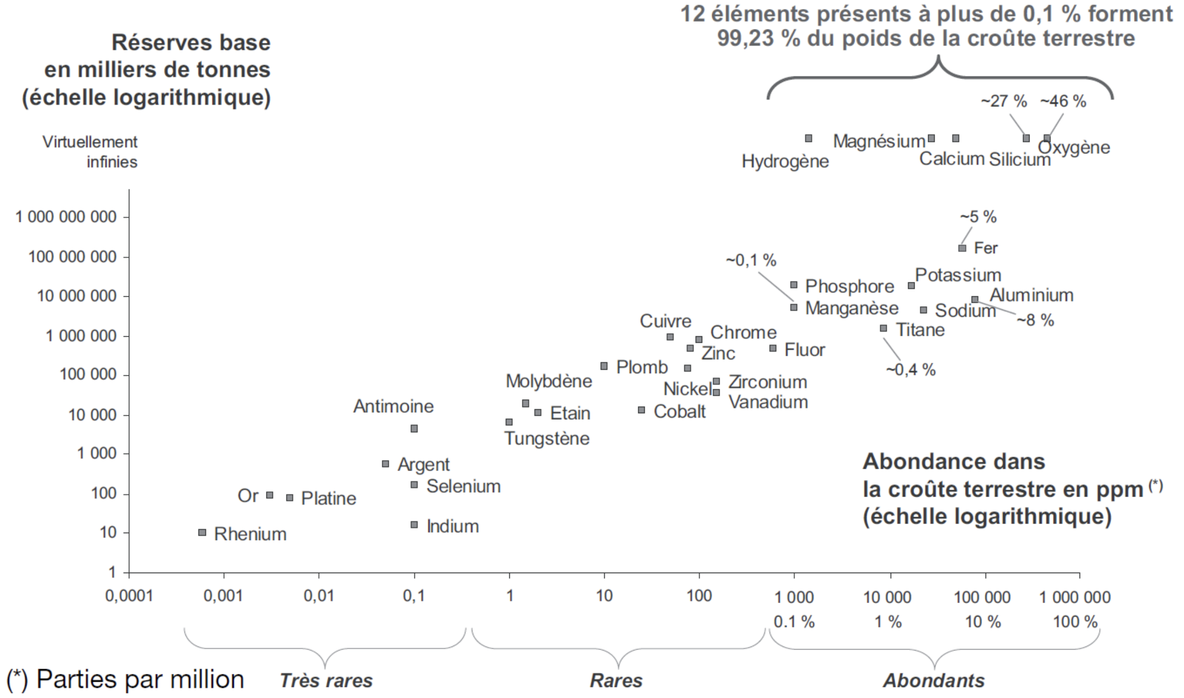
[12] USGS, 2020. *Mineral Commodity Summaries*[online].

- Reserves/Resources data are highly dynamic
  - May be reduced as
    - ore is mined
    - feasibility of extraction diminishes
  - May increase as
    - additionnal deposits are discovered
    - currently exploited deposits are thoroughly explored
- The Copper example : [11] & [12]
  - Reserves/Resources≃500 Mt (2014) -> 870 Mt (2020)
  - InferredReserves≃2.1 Bt(2014)
  - UltimateReserves≃3.5 Bt(2014)

2.3.2. Metals focus

[3] BIHOUIX, P., GUILLEBON, B. ,2010. *Quel futur pour les métaux?*

a)Concentration of minerals



Sources : BRGM, USGS 2007

Extracted from [3]

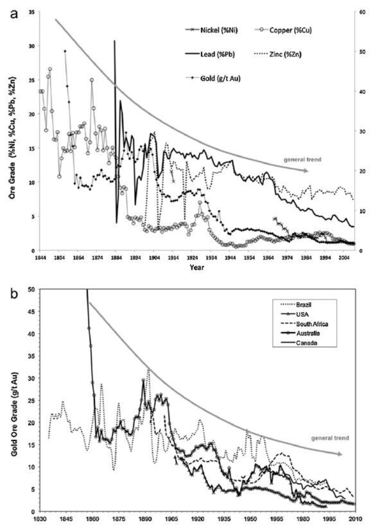
- Average concentrations of minerals in Earth crust must be compared to typical concentrations in exploited ores
- Even for abundant elements, high ratio between economically viable concentrations and Earth crust average
  - Iron(Fe) example: 30-60 % in ores versus 5 % average in Earth crust
- Precious metals are logically the only ones where the order of magnitude is equivalent
  - Typical example: Gold (Au)

Metal	Typical concentration of exploited ores	World mean	Metal mass per ton of ore
Fe	[30-60] %		[300-600] kg
Al	[20-30] %		[200-300] kg
Zn	[3-9] %	8%	[30-90] kg
Pb	[2-7] %	5%	[20-70] kg
Ni	[1,5-3] %		[15-30] kg
Cu	[0,5-2] %	0,8 %	[5-20] kg
Au	[0,0002-0,0006] %	0,0003 %	[2-6] kg

Extracted from [3]

- If no major discoveries, historical tendancy is a decrease in average concentration causing an increase in cost and impacts :
  - Example of Copper (Cu): 1,8% (1930) -> 0,8% 2010
  - See opposite: (a) Concentration of varied ores in Australia(b) Concentration of Golde ores in the world

Extracted from [24]

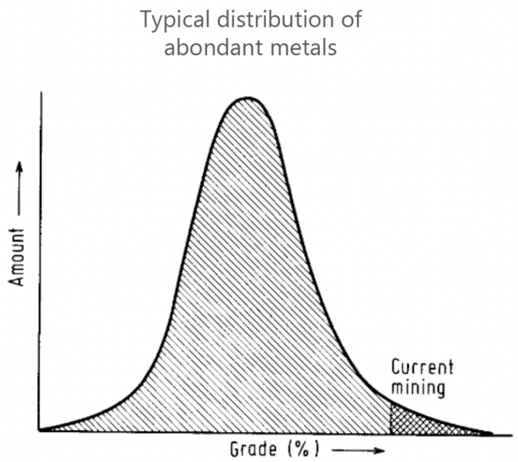


[24] PRIOR, T *et al*., 2012. Resource depletion, peak minerals and the implications for sustainable resource management.

b)B. Mineralogical barrier

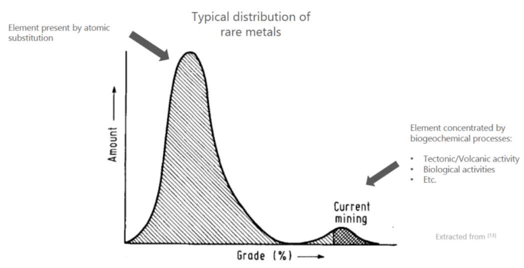
- Abondant metals mining follows a simple curve :
  - Highest-grade ores are mined first, as they're the most available ones– technically and economically
  - Like for any finite resources, mining depletes stocks, then target less high-grade ores, until a production peak happen, after what availability diminishes

Extracted from [13]

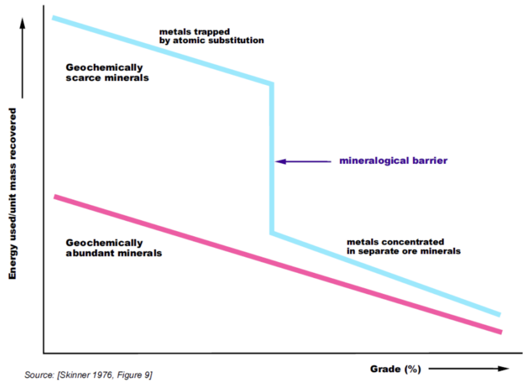


- Scarce metals are usually not found in common rocks as separate minerals but as atoms substitutions (that's makes them rare)
  - Consequently, mining activities directly seek concentrated ores (geologically rarer themselves), then must rely on more common ores, following a bimodal mining curve

Extracted from [13]



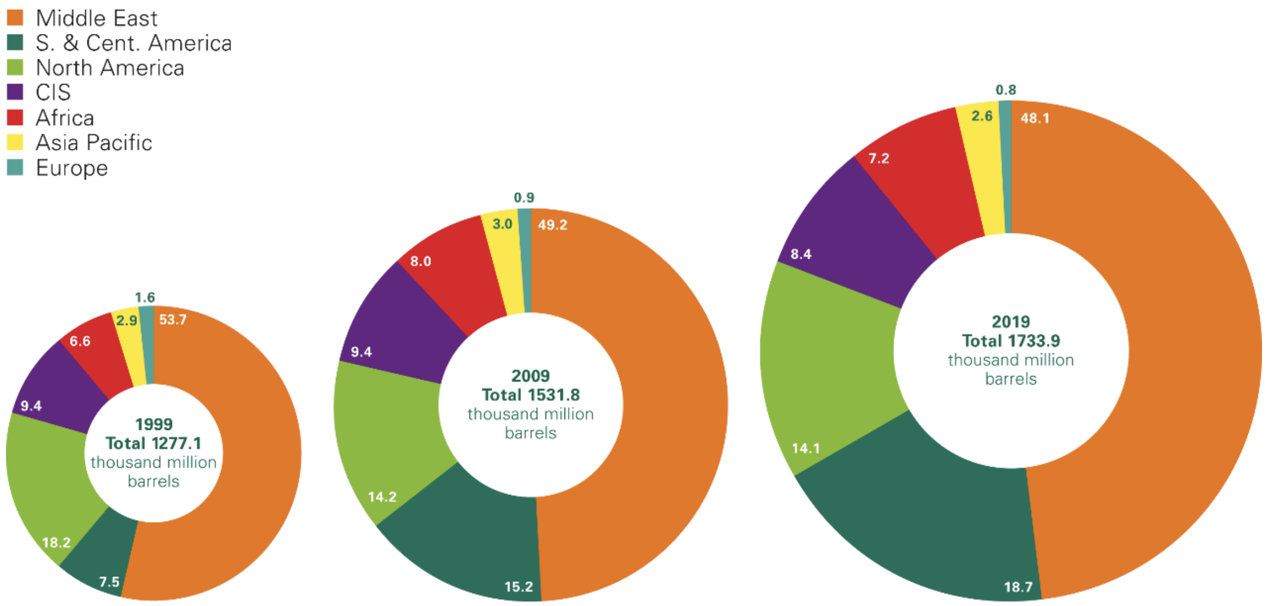
- The shift to these more common rocks can be a turning point in processes needed, and generate a mineralogical barrier



[13] SKINNER, B.J., 1979. Chapter 10 A Second Iron Age Ahead? In: *Studies in Environmental Science*. [14] AYRES, Robert U, 2001. Resources, Scarcity, Growth and the Environment. . 2001. P.35.

2.3.3. Oil focus

a)Assessing reserves [15]

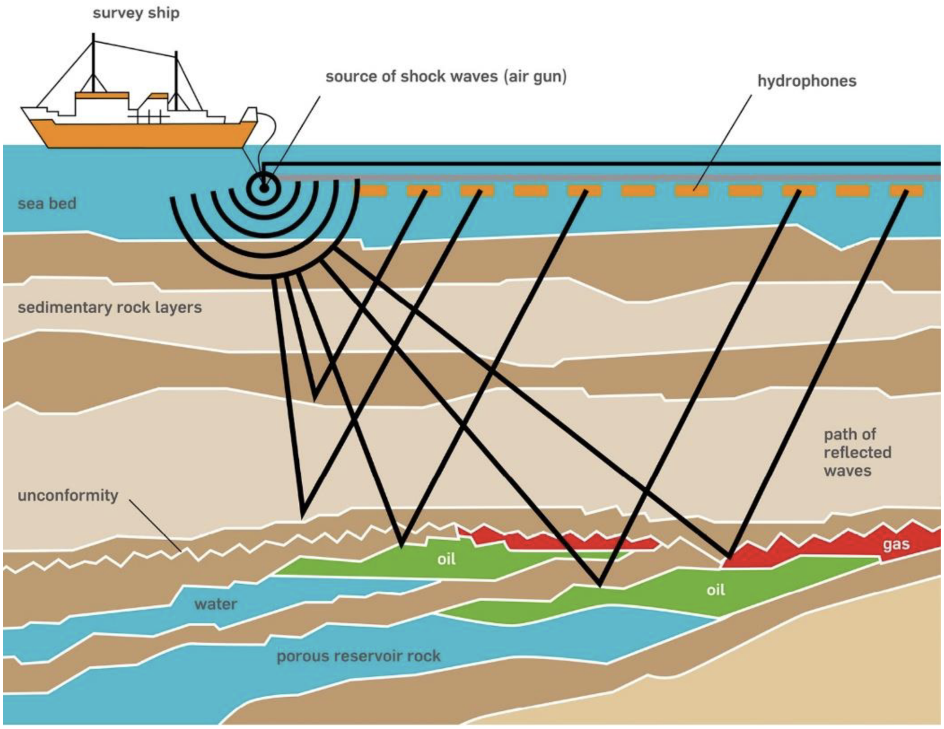


Extracted from [6]

[6] BP, 2020. BP Statistical Review of World Energy. [online].

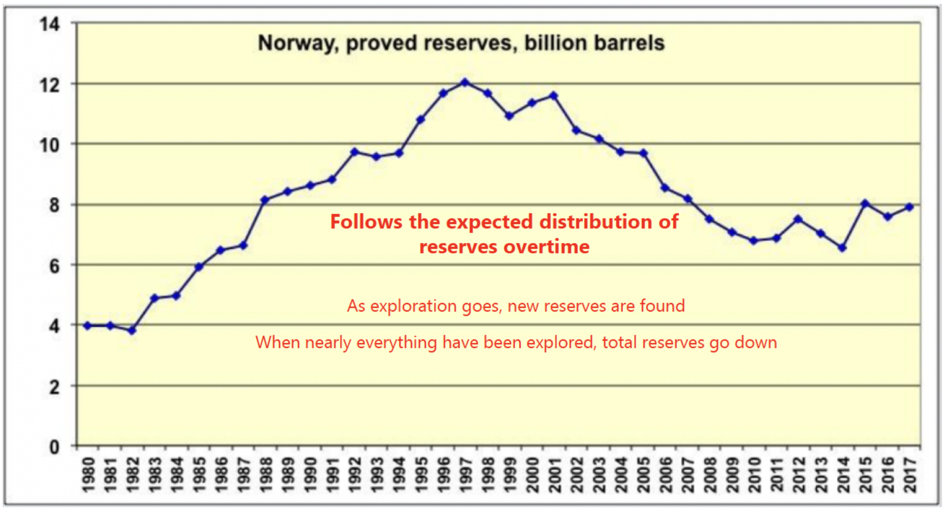
[15] JANCOVICI, Jean-Marc, 2019. Les Energies fossiles. *Ecole des Mines* [online].

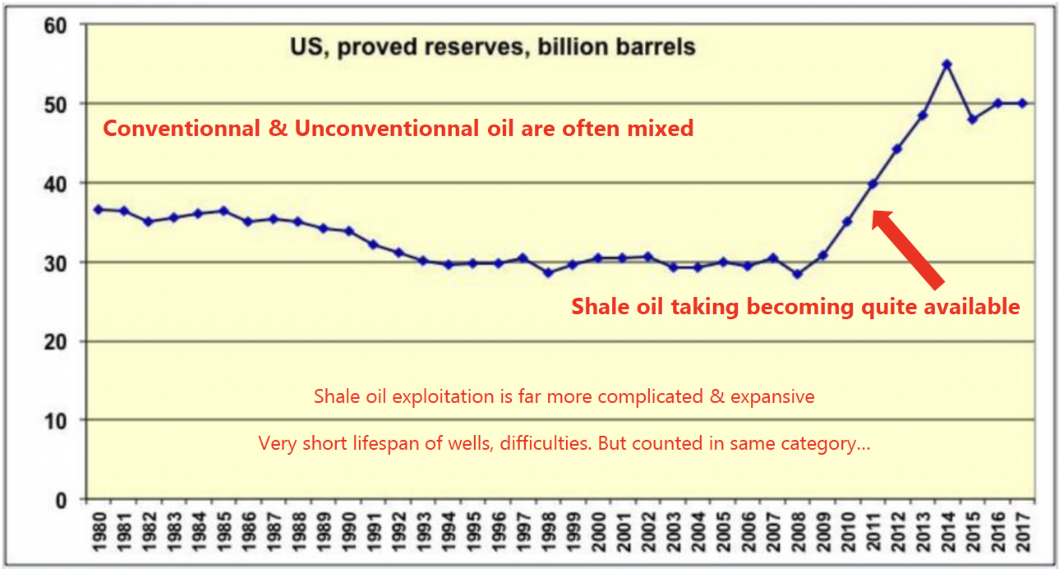
- When a potential reserve of oil is suspected, sismography combined with exploratory drilling is used to estimate :
  - Quantities of oil
  - Probable recovery rate of the oil

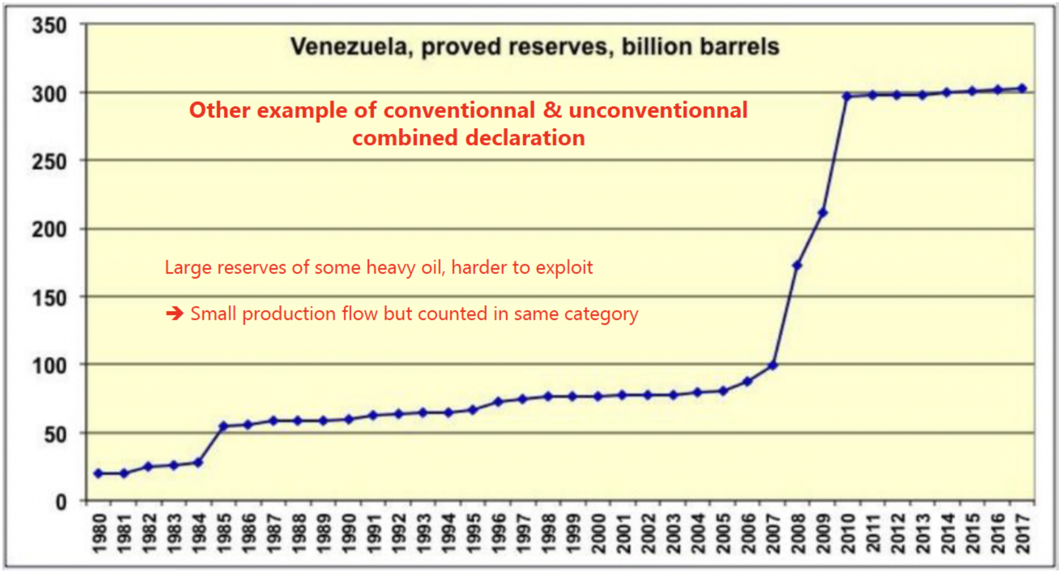


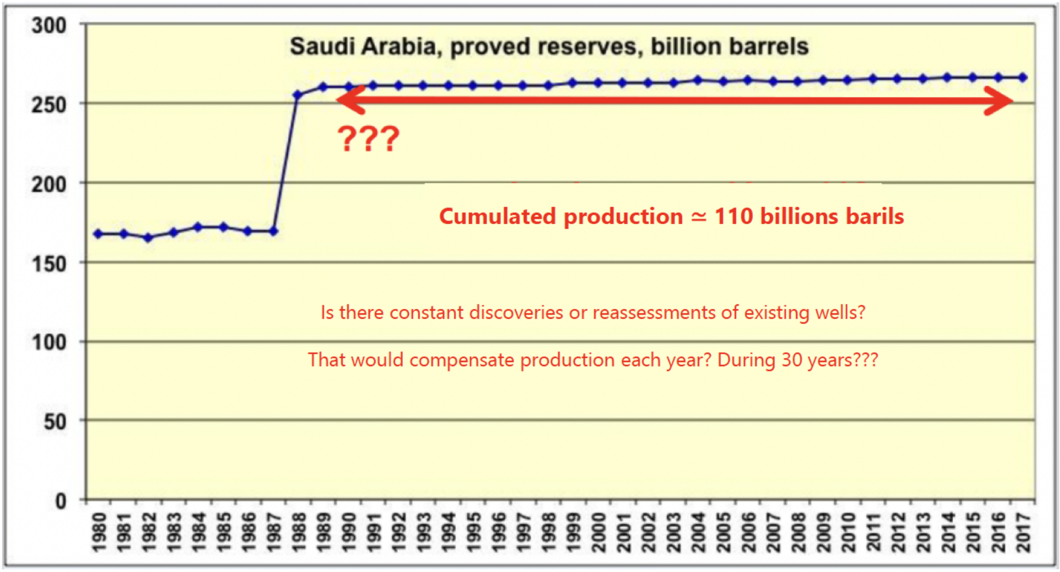
- As any oil extraction needs heavy infrastructure -> CAPEX>>OPEX.
  Which means the dynamics of a specific reserve are :
  - Strongly dependent on quantities& recovery rates estimations accuracy
  - Weakly dependent of variations in oil price(infrastructure already there)
- Who evaluate & declare the reserves?
  - A lot of oil companies are state-owned. Around 10% of oil compagnies are listed on the stock exchange -> legally binded to communicate the estimations
  - Large part of data comes from countries but :
    - Geopolitical strategies due to production international agreements
    - Different conventions on what to count and in which category
    - No independent verifications

b)Caution in interpretation









Adapted from [15]

2.3.4. Medias

https://pod.utt.fr/video/3946-ev14-abiotic-resources-4-extraction-reserves/

2.3.5. Impacts of extractive activities

a)Growing interdependancies

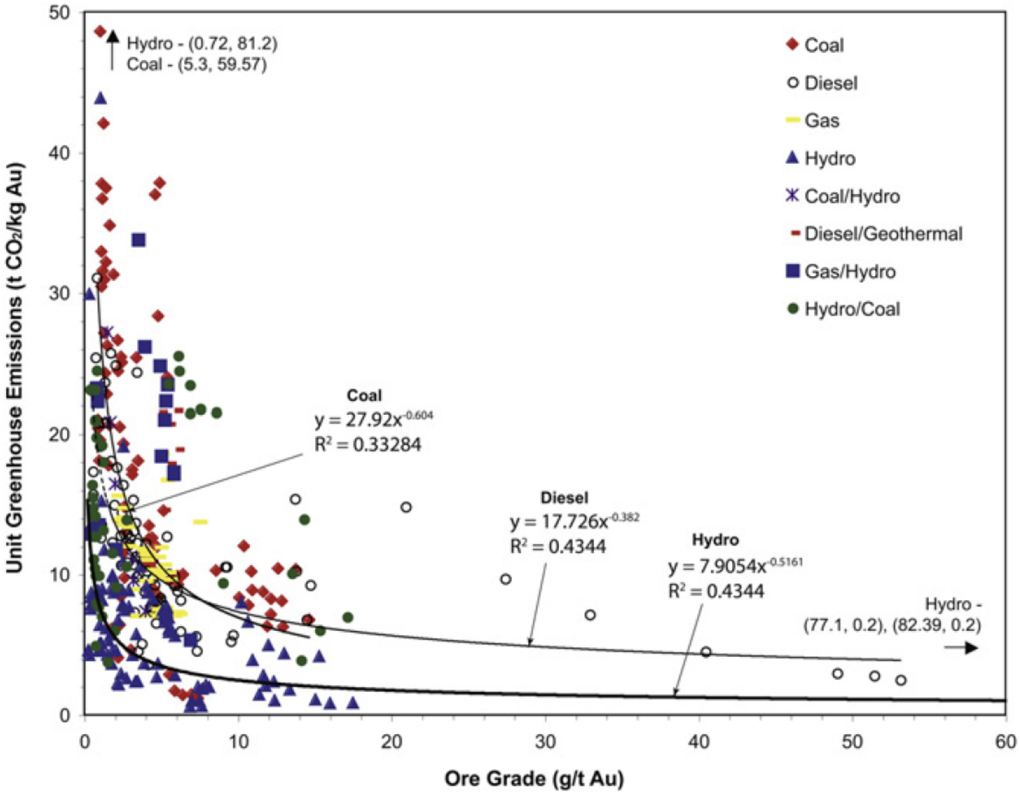
i)Energy footprint of minerals

- A lot of operations involved
  - Extraction, mineral processing, metal working
  - 1st order transformation: smelting and refining
  - Transport between steps
  - This raw metal undergo varied 2nd order transformations to become raw products with diverging final energetical footprint
  - Copper example: tubes 20-30% higher footprint than foils
- Uncertainties in data
  - Diversity of production sites (mineral concentration, efficiency of processes)
  - Varied studies perimeter (no standard approach, weigh of hypothesis)
  - Disparities in sources of information available

Metal	Production energy (tep/t)	Mining production (Mt)	Total energy (Mtep)
Steel	0,4-0,5	1360	544-680
Al	3,8-7,4	39,7	147-288
Cu	0,8-3,6	3,6	12-56
Cr	?	21,5	?
Zn	0,9-1,9	11,3	10-21
Mn	?	14	?
Si	?	5,7	?
Ni	2,7-4,6	1,6	4-7
Mg	8,6-10,2	0,8	7-8
Pb	0,5-1,1	3,8	2-4
Sn	4,6	0,3	1-2
Total (2010)	In Mtep		730-1070
Total (2010)	For World	Primary energy	7-10%

Extracted from [3]

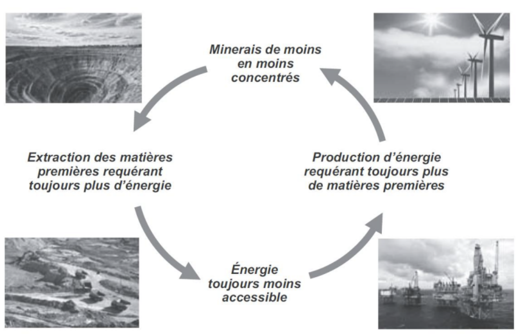
- Extraction & Refining of metals
    - Less & less concentrated mineral resources -> more & more energy



Extracted from [24]

[24] PRIOR, T *et al.*, 2012. Resource depletion, peak minerals and the implications for sustainable resource management.

ii)Material footprint of energy



- Extraction & Refining of oil
    - ≃5% of world Steel use for gas/oil exploration & production
    - 'Offshore', 'Depp offshore', or

      Unconventionnal oil -> rise in the use of platforms, ships, complex tools, etc.
- Even « Renewable energies » are quite materially dependent:
    - A 1MW windmill contains ≃ 3t of Cu, and needs 10x more steel & concrete per kWh than a classical plant
    - A classical PV installation (Si) needs ≃ 4kg of Cu per kW capacity.
    - Most these technologies also need rare metals like In, Ga, Se, Ne, etc.

b)Environmental focus

i)Other abiotic resources: water & air quality

Impacts on abiotic resources: water & air quality [16] & [17]

[16] ELAW, 2010. 1st Edition: *Guide pour l'évaluationde EIE de projetsminiers* [online].

[17] Hydraulic Fracturing 101. *Earthworks* [online].

[3] BIHOUIX, P., GUILLEBON, B. ,2010. *Quel futur pour les métaux?*

- Acid drainage :
  - Most ores contains sulfure -> exposition to the surface through mining -> formation of sulfuric acid -> dissolves other metals and spills out in surrounding rivers or groundwater Ex: Summitville (1992-1995) [3]

- Settling tanks
  - Containment of mining wastes -> infiltration into ground water or over flowsi n case of rain(one of the worst possible industrial accidents in terms of environmental impact) *Ex: Aznacollar 1998 in Spain*

- Mines dewatering
  - Mining sometimes directly meet the groundwater table -> pursuit of mining need pumping of water -> reduction or elimination of water circulation in surrounding zones, varied degradations on soils and wildlife

    Ex: Sadiola Gold mine pumped 5,6 Mm3 of water in a year (≃ consommation of 800 000 Malians) [3]
- Mobile or non-mobile sources of air pollutants
  - Fuel combustion & exhaust gases of machines or vehicules -> CO2, CO, organic compounds -> climate change
  - Waste particles dispersed by wind
  - Precious metals are often melted onsite before sent to rafineries -> high levels of Hg, As, SO2
- Uncontrolled mercury (Hg) rejections

    - [Hg] in ores can rach 10 mg/kg -> 1 Mt of ores produced means 10t of Hg potentially emitted
    - Vaporization of Hg in gold metling is a major cause of Hg mission in atmosphere

Specifics to oil :

- *Hydraulic fracturing & Oil spills contaminations*
- *Details in* [17]

ii)Biotic resources: wildlife and land

[16]ELAW, 2010. 1st Edition: *Guide pour l'évaluationde EIE de projetsminiers* [online].

[17] Hydraulic Fracturing 101. *Earthworks* [online].

- Loss of habitat
    - Excavation or accumulation of waste -> mobile species (birds and some mammals)are hunted out + sedentary species (little mammals, reptiles, invertebrates) are killed
    - Acid drainage or dewatering -> severes impacts on surrounding aquatic life
    - These 2 points -> perturbation of trophic chains (diminution of food for the higher-level predators)
    - Disparition of vegetation
- Fracture of habitat
    - Large portions of land occupied

      -> perturbation of migrations or local isolation of species

Specifics to oil (again):

- *Hydraulic fracturing & Oil spills contaminations*
- *Details in* [17]

c)Socio-economical focus

[16] ELAW, 2010. 1st Edition: *Guide pour l'évaluationde EIE de projetsminiers* [online].

[17] Hydraulic Fracturing 101. *Earthworks* [online].

[3] BIHOUIX, P., GUILLEBON, B. ,2010. *Quel futur pour les métaux?*

i)Contrasted local realities

[16] ELAW, 2010. 1st Edition: Guide pour l'évaluation de EIE de projets miniers [online].

[17] Hydraulic Fracturing 101. Earthworks [online].

[3] BIHOUIX, P., GUILLEBON, B. ,2010. Quel futur pour les métaux?

- Human migrations
    - Displacement & reinstallation of communities (expropriated or not) -> resentment + power perturbations -> local conflicts
    - New high economic activity -> arrival of new populations -> new pressures on land, water or waste management -> tensions & potential conflicts with original inhabitants

      Ex of Grasberg Mines in Indonesia: From <1000 (1973) to 110 000 (1999) ; violent conflicts during 1970-1990
    - New needs of infrastructures -> urbanization -> wide-ranging effects
- Loss of drinkable water access
    - Due to uncontrolled exploitations & industrial pollutions
- Pressures on means of existence
    - Mining activities not correctly managed -> economic cost on other sectors (agriculture & fishing in particular)
- Public health consequences
    - Potential sanitary risks are often seglected

      -> example of improvised mining towns are been shown to threaten food security and availability
    - Indirect effects of exposition to mining activities are higher incidences of tuberculosis, asthma, chronic bronchitis, etc.
    - A review of metals direct toxicity impacts can be found in a dedicated chapter of [3]
- Cultural & Esthetics
    - Destruction of cultural resource by surface perturbation or excavation
    - To pographical or hydrological changes
    - Higher access to previously inacessible locations

      -> theft or vandalism of cultural artifacts
    - Visual impacts due to deforestation& presence of infrastructures

ii)Global frictions...

[25] HUISMAN, J., PAVEL, C., *et al*. 2020. *Critical Raw Materials in Technologies and Sectors - Foresight* [online].

[3]BIHOUIX, P., GUILLEBON, B. ,2010. *Quel futur pour les métaux?*

- Emerging geopolitical stakes for metals
    - As for oil, the main consumer countries are also the ones with the smallest reserves
    - Understanding of these problematics is more recent for metals and is parallel to the recent rise of metals prices in the 2000s
    - The EU Commission now regurlaly pubish reports on the matter[25]
    - Strategical stocks of metals constituted during Cold War, dismantled after the 90s, are back since15-20 years

- Capitalistic concentration of compagnies :
  - in 2008, 4173 compagnies in mining but 149 majors (3,6%) were controlling 83% of the market[3]
  - Power to initiate struggles with states over natural resources and their exploitation, in order to maximize private profits and mutualize losses or environmental externalities
  - Complex conflicts with explicit and implicit actors

[3] BIHOUIX, P., GUILLEBON, B. ,2010. *Quel futur pour les métaux?*

- Armed conflicts already existing
  - Not as visible as oil conflicts yet
  - DRC (Democratic Republic of the Congo) being the richer african country in metals, its history since mid-XXth is a paradigmatic example
- Crossings with colonization & neocolonization
  - 1961 Defense agreements between France, Niger, Dahomey & Ivory Coast garantee limitation of exportations to other countries than France in case of needs
  - 2007 contract of China & RDC: heavy construction work (6 billions $) in in exchange of metal mining authorizations (10 Mt of Cu, 200 000 t of Co, 372 t of Au)
    - With explicit intention of asking land if the metal provisionning does not meet expectations
    - Direct implication in local economy

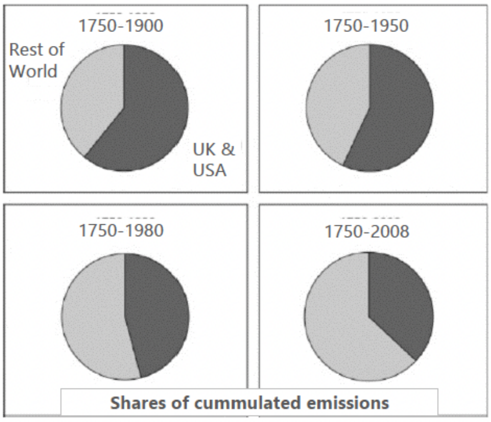
No need to developp on the well known history of oil geopolitical conflicts since mid-XXth!

iii)Rooted in historical inequalities

[3] BIHOUIX, P., GUILLEBON, B. ,2010. *Quel futur pour les métaux?*

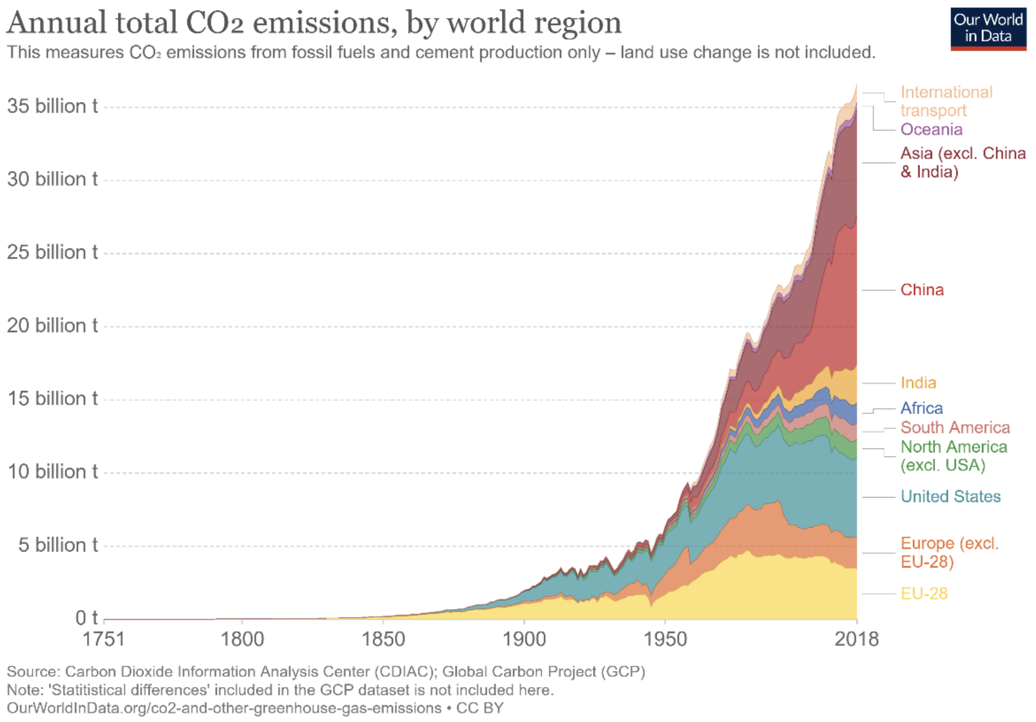
[18] RITCHIE, Hannah and ROSER, Max, 2017. CO_2 and Greenhouse Gas Emissions. *Our World in Data*[online].

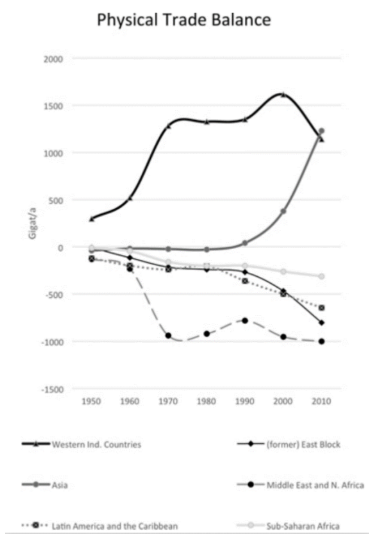
[19] BONNEUIL, C., FRESSOZ, J-B., 2016. *L'événement anthropocène: la Terre, l'histoire et nous*.



Adapted from [19]

- Developed countries did develop themselves on the exploitation of countries now productors & consumers
  - Between 1815-1880, 5/6 of British investments were outside their empire, chiefly to develop mining (coal, in particular) and transport of ores by rail in dominated countries [19]





- 20th century have mainly reorganized exploitation, but it continued on
  - USA based its economic rise on intensive use of its own resources during 1870-1940
  - Supported decolonization mainly to gain access to material resources of newly independant countries
  - Conversely, East block exploited its own environnment above all
- Emerging trend ->
  - Reappropriations of national resources & path of developpmen
  - Setting of export restrictions [3]

d)Medias

https://pod.utt.fr/video/3947-ev14-abiotic-resources-5-extraction-impacts/

2.4. Perspectives of abiotic resources

2.4.1. A matter of Stocks

a)The stocks's stakes

i)Climate change - CO2 eq « stock »

[6] BP, 2020. BP Statistical Review of World Energy. [online].

[20] EIA, U.S. Energy Information Administration, 2016. Carbon Dioxide Emissions Coefficients. [online].

[21] IPCC. 2018. Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development. . P. 82.

- Oil emissions of current reserves
  - Proven reserves :

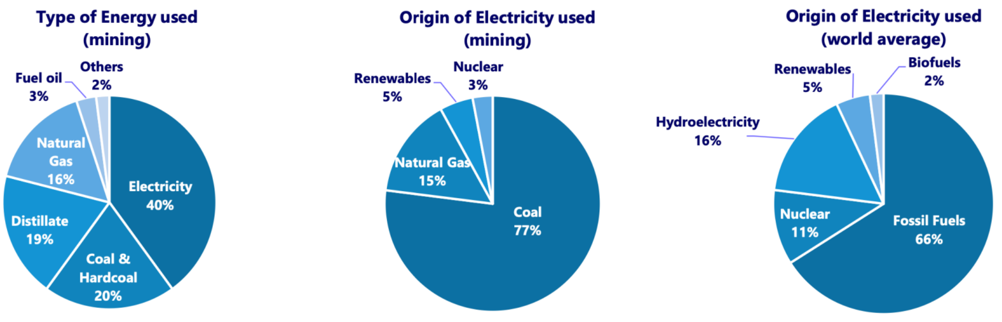
    -> 1733,9 billions barrels [6]
  - 53750,9 billion gallonsAverage on varied oil uses gives ≃ 10 kg CO2 emitted per gallon [20]

    -> 537,5 Gt CO2
- World CO2 eq budget, current estimations : [21]
  - 1170 Gt CO2 eq to stay <2°C of global warming
  - 420 Gt CO2 eq to stay <1,5°C of global warming
- Consomption of all current proven oil reserves is half of our total 2°C world budget and more than our total 1,5°C budget!
  - Without even considering natural gas, coal, or other emissions (CH4, for example) contributing to radiative forcing...
  - This considered, without changes, the 2°C threshold should be crossed in about 26 years

[3] BIHOUIX, P., GUILLEBON, B. ,2010. *Quel futur pour les métaux?*

[10] Data & Statistics,. *IEA*[online]. Available from : https://www.iea.org/data-and-statistics

And mining is very dependent of highly carbonated, non renewable energy vectors



Adapted from [3] .The values for World averages of Electricity origin were replaced by updated data rom [10]

ii)Production peak

[6] BP, 2020. BP Statistical Review of World Energy. [online].

[15] JANCOVICI, J-M, 2019. Les Energies fossiles. *Ecole des Mines* [online].

[22] World Energy Outlook 2018. *IEA –International Energy Agency*.

- Hypothesis: we don't mind $CO_{2\ eq}$ emissions
  - Either we consider it's not a problem
  - Or we think innovation or start-ups will solve that

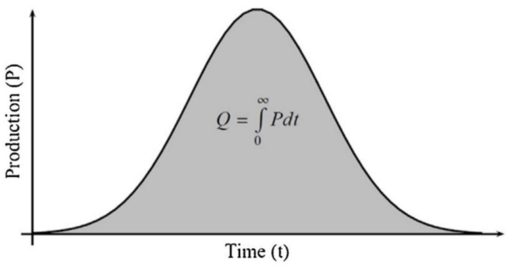
  -> Exhaustion of Reserves through Production will still occur!
  - R/P ratio: most simplified model
  - Considering current reserves [6]
  - And 2019 rate of consomption [6] taken as constant for the years to come (quite unrealistic hypothesis of no flow reduction)

    -> No oil remaining in ≃ 50 years

[23] CALVO, G. et al.., 2017. Assessing maximum production peak and resource availability of non-fuel mineral resources.

[15] JANCOVICI, J-M, 2019. Les Energies fossiles. *Ecole des Mines* [online].

[22] World Energy Outlook 2018. *IEA – International Energy Agency.*



- A slightly better estimate: the Hubbert peak model (1956)
  - We know there is no production at t = 0 and t = t final
  - The area below the production curve must be equal to the reserve
  - Regarding conventionnal oil, several countries seems to have peaked already. A review can be found here [15]
  - It is commonly believed that world production peak of conventionnal oil already happened, in 2008 [22]

Extracted from [23]

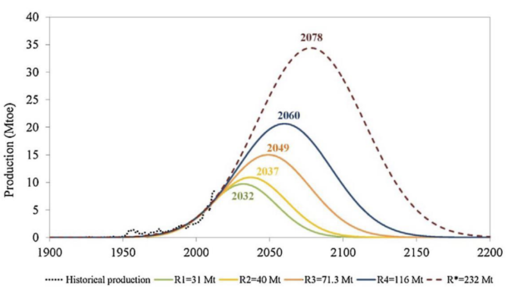


Fig. 4. The Hubbert peak applied to lithium with different resources estimations. The curve corresponding to R* values was calculated assuming that the most optimistic estimations (R4) were doubled.

- Reliability is influenced by several parameters
  - Uncertainty regarding reserves information
  - Particular environmental issues: health, water use, ore grade
  - Sociopolitical issues: new objects, changes of regulation, or armed conflicts
  - Interdependencies of byproducts
  - Substitution & recycling
- That said, influence of reserves' variation is limited when rapported to the current trends in production and growth of production

  -> Li case study: estimated reserves x 8 only delayed the peak by 46 years

Extracted from [23]

- This recent try of systematic assessment is quite interesting to read[23] and accessible!
  - The time scaling is quite short, even for base metals

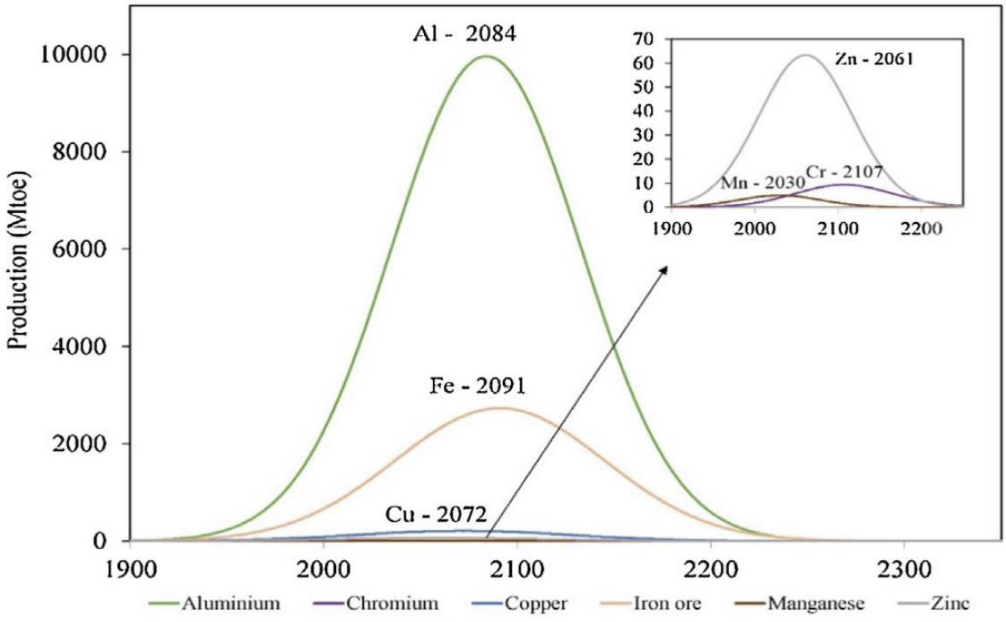
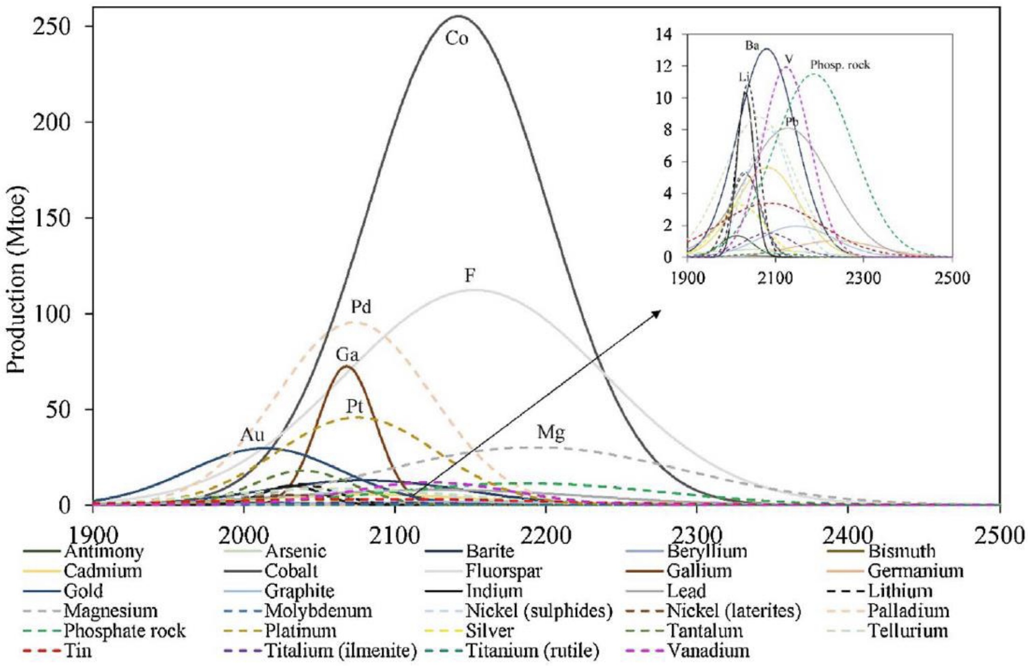


Fig. 5. The Hubbert peak applied to the "big six" resources.

Extracted from [23]

- Expected peak in the next 50 years : 12 metals over 47 studied: As, Bi, In, Li, Mn, Mo, Ni, Ag, Ta, Te, Zn
- 30 metals over 47 have their expected peak in the next 100 years
- Gold & Antimony peaked arround 2015 (agreement for Gold with [3])



Extracted from [23]

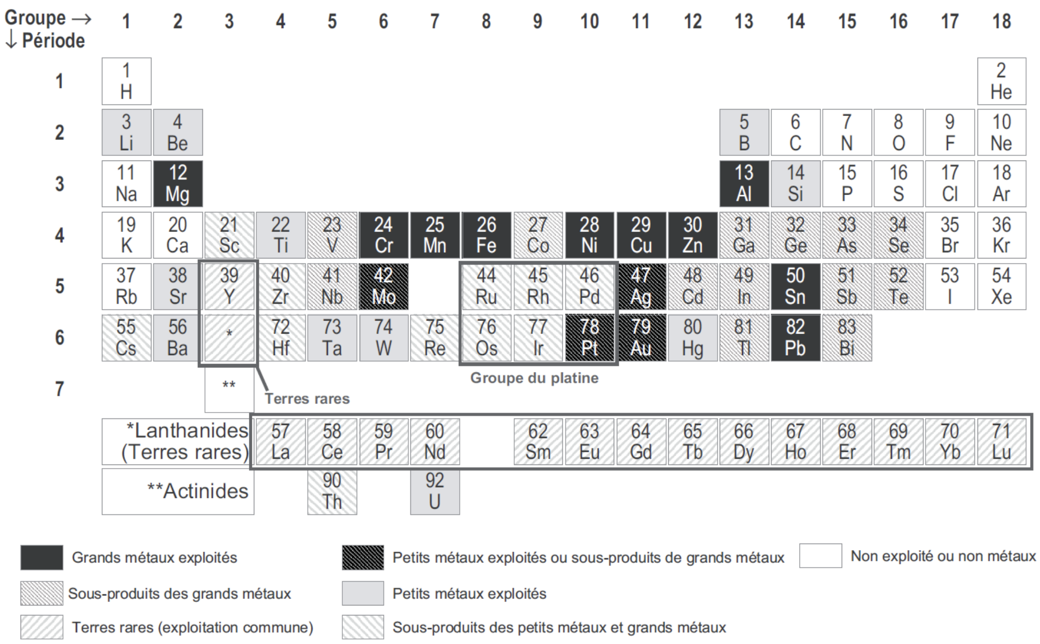
- Taking into account the interdependencies of metals
  - Bold indicates it is the main production process of said **metal**

Major metals exploited	**Main non-dependent byproducts**	**Main dependent byproducts**
Fe	Zb, Pb	
Al		**Ga**, V
Cr	Pd, Pt	
Cu	Ag, Au, Mo, Pd, Pt, Zn	**As**, Bi, Co, Ir, Os, **Re**, Rh, Ru, **Se**, **Te**
Ti		Zr, Hf
Pb/Zn	Ag	As, **Bi**, **Cd**, Co, Ga, **Ge**, **In**, **Sb**, **Tl**
Ni	Ag, Au, Cu, Pd, Pt	**Co**, Ir, Os, Rh, Ru, Se, Te
Sn	Ag	In, Nb

Extracted from [3]

[3] BIHOUIX, P., GUILLEBON, B. 2010. *Quel futur pour les métaux?*

- Nearly a half of metals today exploited are interlinked



Sources : E. Verhoef, G. Dijkema and M.A. Reuter (2004), USGS, BRGM

Extracted from [3]

iii)Criticality

[26] GRAEDEL, T. et al., 2015. Criticality of metals and metalloids. DOI 10.1073/pnas.1500415112[1].

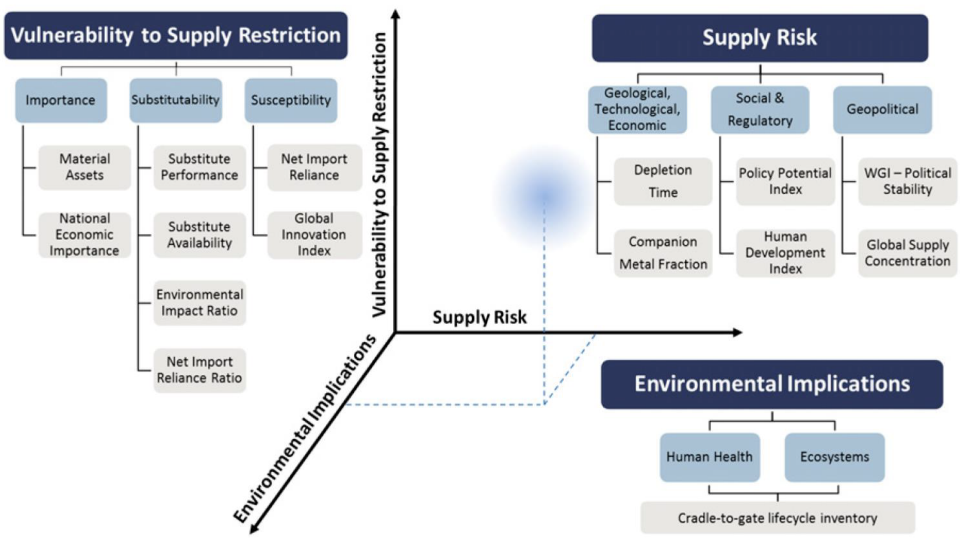
- Notion related to the attempt to assess the relative risks concerning the availability of resources
  - Relatively recent preoccupation
  - As availability is an already complex notion, its risk analysis is also complex

[1] https://www.pnas.org/doi/full/10.1073/pnas.1500415112

- Geological abondance & concentrations
- Potential for substitution
- State of the art of mining technology
- Amount of regulatory oversight
- Geopolitical initiatives
- Governmental instability
- Economic policy

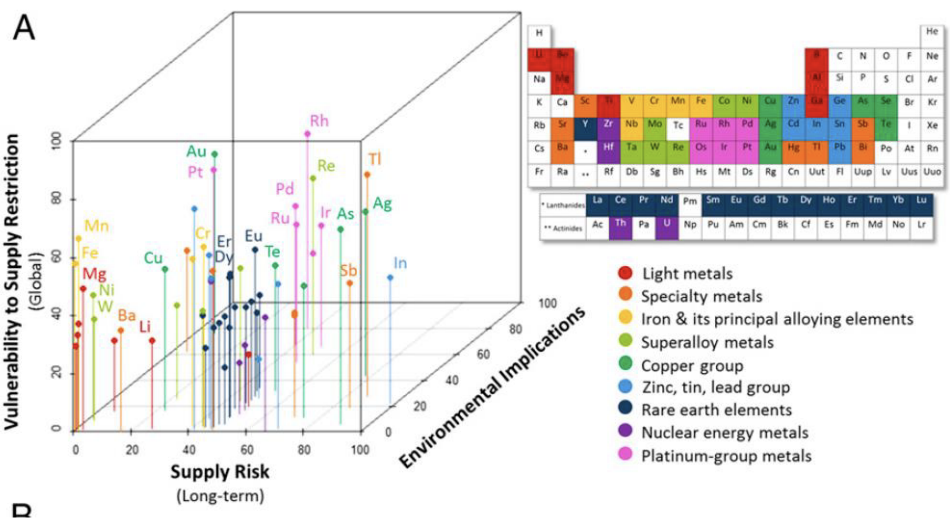
  - As reserves are part of the assessment, it is also dynamic

- Several methodologies
  - At different scales of organizations
  - For different scales of time
  - With then varied results difficult to compare between each other



Extracted from [26]

- Criticality space: a first step is to get an overall idea
  - A number of metals are concentrated on the middle: moderately high on at least 2 axis (rare earths, Cr, Te, etc.)
  - Some are regrouped toward lower left: relatively low criticality (Fe, Mg, Ni, Mn, etc.)
  - The right side: high supply risk (In, Ag, Tl, As, Sb)
  - The particular case of Au & Pt



Extracted from [23]

- This methodology allow the comparison of varid elements for (here at global level) :
    1. Supply risk
    2. Environmental implications
    3. Vulnerability to supply restriction
- Keep in mind it is a relative assessment
    - Per kg comparison
- Results may be underestimated
    - Database of 2008 (they were in the process ofupdating up to 2012 at publication in 2015)
    - As data revisions are not frequent & major technology changes occurs slowly, they recommand reassessment on a 5 years basis

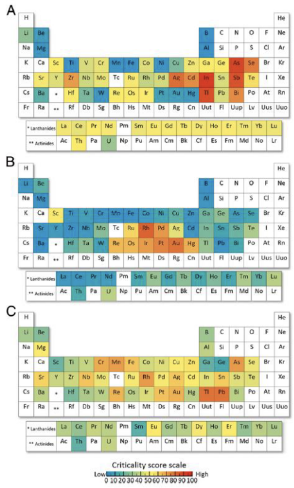
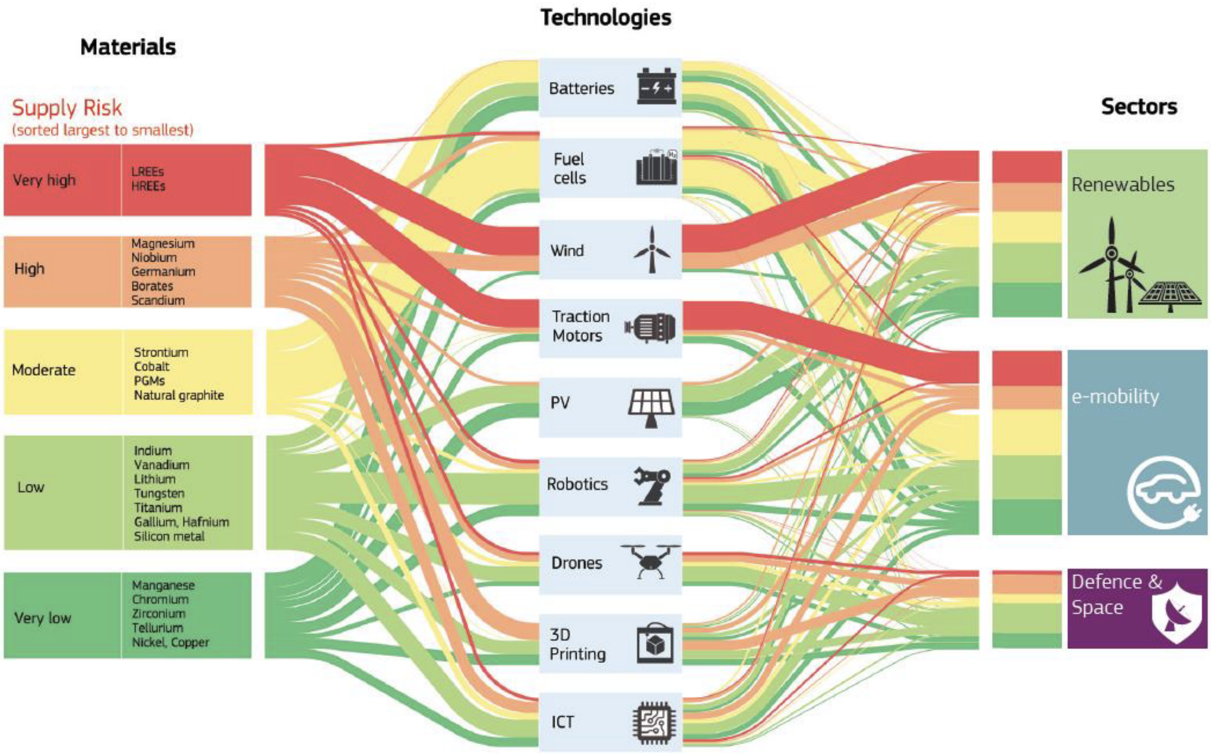


Fig. 6. Periodic tables of criticality for 62 metals, 2008 epoch, global level for (A) supply risk, (B) environmental implications, and (C) vulnerability to supply restriction.

Extracted from [23]

[25] HUISMAN, J., PAVEL, C., *et al. 2020. Critical Raw Materials in Technologies and Sectors - Foresight* [online].

Figure 2. Semi-quantitative representation of flows of raw materials and their current supply risks to the nine selected technologies and three sectors (based on 25 selected raw materials, see Annex 1 – Methodological notes)

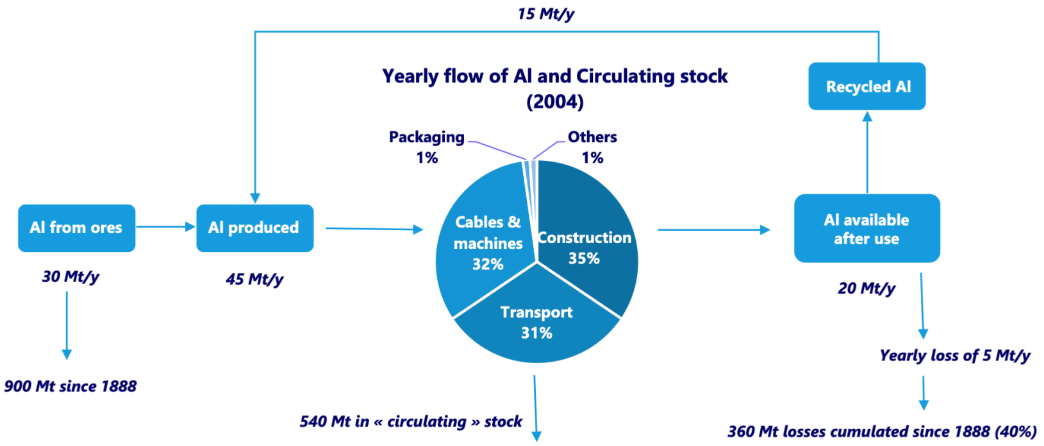


b)Preserving stocks

i)Necessity & Limits of Recycling

[3] BIHOUIX, P., GUILLEBON, B. 2010. *Quel futur pour les métaux?*

- Major difference between oil (energy resources) and metals (mineral ressources) :
    - Oil, Coal & Natural Gas -> mostly burned -> The flow is not retrievable
    - Metals -> mostly materially conserved -> The flow is retrievable + there is a stock in circulation!
- Each year, stocks of metals :
    - Increases of the producted quantity
    - Decreases of the lost quantity
        - Dispersive uses (metals used as dyes or fertilizers)
        - No recycling (incineration or landfill disposal)
- Current recycling
    - Precious metals (Au) or with moderately high value (Cu): few losses
    - Less noble metals (Al, Zn) have more important loss rates
    - No data for a lot of metals used in specific applications (electronics...)



- Metals are one of the most interesting category of materials for recycling
    - Theoretically recyclable an infinite amount of time without diminishing their properties
    - Have high yield for stock preservation
        - 40% recycling rate -> 80% recycling rate <-> Reserves x 3
        - 50% recycling rate -> 99,9% recycling rate <-> Reserves x 500
- Rich countries show that recycling rate can reach high levels for base metals
    - France (2010): 85% for Fe ; 80% for Al & Cu ; 70% Pb ; 50% Zn [3]
- But it cannot do everything
    - No industrial process have a 100% efficiency -> same for recycling (remelt Al generate a dispersed loss of 1-2%)
    - A lot of our uses are not compatible with recycling
- The trend of higher complexity
    - > 30 metals in a computer
    - > 10 alloys of Steel in a car
    - Prevent us from retrieving the resources: not easy and sometimes techically impossible to detect or separate metals of an allow

- This phenomena exist for a lot of our metarials
    - Glass: mix of transparent & colored glasses -> no more use in most of construction or cars, only bottles
    - Plastic: often reused in less demanding uses (technically or aestetically)

-> Important to rethink life-cycles of products, raw materials, and mostly uses

- -> Integrate less performant or pretty materials & more recycled materials
- -> Organize recovery channels to boost recycling rate
- -> But also question the trend of high tech solutions instead of low tech ones
- -> That is, question the needs
- The trend of direct dispersive uses
    - Dyes (98% of Ti used as TiO_2 for white dyes)
    - Fertilizers (P, Zn, etc.)
    - Additives (Cr in Glass)
    - Pesticides ($CuSO_4$ in some organic farming plants)
- And « indirecty » dispersive uses (very difficult to recover)
    - 33% of Sn is used in welding
    - 50% of Zn is used in galvanizing
- Some metals like Co or Mb are nearly exclusively used in dispersive uses or alloys
- The socioeconomic limits
    - Economical incentives to constructors are not present or sufficient
    - Lack of reglementation and means to enforce it
    - Complexity of products and recovery channels does not help

ii)Substitution

- Limit the use in rare or noble metals in favor of abondant metals
    - Critical lens on « innovation »
    - Aim to maximize a low tech approach as much as possible at the level of product and technology

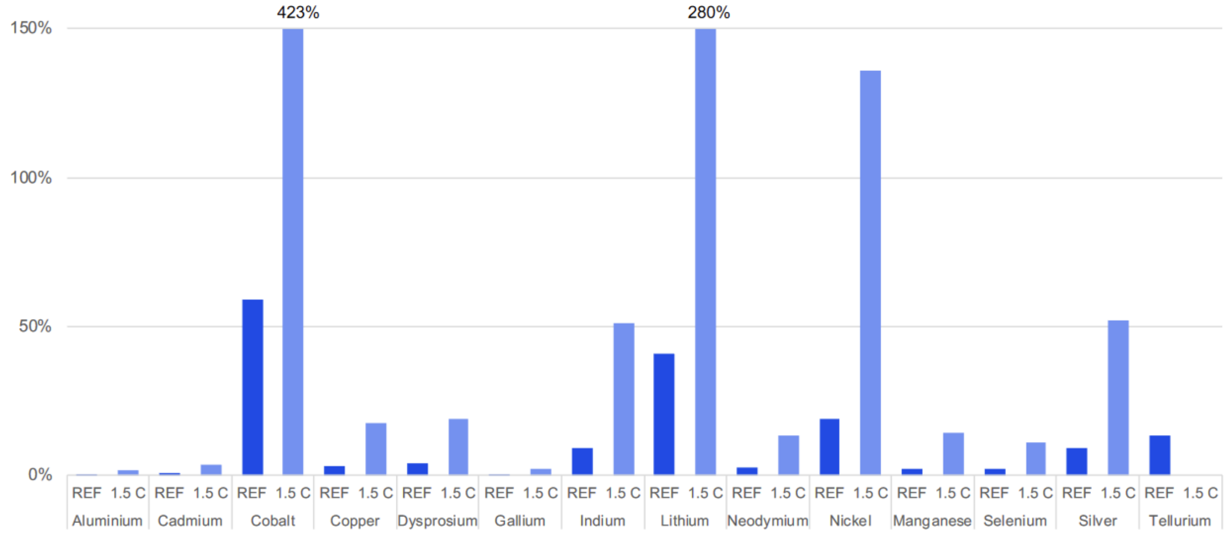
  -> For inorganic solar pannels, Si should be prefered to GaAs, CIGS, and others, even if the conversion efficiency is less important
- For critical cases, possibilities needs to be carefully explored :
    - Cr nearly indispensible for anti-corrosion

      -> Ti can replace Cr in certain cases but its energy footprint is 4-5 times higher
    - Cu nearly indispensible for electrical applications

      -> Al can replace Cu in certain cases but its energy footprint is 2-3 times higher

- Substitute oil by electrification? [27]
    - Li-ion batteries represented 37% of Li consumption in 2016 (and 40% of Co)
    - Batteries for electric vehicules were only 10% of Li-ion consumption in 2018
    - Most elements at disposal indicates that strong choices of resources's uses will have to be made in the years to come :

Figure 6: Cumulative total demand from renewable energy and storage by 2050 compared to reserves in the 1.5 degree and Reference scenarios



[27] Responsible minerals sourcing for renewable energy, 2019. *University of Technology Sydney* [online].

[28] ABDALLA, A. *et al*., 2018. Hydrogen production, storage, transportation and key challenges with applications: A review. DOI 10.1016/j.enconman.2018.03.088[1]

[29] SCHMIDT, O., *et al*., 2017. Future cost and performance of water electrolysis: An expert elicitation study. DOI 10.1016/j.ijhydene.2017.10.045[2].

- Substitute oil by « hydrogen »?
    - Currently > 90% of H_2 is produced by steam reforming (10 kg CO_2 per kg of H_2 produced) [28]
    - Water electrolysis / fuel cells have problems of their own [29]
        - Alkaline electrolysis is not adapted for electric cars
        - New technologies currently depends either on Pt and are not industrially mature (PEM) or rare earths and are at the state of demonstrators (SO)
- In need of a big & new infrastructure for supply of cars

-> We are back to the vicious circle of energy & material footprint

iii)Challenging needs

[1] https://www.sciencedirect.com/science/article/pii/S0196890418303170?via%3Dihub
[2] https://www.sciencedirect.com/science/article/pii/S0360319917339435?via%3Dihub

[30] BIHOUIX, Philippe, 2014. *L'Age des low techs : vers une civilisation techniquement soutenable.* Seuil.

- The often most efficient stategy to preserve abiotic resources stock
  - House thermally isolated + put on a sweater >>> room heating technical solution
  - Most transport on bicycle (short distance) + train (long distance) with minimal use of a car (occasional rental) >>> electric cars replacing current diesel and petrol cars
  - Simple dismountable and repairable electronics >>> computer assembly with glue with digital prints technology
- It is the first of the 7 principles of low-techs [30]
  1. Challenging needs
  2. Design and produce truly sustainable
  3. Orienting knowledge to resources' savings
  4. Striking a technical balance between performance & conviviality
  5. Relocalize without losing the right scale effects
  6. De-machinizing services
  7. Knowing to remain modest
- Indeed this kind of transition imply numerous socioeconomical consequences
  - As any kind of transition, it is also a matter of flows and their evolution

c)Medias

https://pod.utt.fr/video/3948-ev14-abiotic-resources-61-stakes-of-the-stocks/

https://pod.utt.fr/video/3949-ev14-abiotic-resources-62-preserving-stocks/

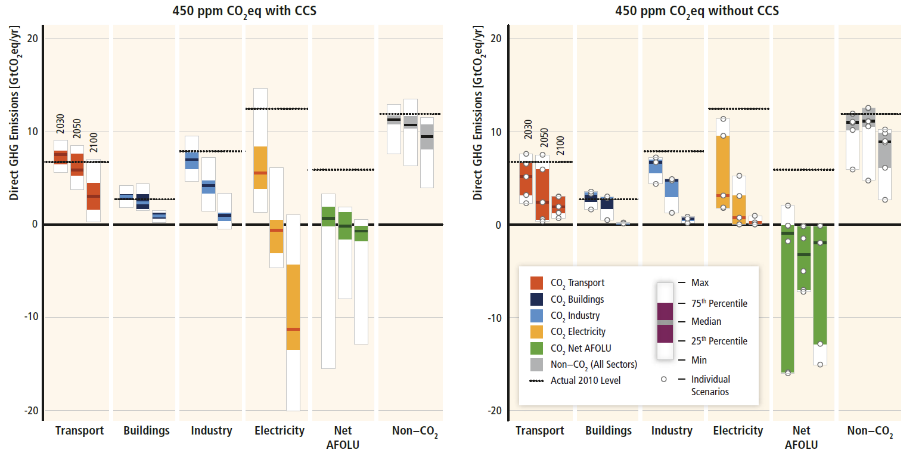
2.4.2. A matter of Flow

a)The flows's stakes

i)Climate change

[31] IPCC. *2014: mitigation of climate change: Working Group III contribution to the 5th Assessment Report of the IPCC.*

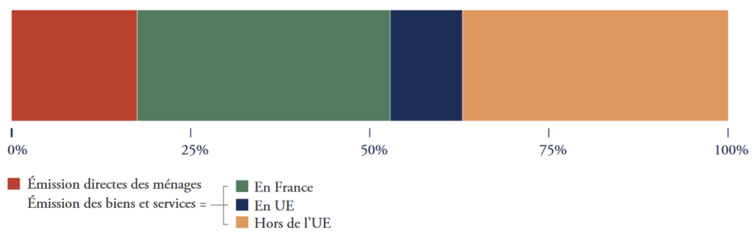
- Trajectories mitigating climate change all require a global limitation of material & energy flows
  - Even with the hypothesis of a high developpment of the use of carbon capture and storage (CCS) technologies



[32] HCC, 2020. Maîtriser l'empreinte carbone de la France. *Haut Conseil pour le Climat* [online].

- The French carbon footprint
    - A large part of our carbon footprint comes from importations

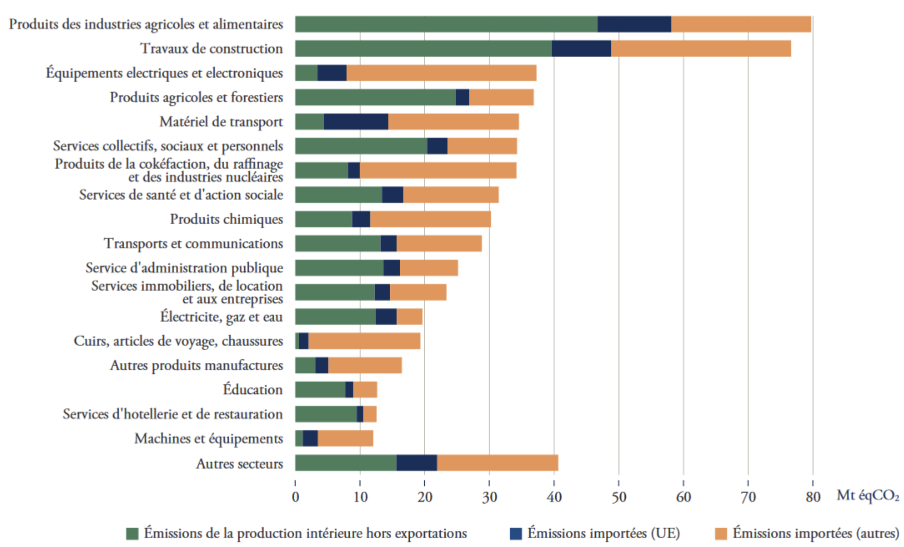
Figure 8 – Localisation des émissions
qui composent l'empreinte carbone de la France en 2011



Source : Traitements HCC 2020 d'après Malliet (2020)

- The French situation
    - Mineral resources: metals & cement
    - Energy resources & chemical products: oil
    - Abiotic resources are a large part of it, metals in particular!
    - In terms of weight of abiotic resources in domestic emissions: oil is dominant through transport (direct emissions), followed by metals & cement (indirect and distributed emissions)

Figure 10 – Secteur et localisation des émissions qui composent l'empreinte carbone,
hors émissions directes des ménages, en 2011



Source : Traitements HCC 2020 d'après Malliet (2020)

Figure 12 – Répartition par bien ou service et par lieu de leur dernière transformation **des émissions de GES de la chaîne amont de l'empreinte carbone en 2011**

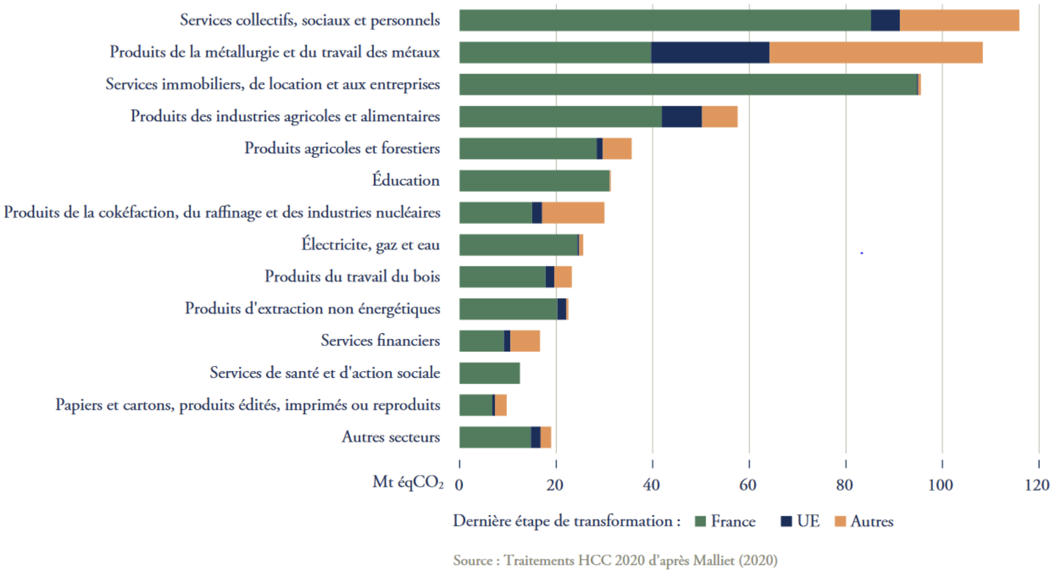
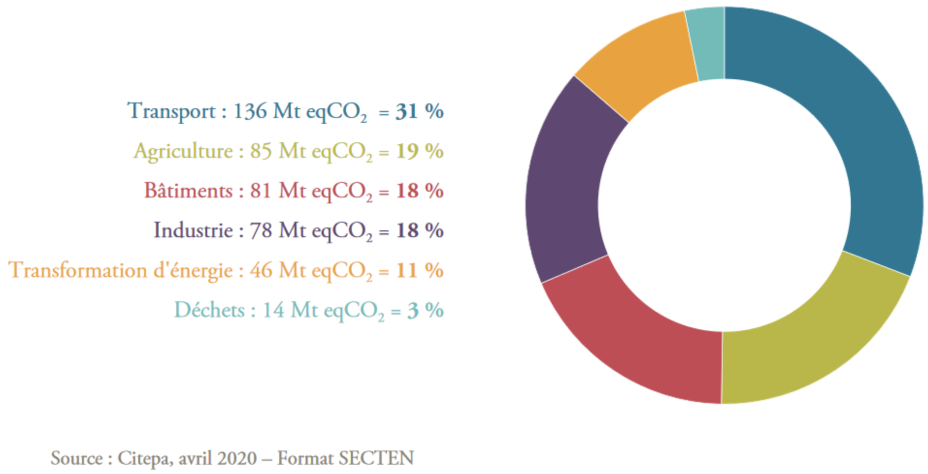


Figure 1 – Émissions nationales de **gaz à effet de serre en 2019**



- High mitigation potential in transport <-> Combination of varied measures [31]
  - Low-carbon fuels -> higher flows of metals & lower flow of oil
  - Lowering vehicules energy intensities -> lower flows of oil & metals
  - Encouraging modal shift to lower-carbon passenger & freight systems

    -> lower flows of oil + short-to-medium term higher flows of metals for infrastructure investments
  - Avoid journeys where possible -> lower flows of oils
- This kind of configuration apply generally
  - Specific augmentations in flows of metal are required to lower oil flows
  - Competition between uses requiring metals -> priorities will need to be established

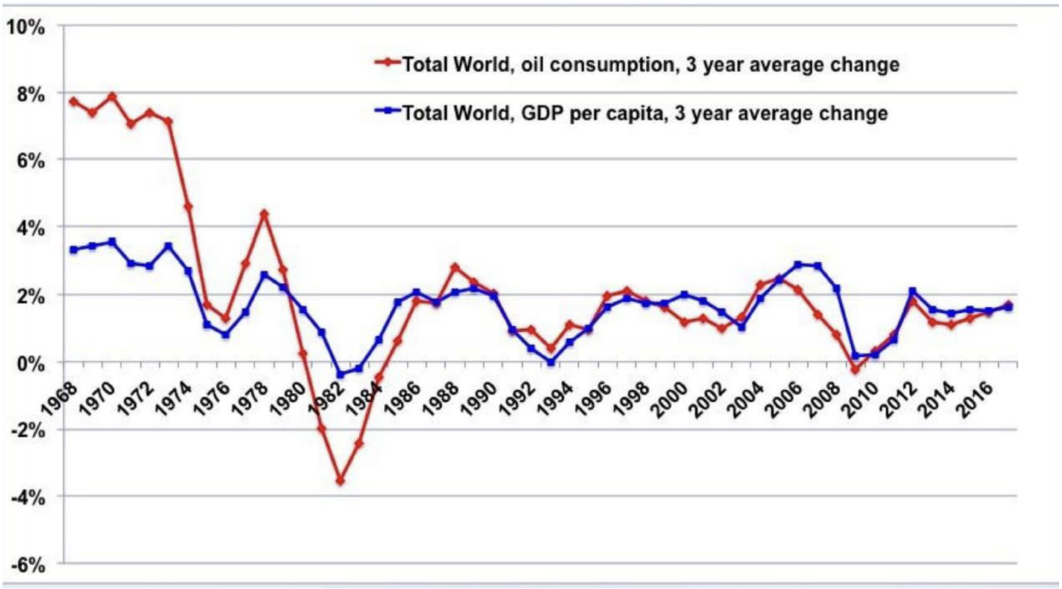
ii)Economics interdependancies

[15] JANCOVICI, Jean-Marc, 2019. Les Energies fossiles. *Ecole des Mines* [online].

[34] HABERL, H., *et al*, 2020. A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II : synthesizing the insights. DOI 10.1088/1748-9326/ab842a[1].

[33] HCC, 2020. Rapport annuel - Redresser le cap, relancer la transition. *Haut Conseil pour le Climat* [online]. 2020.

- At world scale, there is a historical link between primary energy & material consumption, and economic production (as measured by GDP) [15] & [34]
    - There is no consensus on the exact nature of the relationship nowadays [33]
    - But we know that energy & material availability enables GDP growth
    - And GDP growth, by anticipation of economic growth causes energy & material use



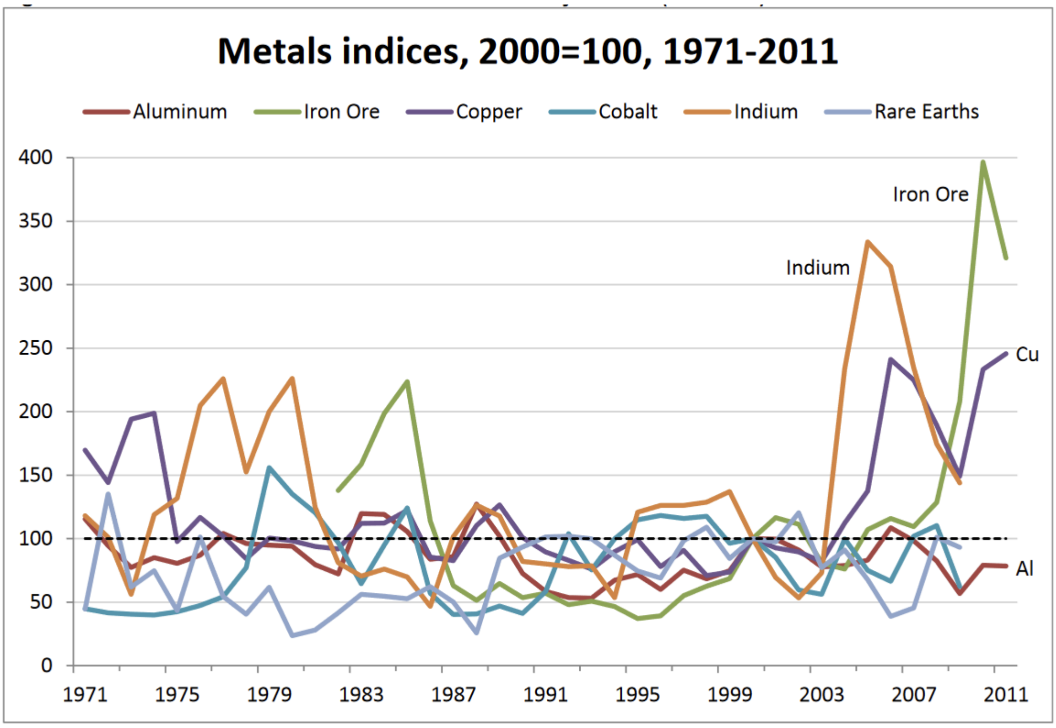
- A lot of ambitious climate target rely on the concept of « decoupling » [34]
    - Promotion of economic growth while reducing material & energy footprint (EMF)
    - When theorized as absolute -> EMF reduction & GDP growth
    - When theorized as relative -> EMF slow growth & GDP high growth
- Recent systematic review clarifies that :
    - Relative decoupling is frequent for material use, GHG emissions, but not exergy
    - Relative decoupling of GDP and primary energy use can be caused by energy efficiency (higher ratio of exergy / primary energy use)
    - Absolute decoupling situations are very rare and are related to small short-term reductions of emissions
    - No evidence that absolute decoupling can be generalized
- Degrowth/Sufficiency currently seems indispensible to meet climate target and sustainable use of abiotic resources:
    - Require a contraction of current economics functionning
    - And even fundamental changes in its functionning too
    - A byproduct of this scientific inquiries is that GDP is more & more considered as an irrelevant indicator for these problematics

[1] https://doi.org/10.1088/1748-9326/ab842a

iii)Volatility of prices

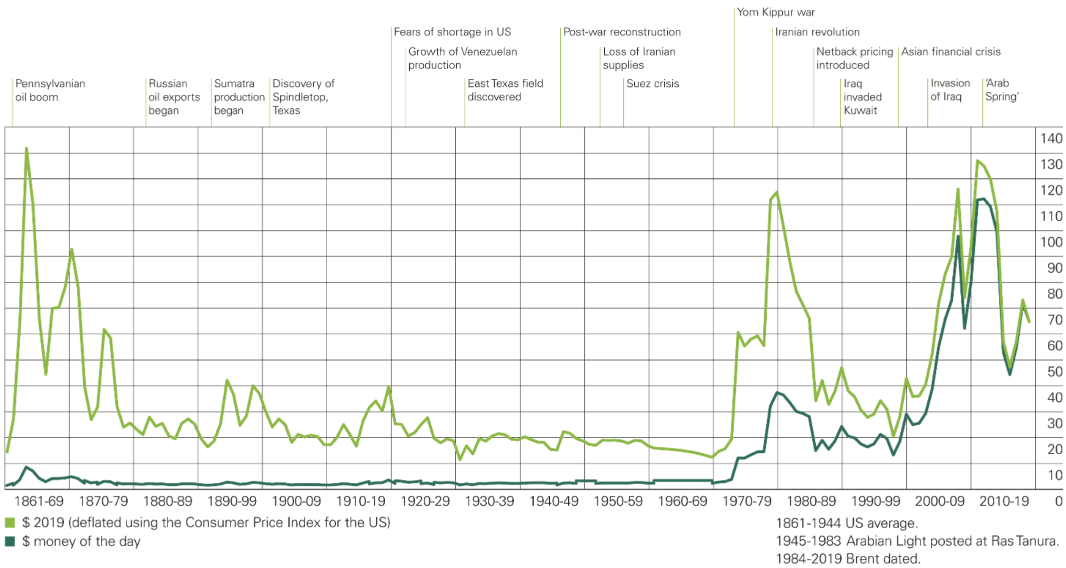
[35] ECORYS, 2012. *Mapping resource prices: the past & the future* [online]. Final report to European Comission.

- Base metals' prices are historically quite constant relatively to each others but individual resource's price is highly volatile [35]



[6] BP, 2020. BP Statistical Review of World Energy. [online].

- Oil's price is highly volatile too[6]



- Resources's prices underlying determinations
    - Percieved availability through control of producers
    - Degree of substitutability
- Resources's prices mecanisms of formations

- Over-the-counter (OTC) markets: traditionnal mecanism
- Annual or multi-year supply contracts: mainly, Fe and Fe allows
- Pricing on forward markets
- Special case of precious metals: considered as quasi-money or OTC.

- Historically, numerous resources exchanges were operated by intermediates
    - Contemporary period: developpment of financialization
    - Alignment of Raw materials on securities -> far less intermediaries
    - Developpment of financial product derivatives + capitalistic concentrations of producers

      -> overvalued prices and speculations

[36] MITTEAU, Gilles, 2018. Economie et finance du pétrole - Heu?reka. [online].

- Financial markets's specific effects
    - Efficiency of market -> Trends of prices themselves tend to diseapear
    - Short-term interest of traders -> Short-term volatility
    - Complexity of the product and implications of prices variations on the economy

      -> Long-term volatility + impossibility to know for sure the causes of prices variations

  -> There is no « natural price-signalling » mecanism that makes a non- renewable resource progressively more expensive overtime

  -> The « natural » functionning of Financial markets seems to impply that the reduction of energy & material flows lead to higher volatility, or maybe higher « volatility of volatility »

For detailed reasonning, strong recommendation of Youtuber Heu?reka on Economy & Finance of oil

b)Contracting flows

i)Limits of efficiency

- Like recycling, energy efficiency is necessary
    - Allow to reduce flows for a given performance
    - 25% energy yield -> 30% energy yield -> 1/6 of oil flows spared per year
    - 25% energy yield -> 50% energy yield -> 1/2 of oil flows spared per year
    - Same goes for « material efficiency » (diminshing the quantity of material needed to achieve a given functionnality)
- But it is not sufficient, and could even be harmful on the global scale
    - Energy efficiency, when only measure applied, have mainly cost reduction effects
    - Cost reduction could then lead to democratize preexisting uses or create new ones
    - This then would lead to an overall increase in energy consumption

[37] SORRELL, Steve, 2007. *The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency*. [online]. UKERC

- This would be called a « ***rebound effect*** » [37]
    - The « economy-wide » rebound effect is of combination of direct and indirect rebound effects that can interact with each other

- Some basic examples of direct rebound effect :
    - If fuel-efficient vehicules make travel cheaper -> Consumers may choose to drive further / more often -> Offsets the energy savings
    - If a factory uses energy more efficiently -> Becomes more profitable -> May generate further investments -> More production
- Some basic examples of indirect rebound effect :
    - Drivers of fuel-efficient cars may spend the money saved bying petrol on other energy intensive goods or services (ex: overseas flight)

[38] JEVONS, William Stanley, 1865. The Coal Question. . 1865. P. 213.

- Rebound effect concept coms back to the XIXth century
    - Firstly known as « Jevons paradox » from W. J. Jevons [38]
    - Steam-engines' efficiency had been increased by 10-fold at least in a century
    - Consumption of coal had greatly increased anyway (x 6 in 50 years)
- The same considerations could be made about today :
    - Energy efficiency of cars' engines have never been better
    - Our oil cosumption dedicated to it have never been higher

  -> Could be explained by:
    - The growth of car use driven by low cost of oil
    - And spared cost of cars invested in high-tech supplementary functions which increase car's weight and maintain oil consumption
    - The increase in heavy vehicules like SUVs

[39] STERN, David I., 2017. How accurate are energy intensity projections?. DOI 10.1007/s10584-017-2003-3[1].

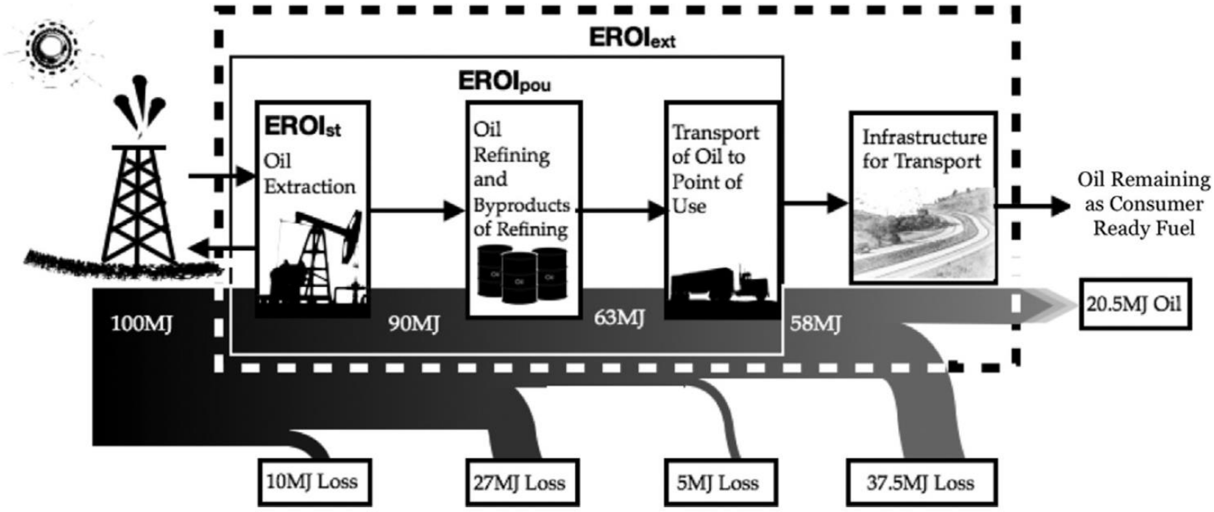
- Quantified contemporary estimations are complicated :
    - There is indeed a correlation between various measures of energy efficiency and continuing growth of overall energy consumption
    - But the causal links between these trends are not clear
    - Difficulty to assess other things than direct rebound effects
- That being said, evidence suggest that : [37]
    - It has the potential to widely vary between technologies, sectors, income groups
    - In OECD countries, automotive transport, household heating & cooling can relatively robustly be considered subjects to a direct rebound effect of 10-30% (microscale)
    - Current energy or material efficiency policies are not up to the task (macroscale)
- Predictions of energy footprint decline itself are generally too optimistic [39]

ii)Physics inevitability

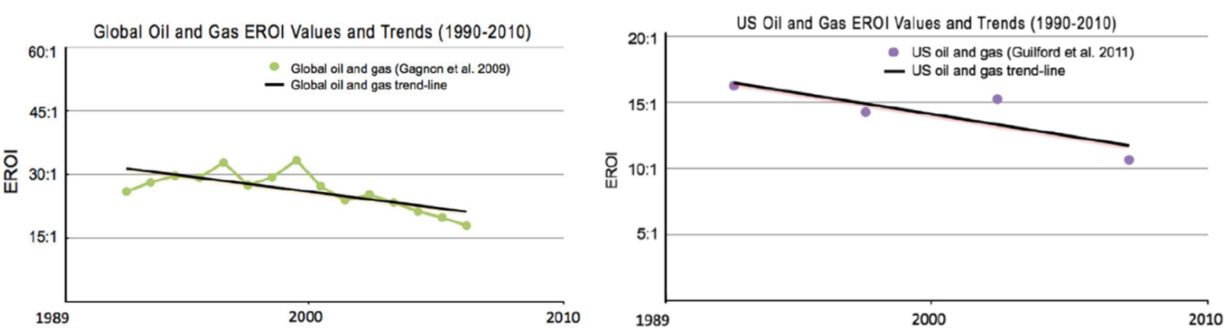
[1] https://doi.org/10.1007/s10584-017-2003-3

[40] HALL, Charles A. S., et al., 2014. EROI of different fuels and the implications for society. DOI 10.1016/j.enpol.2013.05.049[1].

- Material & Energy flows will decline anyway due to the physics underlying the production peak
  - We've seen that the decline in ores's grade do lead to an exponential demand in energy for base metals extraction, and that a mineralogical barrier can happen for rarer metals
  - But oil itself needs energy to be extracted!
- Last notion of this course : ***EROI – Energy return on investment***
  - Ratio of energy delivered by a specific energy vector and the energy invested in the capture & delivery of this energy
  - Measures the relative quality of energy vectors
- Varied possible choices of boundaries in systemic assessments, so as much EROI calculations: standard ; point of use ; extended ; societal
  - Estimates re complicated due to oil compagnies low level of transparency

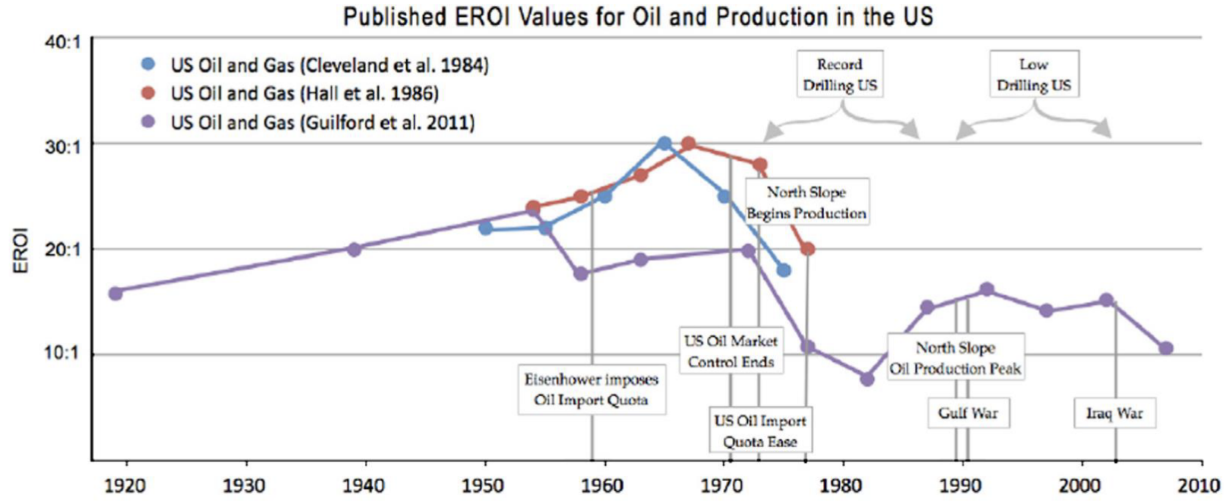


- As oil is often extracted together with natural gas, calculations can be tricky
  - But all estimates tend to show a progressive decrease in EROI for every place where data is available : ***here in USA***

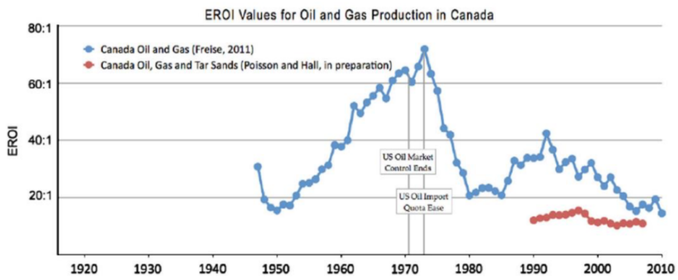


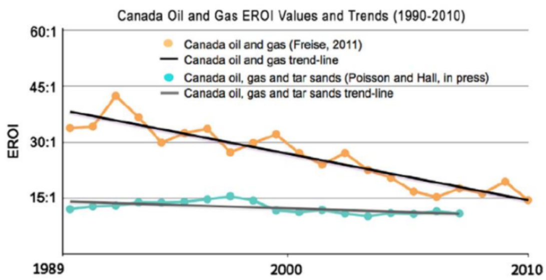
- Is there a trend for oil already?
  - It seems so
  - All estimates tend to show a progressive decrease in EROI for every place where data is available : ***here in USA***

[1] https://www.sciencedirect.com/science/article/pii/S0301421513003856?via%3Dihub

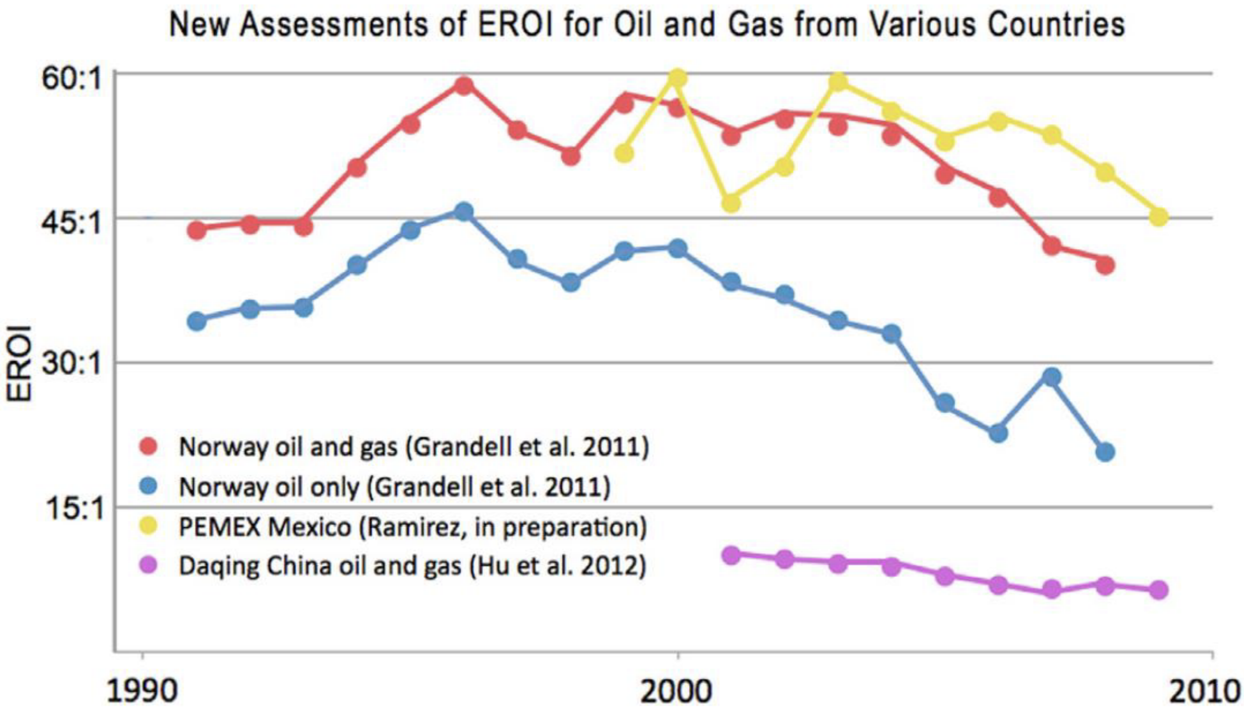


- Is there a trend for oil already?
    - Pretty much so!
    - All estimates tend to show a progressive decrease in EROI for every place where data is available : ***here in Canada***

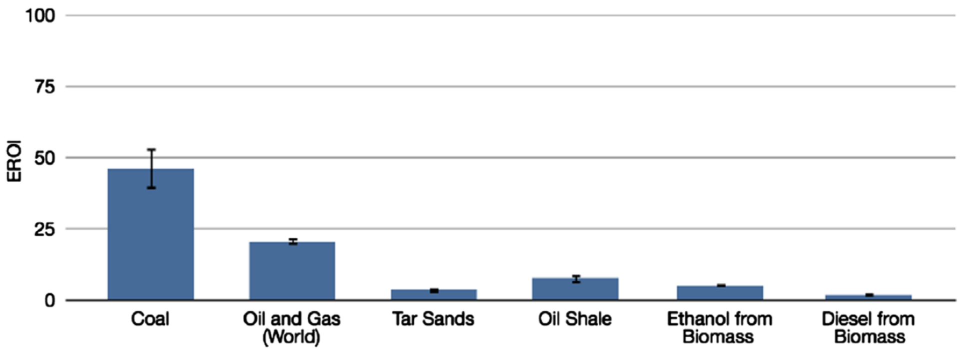




- Is there a trend for oil already?
    - Undeniably so!
    - All estimates tend to show a progressive decrease in EROI for every place where data is available : ***here in various other countries***



- It is logical from what we've seen about the concentration of resources in general. But why does it especially matter here?
  - The decrease of the EROI of conventionnal oil means we'll need to set aside a growing share of the oil flows just to continue to have a flow
  - This share of oil « lost » will no longer be used to supply other sectors [36]
  - Non conventionnal oils have a base EROI quite lower than conventionnal (and will also decrease with their further exploitation) [40]



iii)Managing consequences, tackling causes

[36] MITTEAU, Gilles, 2018. Economie et finance du pétrole -Heu?reka. [online].

[40] HALL, Charles A. S., *et al.*, 2014. EROI of different fuels and the implications for society. DOI 10.1016/j.enpol.2013.05.049[1].

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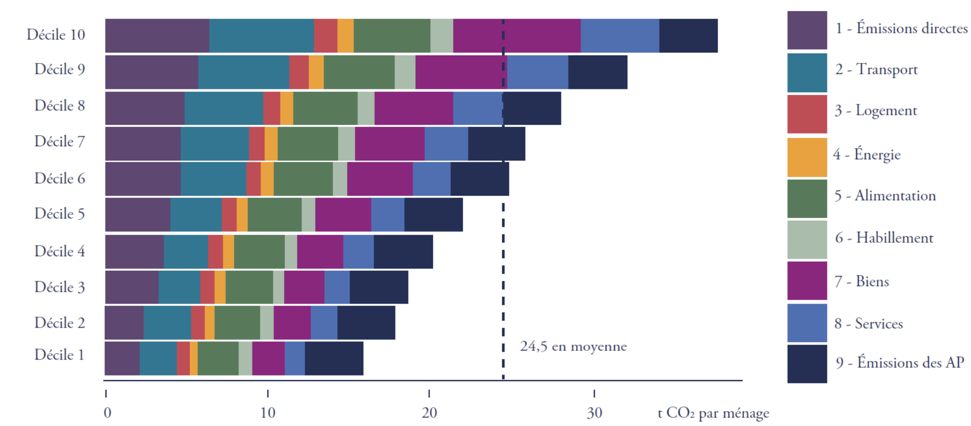
- As there is no absolute decoupling, a contraction & instability of economy and as we know it seems unavoidable in the medium-term, regardless of climate change [36] & [40]
  - By « economy », here, we mean that all socioeconomical & geopolitical relationships will be impacted
  - Social acceptability of dynamics created by contracting flows will be a key component of the success ofmitigating policies [33]

-> Ecological transition is also a social one

Figure 23 – Empreinte carbone par ménage, décomposée par source et produit selon les déciles de niveau de vie



Source : Malliet *et al.* (2020) d'après EXIOBASE 3, INSEE BdF 2011 et SDES-CGDD - http://carbonconsumptionsurvey.eu/

[1] https://www.sciencedirect.com/science/article/pii/S0301421513003856?via%3Dihub

- This is were we, as engineers & citizens, have apart to play
- We would gain a lot to take inspiration from the 7 principles of low-techs [30]
    1. Challenging needs
    2. Design and produce truly sustainable
    3. Orienting knowledge to resources' savings
    4. Striking a technical balance between performance & conviviality
    5. Relocalize without losing the right scale effects
    6. De-machinizing services
    7. Knowing to remain modest

[30] BIHOUIX, Philippe, 2014. *L'Age des low techs : vers une civilisation techniquement soutenable.* Seuil.

c)Medias

https://pod.utt.fr/video/3950-ev14-abiotic-resources-71-stakes-of-flows/

https://pod.utt.fr/video/3951-ev14-abiotic-resources-72-contracting-flows/

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[1] https://doi.org/10.1016/j.resconrec.2020.104748

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[4] https://doi.org/10.1016/j.jclepro.2014.04.035
[5] https://doi.org/10.1126/science.1217501
[6] https://doi.org/10.1016/j.gloenvcha.2014.03.013
[7] https://doi.org/10.1016/j.resconrec.2019.104617
[8] https://doi.org/10.1016/j.enpol.2020.111870

3. Carbon Cycle

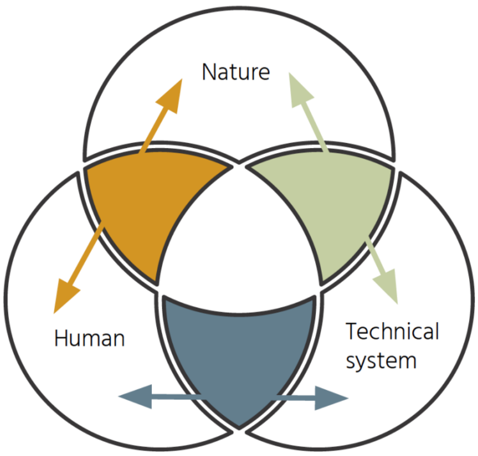
Table of contents

1. Introduction to carbon
    - Goal of the class
    - What is carbon?
2. Carbon Reservoirs
    - In this part you will have an overview of the different carbon reservoirs or carbon pools.
3. Carbon cycle
    - Here you will see short carbon cycles, and long carbon cycle.
4. Anthropogenic activities and carbon cycle
    - You will see the anthropogenic causes of the carbon cycle disruption and the consequences on the biosphere and on human organizations.

3.1. Introduction to carbon

3.1.1. Why are we talking about carbon?

- There are interactions between nature, the technosphere and human organizations.
- This cycle is disturbed by anthropogenic activities.



3.1.2. What is the link with the project?

Technical system				S <=> N	N <=> H	S <=> H
Stages	Description	Cause / Consequence	Modeling scale			
First life cycle stage : Conception		Cause	Macro			
			Meso			
			Micro			
		Consequence / impacts	Macro			
			Meso			
			Micro			
...						

3.1.3. What will you learn?

- Know the different resevoirs of carbon and how the carbon cycle works.
- Know the anthropogenic causes of the disruption of the carbon cycle.

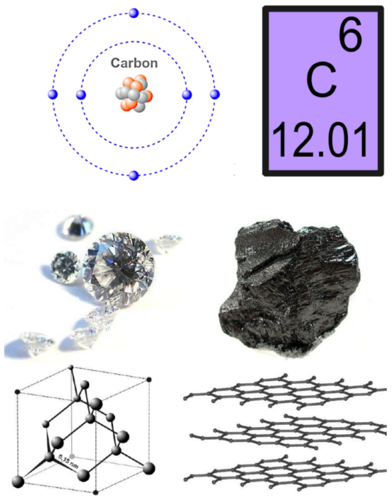
The competences developed are :

- systemic thinking
- critical thinking

3.1.4. What is carbon?

Définition

"Carbon : the building block of life. You may have heard this sentence, but have you fully considered what it really means? All living things are made of elements, the most abundant of which are, oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus. Of these, carbon is the best at joining with other elements to form compounds necessary for life, such as sugars, starches, fats, and proteins. Together, all these forms of carbon account for approximately half of the total dry mass of living things."



Carbon atom model, diamond and graphite *(Sundqvist, 2021)*

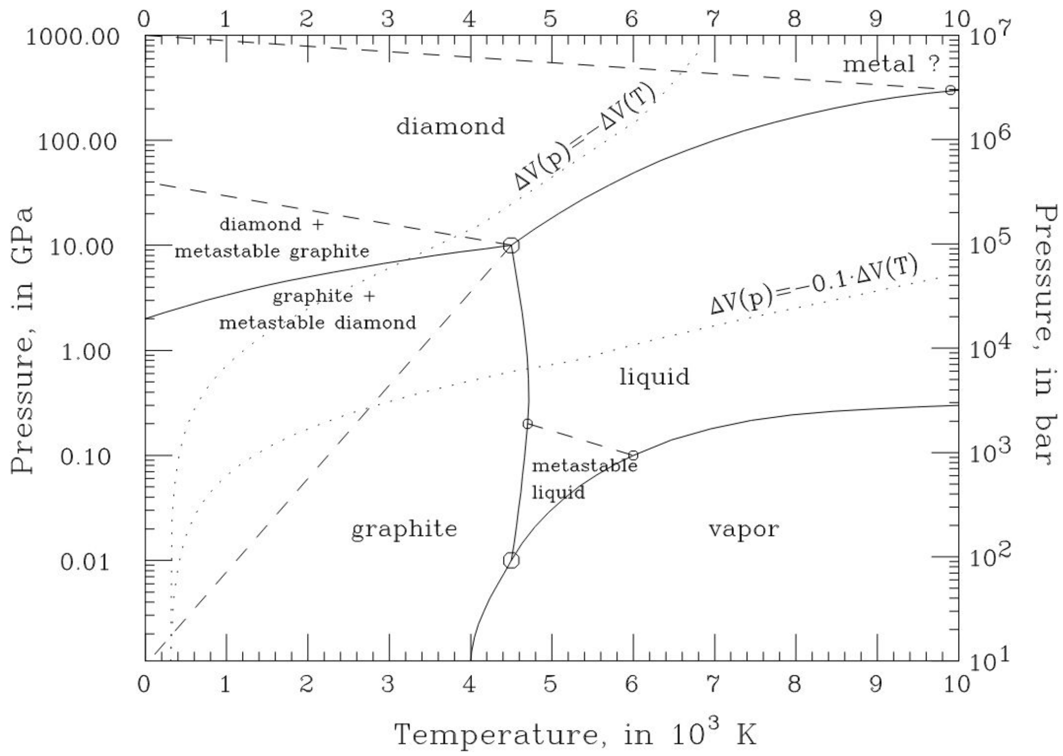
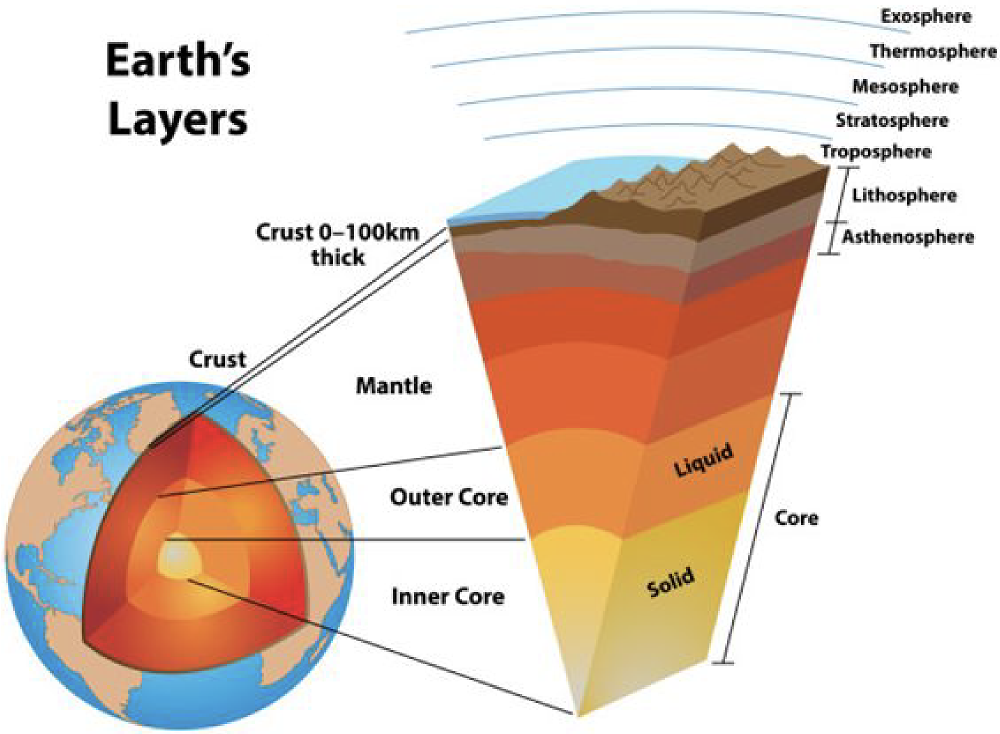


Figure : Phase diagram of carbon taken from http://cds.cern.ch/record/691793/files/project-note-78.pdf

3.1.5. Reminder : Earth's Layers



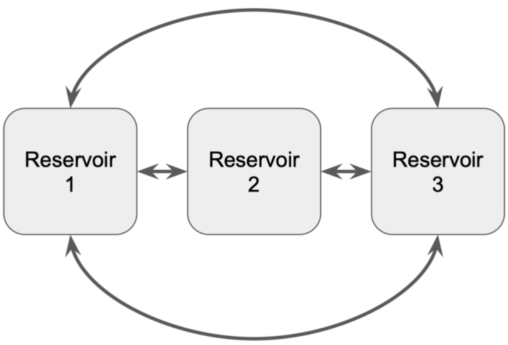
Video to watch
https://www.youtube.com/watch?v=QCKr-rP_o5U

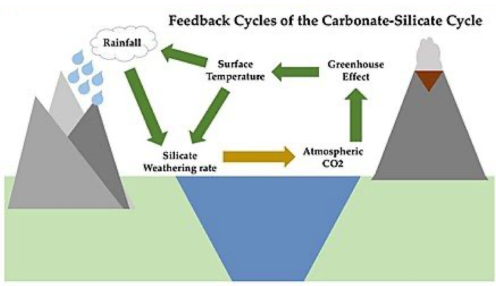
3.1.6. Media

https://pod.utt.fr/video/4140-carboncycle-video1mov/

3.2. Carbon Reservoirs

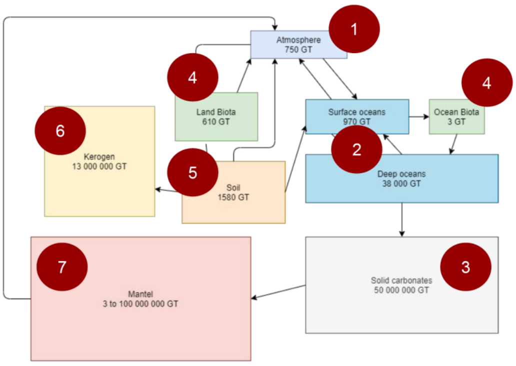
3.2.1. The concept of reservoir





source : Wikipedia

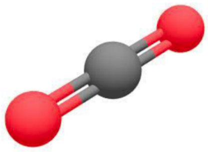
3.2.2. Carbon reservoirs



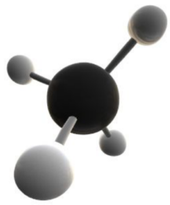
The global carbon-cycle showing the different reservoirs for carbon and the exchanges between reservoirs in GT (109) . The arrows represent natural processes of carbon transfer between atmosphere and earth.

Reservoir 1 : Atmosphere

- CO_2



- CH_4



Reservoir 2 : Ocean

- 2⁄3 of the Earth's surface.
- store and transporte heat.
- making the atmosphere warm and moist.
- enable life to flourish in the sea and on land.

Table 1.1 | Properties of water and their implications for the ocean.

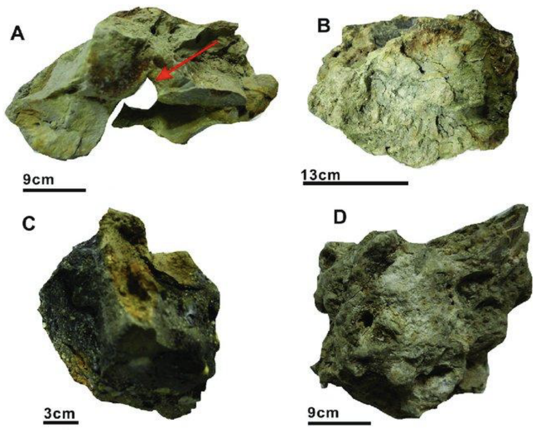
Property	Definition	How water compares with other substances	Implications for the ocean and climate system
Specific heat capacity	Heat required to raise temperature of a unit mass by 1 K.	Highest for all liquids and solids (except NH_3).	Limits temperature range over the Earth.
Latent heat of evaporation	Heat required to evaporate a unit mass.	Highest.	Phase changes are important for the storage and release of heat.
Solvent power	Ability to dissolve substances.	Highest.	Ocean has a high storage of dissolved elements, including nutrients.
Surface tension	Attraction of liquid surface to itself.	Highest.	Bubbles and drops form, which enhance the air–sea transfer of water and gases.
Conduction of heat	Transfer of heat between molecules.	Highest of all liquids.	Heat easily transferred, although turbulence usually dominates.
Molecular viscosity	Resistance to flow.	Less than most liquids.	Ocean easily circulates over the Earth.

- CO_2 (aqueous),
- H_2CO_3 (carbonic acid),
- HCO_3^- (bicarbonate ion),
- CO_3^{2-} (carbonate ion).

$DIC = [CO_2(aq)] + [H_2CO_3] + [HCO_3^-] + [CO_3^{2-}]$

Reservoir 3: Solid carbonates or carbonates rock

Calcite or calcium carbonate, $CaCO_3$

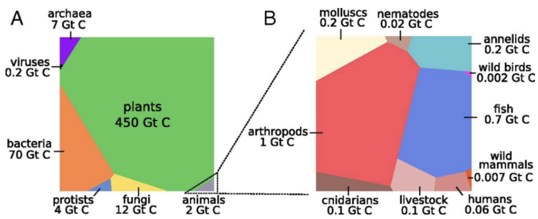


Photographs of typical seep carbonate rocks.

Layers of sedimentary rock in Makhtesh Ramon

Xi, Shichuan, Xin Zhang, Zengfeng Du, Lianfu Li, Bing Wang, Zhendong Luan, Chao Lian, et Jun Yan. 2018. « Laser Raman Detection of Authigenic Carbonates from Cold Seeps at the Formosa Ridge and East of the Pear River Mouth Basin in the South China Sea ». Journal of Asian Earth Sciences 168 (décembre) : 207-24. https://doi.org/10.1016/j.jseaes.2018.01.023

Reservoir 4: Biomass (oceanic and continental)



- Polysaccharides
- Protein
- Lipids

Graphical representation of the global biomass distribution by taxa.

Bar-On, Yinon M., Rob Phillips, et Ron Milo. 2018. « The Biomass Distribution on Earth ». Proceedings of the National Academy of Sciences 115 (25): 6506-11. https://doi.org/10.1073/pnas.1711842115.

Reservoir 5 : Soil

950 GtC is inorganic carbon.

Credit: Antonio Jordán (distributed via imaggeo.egu.eu)

1500 Gt is organic carbon.

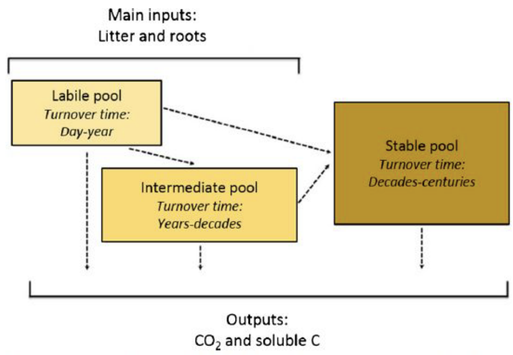


Fig. 1 Conceptual pools of soil C depending on its turnover time: labile, intermediate and stable pools

Dignac, Marie-France, Delphine Derrien, Pierre Barr , S bastien Barot, Lauric C cillon, Claire Chenu, Tiphaine Chevallier, et al. 2017. Increasing Soil Carbon Storage: Mechanisms, Effects of Agricultural Practices and Proxies. A Review . Agronomy for Sustainable Development 37 (2) : 14. https://doi.org/10.1007/s13593-017-0421-2.

Organic matter turnover (EN) = renouvellement de la matière organique (FR)

shoots (EN) = pousses (FR)

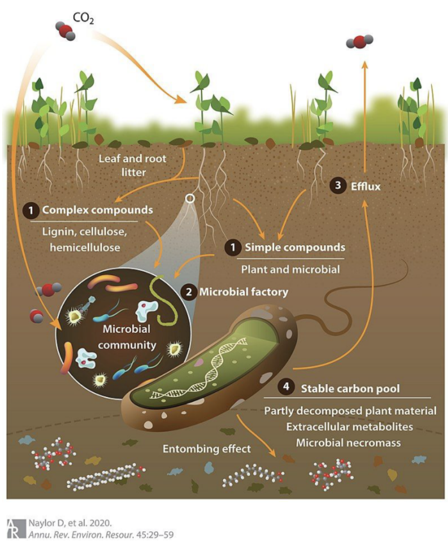


Figure : Soil carbon (C) cycle through the microbial loop. Carbon dioxide (CO2) in the atmosphere is fixed by plants (or autotrophic microorganisms) and added to soil through processes such as ❶ root exudation of low-molecular weight simple carbon compounds, or deposition of leaf and root litter leading to accumulation of complex plant polysaccharides. ❷ Through these processes, carbon is made bioavailable to the microbial metabolic “factory” and subsequently is either ❸ respired to the atmosphere or ❹ enters the stable carbon pool as microbial necromass. The exact balance of carbon efflux versus persistence is a function of several factors, including aboveground plant community composition and root exudate profiles, environmental variables, and collective microbial phenotypes [i.e., the metaphenome (19)].

Naylor, Dan, Natalie Sadler, Arunima Bhattacharjee, Emily B. Graham, Christopher R. Anderton, Ryan McClure, Mary Lipton, Kirsten S. Hofmockel, et Janet K. Jansson. 2020. « Soil Microbiomes Under Climate Change and Implications for Carbon Cycling ». Annual Review of Environment and Resources 45 (1): 29-59. https://doi.org/10.1146/annurev-environ-012320-082720.

Reservoir 6 : Kerogen

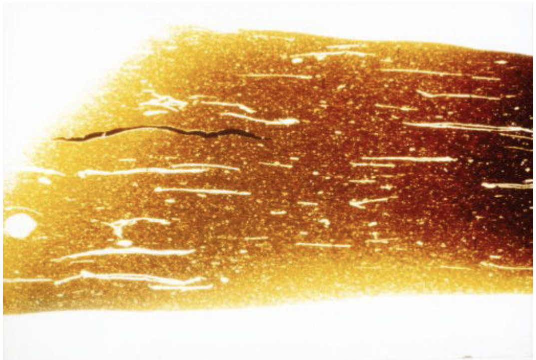
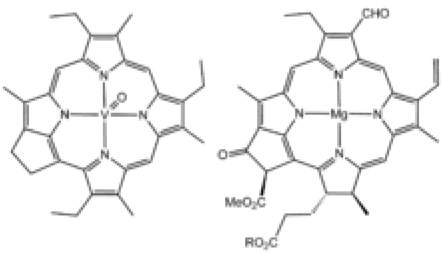


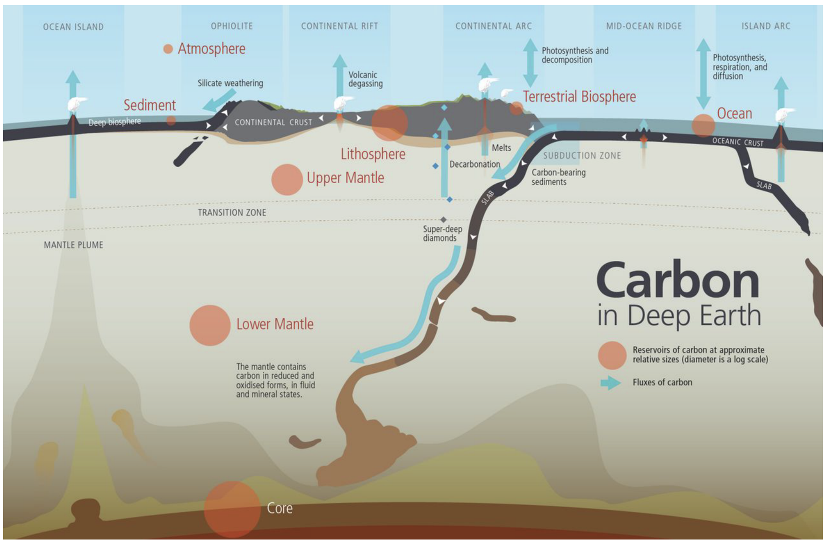
Figure. Photomicrograph of kerogen. This is the sapropelic Kimmeridge Coal (Upper Jurassic) from Dorset, UK. Cross-sections of bivalves are ubiquitous, and carbonized plant detritus is also visible. Reproduced with permission from Selley RC (2000) Applied Sedimentology, 2nd edn. London: Academic Press.



Structure of a vanadium porphyrin compound (left) extracted from petroleum by Alfred E. Treibs, father of organic geochemistry. The close structural similarity of this molecule and chlorophyll a (right) helped establish that petroleum was derived from plants

Kvenvolden, Keith A. 2006. « Organic Geochemistry – A Retrospective of Its First 70 Years ». *Organic Geochemistry* 37 (1): 1-11. https://doi.org/10.1016/j.orggeochem.2005.09.001.

Reservoir 7 : Mantle



3.2.3. Media

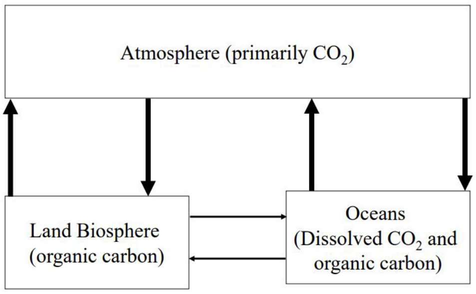
https://pod.utt.fr/video/4141-carboncycle-video2mov/

3.3. Carbon cycle

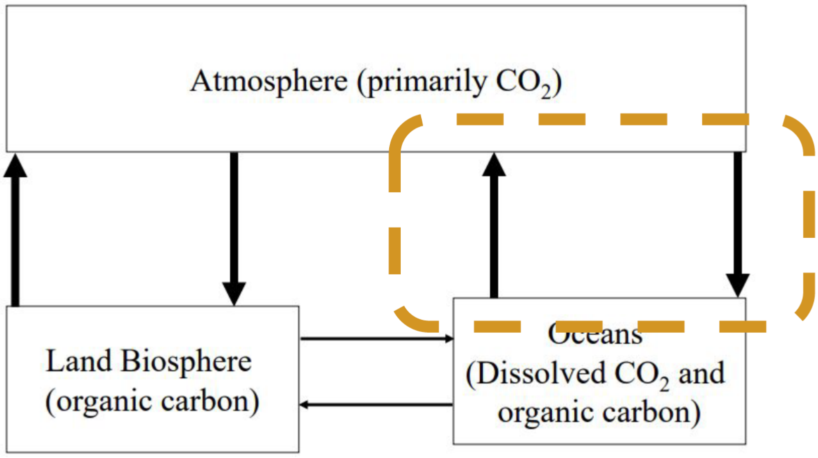
3.3.1. Short cycle

a)Carbon cycle : Short cycle part 1

SHORT CYCLE



Hydrosphere - atmosphere exchanges



Dissolution of atmospheric CO2 in the ocean and degassing of CO2 from the ocean to the atmosphere

- Exchange of 300 GT of CO2 per year ;
- Residence time = quantity of the element in the reservoir / sum of the flows of contribution in the reservoir.

Video to watch :

Henry's Law and Gas Solubility Explained https://www.youtube.com/watch?v=9JtTpPEesOk

At constant temperature and saturation, the partial pressure in the vapor phase of a volatile solute is proportional to the mole fraction of that body in the liquid solution.

So the higher the temperature, the less CO_2 is soluble, and the more carbon is redistributed to the atmosphere.

For a given amount of carbon in the ocean+atmosphere, the amount of CO_2 in the atmosphere increases if the temperature increases.

CO_2 control : CO_2 balance in the hydrosphere

$$CO_2(g) + H_2O \Leftrightarrow CO_2(aq) + H_2O$$

$$CO_2(aq) + H_2O \Leftrightarrow H_2CO_3$$

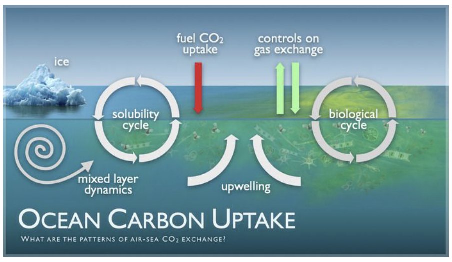
$$Ko = \frac{[H_2CO_3]}{P_{CO_2}}$$

$$H_2CO_3 + \Leftrightarrow H^+ + HCO_3^-$$

$$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$$

Ocean pH	Prevailing form
pH<5	H_2CO_3
pH 7-8	HCO_3^-
pH>9	CO_3^{2-}

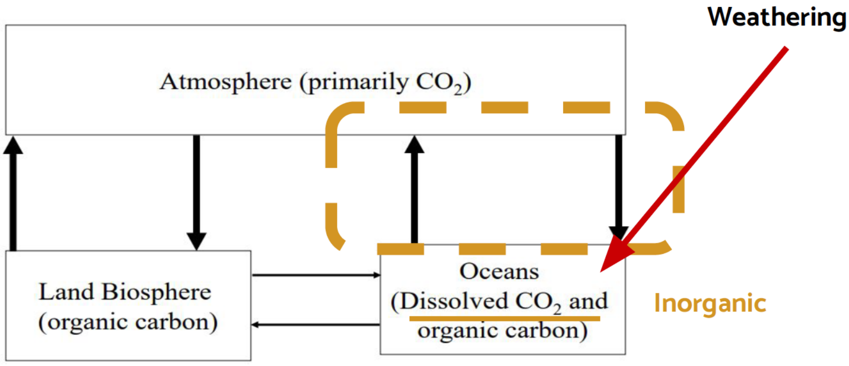
$DIC = [CO_2(aq)] + [H_2CO_3] + [HCO_3^-] + [CO_3^{2-}]$



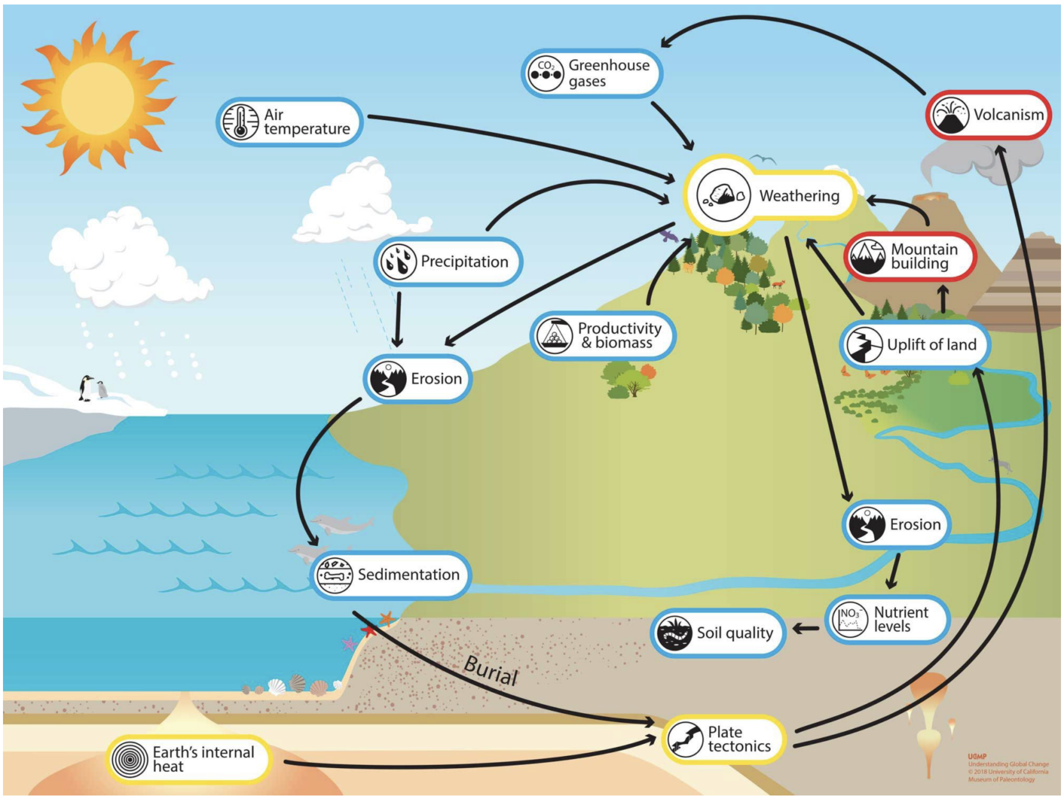
b)Carbon cycle : Short cycle part 2

Diversion and leakage in the hydrosphere-atmosphere physical exchanges

There is a diversion of carbon flux from the atmosphere to the ocean through the weathering of rocks.



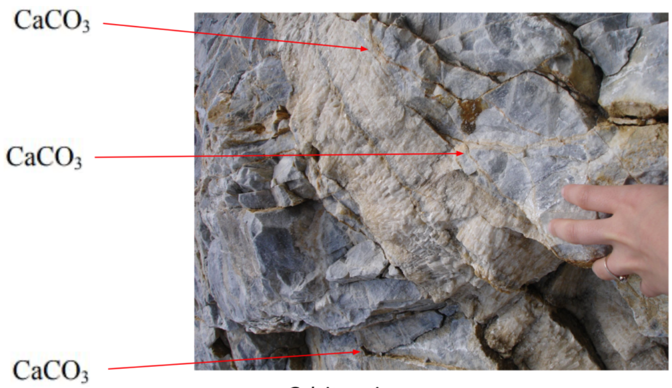
To know more about weathering of rocks : https://www.youtube.com/watch?v=sk B_A2sfBcY



There is a leakage of carbon from the hydrosphere to the lithosphere : the formation of carbonates.

1 Gt of calcite per year.

Brow calcite crystals

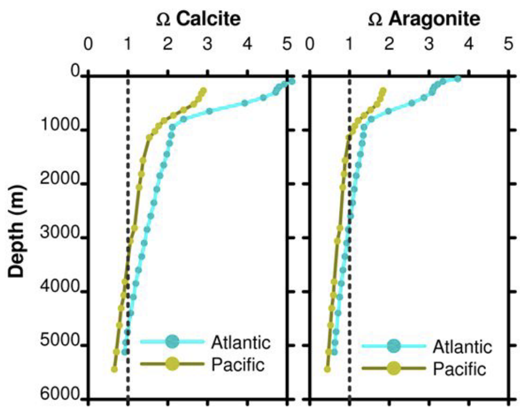


Calcite veins

Calcium carbonate solubility

$$CaCO_3 \Leftrightarrow Ca^{2+} + CO_3^{2-}$$

$$\Omega = \frac{\text{have}}{\text{need for saturation}} = \frac{[Ca^{2+}\text{ present}][CO_3^{2-}\text{ present}]}{[Ca^{2+}\text{ needed}][CO_3^{2-}\text{ needed}]}$$



$\Omega > 1$ Precipitation

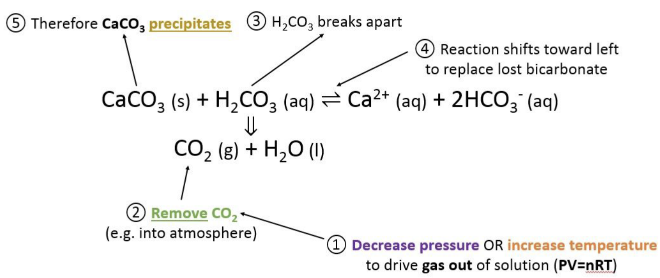
$\Omega = 1$ Equilibrium

$\Omega < 1$ Dissolution

Modern Sea Surface $\Omega \approx 2\text{-}5$

Sea surface is supersaturated with respect to $CaCO_3$, but calcium carbonates are not constantly precipitating.

To precipitate calcium carbonate :



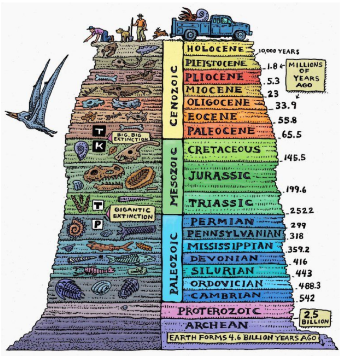
(http://www.luckysci.com)

$$CaAl_2Si_2O_8 + 3H_2O + 2CO_2 = Al_2Si_2O_5(OH)_4 + Ca^{2+} + 2HCO_3^-$$

Anorthite Kaolinite bicarbonate ion

with $Ca^{2+} + HCO_3^- \Leftrightarrow CaCO_3 + H_2CO_3$

$$CaAl_2Si_2O_8 + \mathbf{2}H_2O + CO_2 \rightarrow CaCO_3 + Al_2Si_2O_5(OH)_4$$



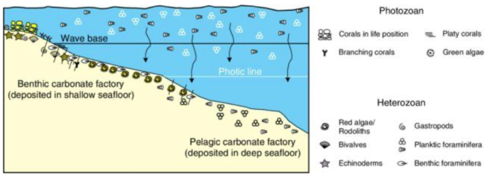
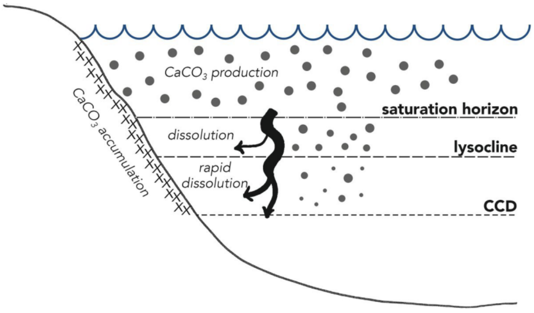
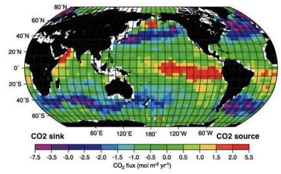


Figure. Main tropical marine biogenic carbonate producers and carbonate factories with respect to water depth.

Sgc, Servicio Geológico Colombiano. 2019. « Chapter 9 ». 38. Bogotá: Servicio Geológico Colombiano. https://doi.org/10.32685/pub.esp.37.2019.09



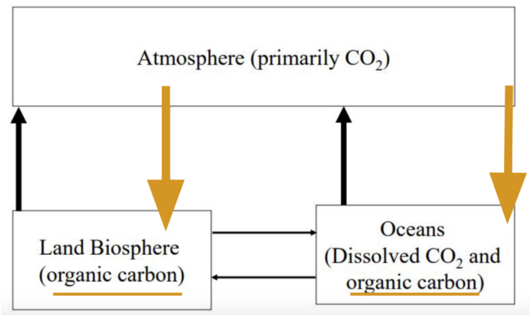
Woosley, Ryan J. 2018. « Carbonate Compensation Depth ». In *Encyclopedia of Geochemistry*, édit par William M. White, 204-5. Encyclopedia of Earth Sciences Series. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-39312-4_85.



c)Carbon cycle : Short cycle part 3

Photosynthesis and respiration

From atmosphere to biomasse continental and oceanic



Photosynthesis

440 Gt of CO_2 per year, shared equally between the oceans and the continents.

Oxygenic photosynthesis

$6CO_2 + 12H_2O$ + light energy → $C_6H_{12}O_6 + 6O_2 + 6H_2O$

carbon dioxide, water → glucose, oxygen, water

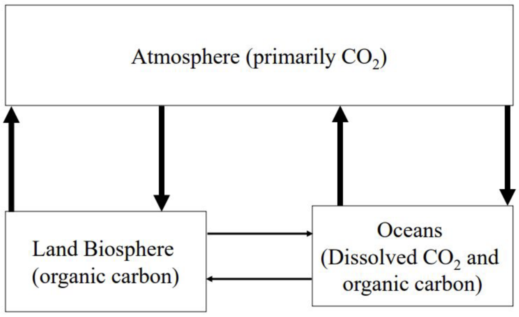
Anoxygenic photosynthesis

$CO_2 + 2H_2A$ + light energy → $[CH_2O] + 2A + H_2O$

carbon dioxide, electron donor* → carbohydrate, water

*$H_2A = H_2O$, H_2S, H_2, or other electron donor

From biomass to atmosphere

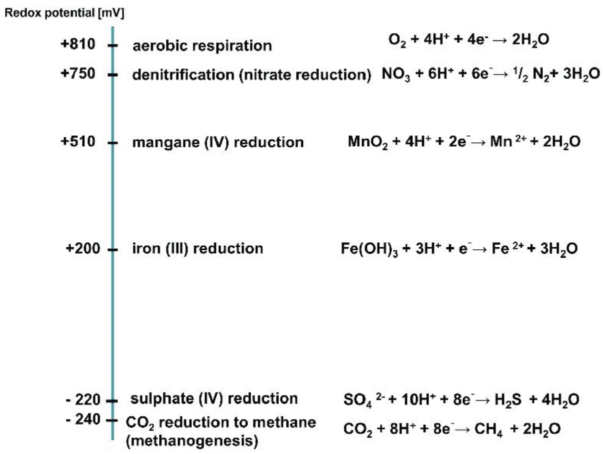


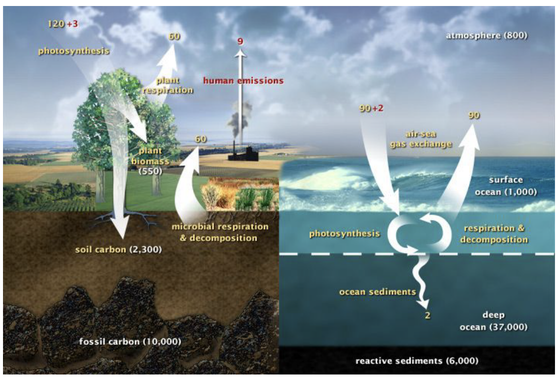
- Breathing 90º
- Natural combustion 10º

Aerobic respiration chemical reaction :

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_20 + 6CO_2 + \textbf{energy}$$

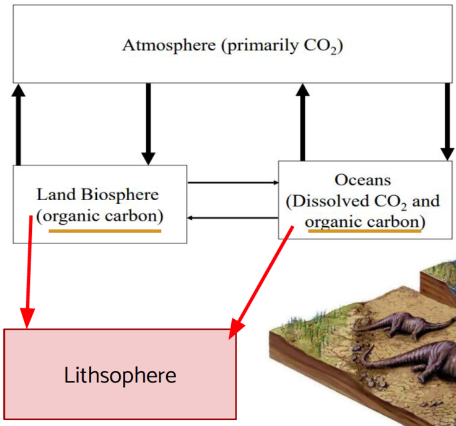
(glucose + oxygen → water + carbon dioxide + energy)

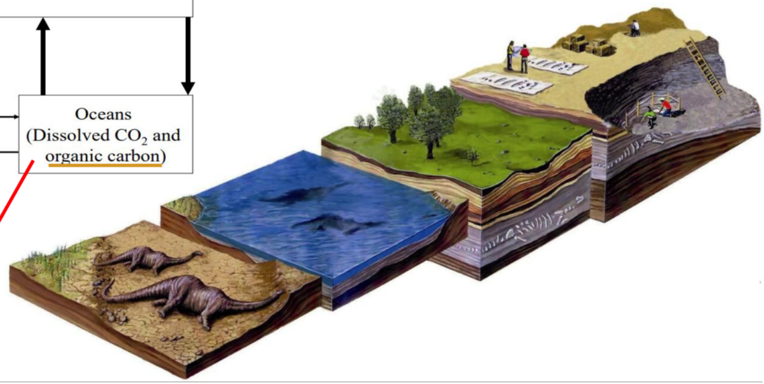




d)Carbon cycle : Short cycle part 4

Organic carbon leakage to lithosphere :kerogen formation





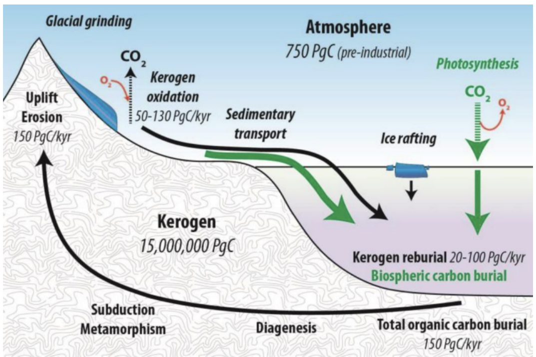
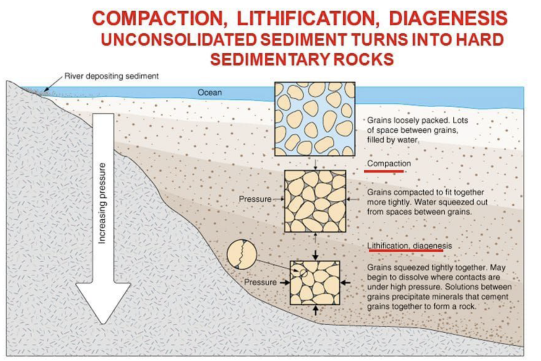
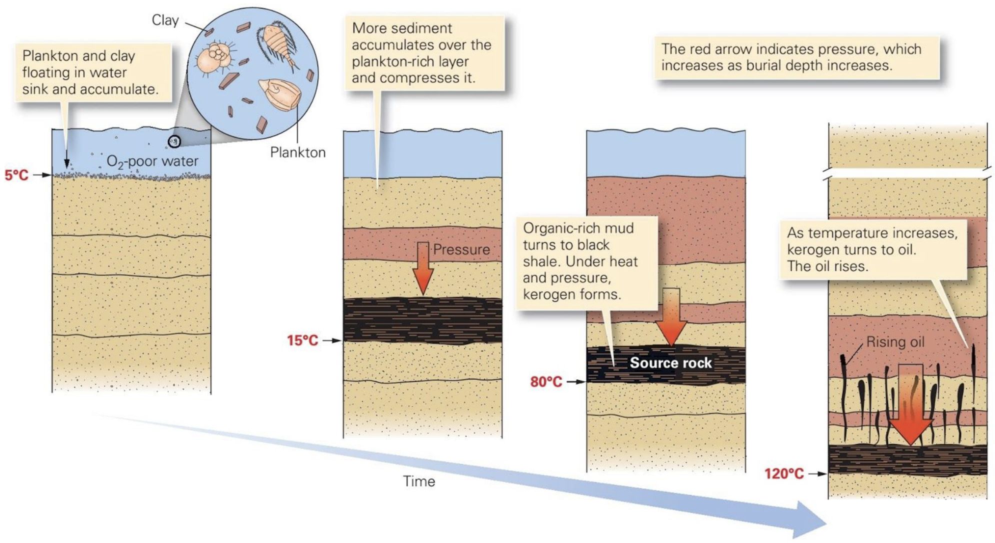


Figure : Organic carbon cycle with the flow of kerogen (black solid lines) and the flow of biospheric carbon (green solid lines) showing both the fixation of atmospheric CO2 by terrestrial and marine primary productivity. The combined flux of reworked kerogen and biospheric carbon into ocean sediments constitutes total organic carbon burial entering the endogenous kerogen pool (Galy et al., 2015; Hedges and Oades, 1997).

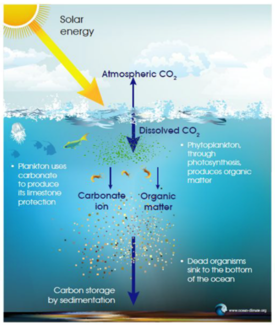


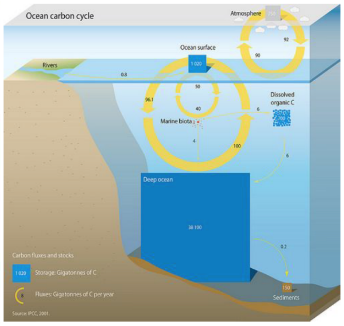
Davidson 4.25

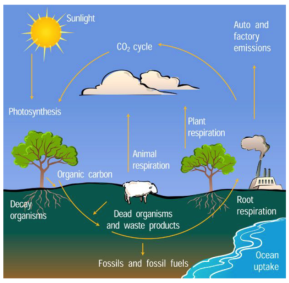
Similar to snow turning to ice



e)Conclusion of the short cycle

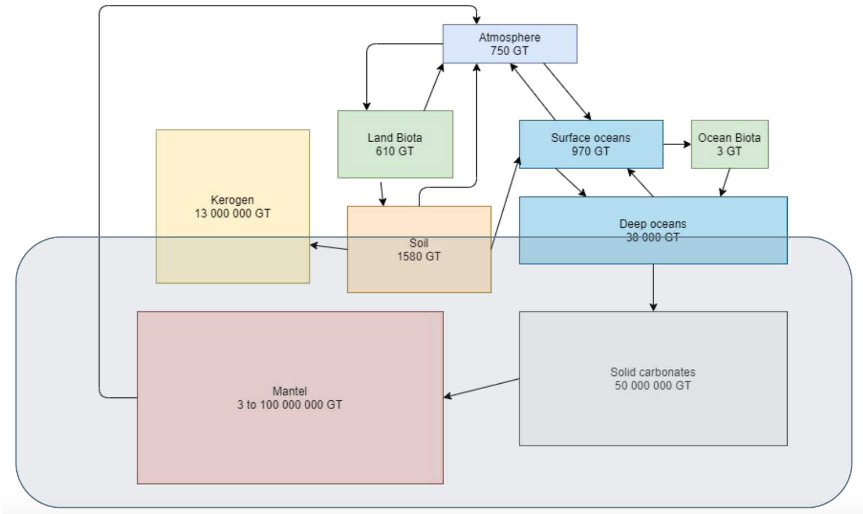


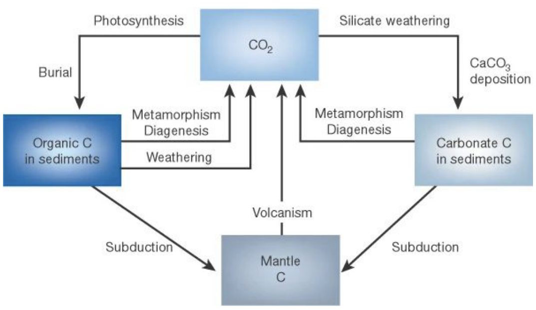




3.3.2. Long cycle

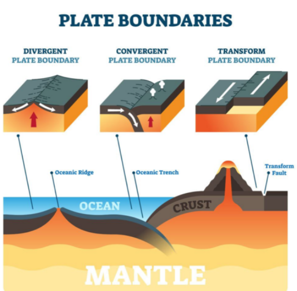
Long carbon cycle

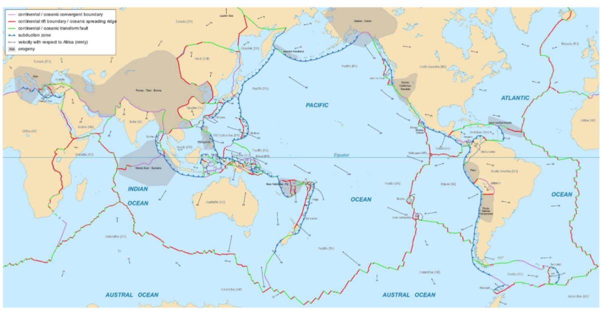


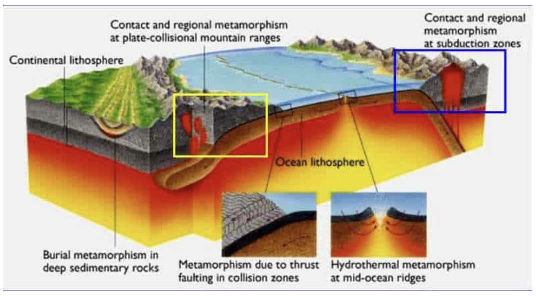


1. $CO_2 + CaSiO_3 <-> CaCO_3 + SiO_2$
2. $CO_2 + H_2O <-> CH_2O + O_2$

Berner, Robert A. 2003. « The Long-Term Carbon Cycle, Fossil Fuels and Atmospheric Composition ». Nature 426 (6964): 323-26. https://doi.org/10.1038/nature02131.







$CO_2 + CaSiO_3 \leftrightarrow CaCO_3 + SiO_2$

Contact Metamorphism Vs. Regional Metamorphism
https://www.geologypage.com/

Trap rock forming a characteristic pavement, Giant's Causeway, Northern Ireland (left)

Three Devil's Grade in mid-Moses Coulee , USA (right)

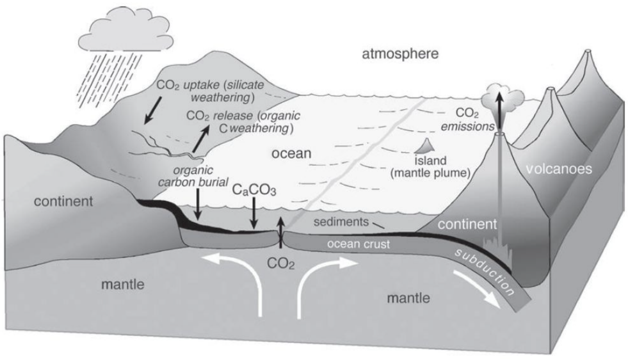
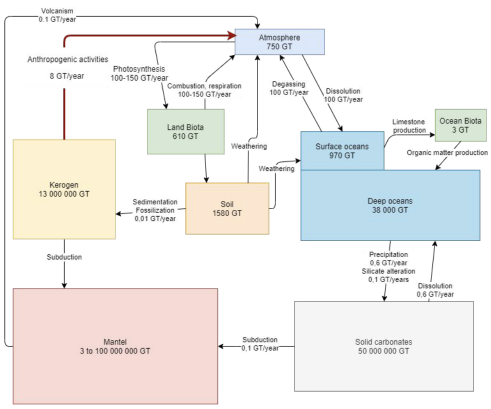


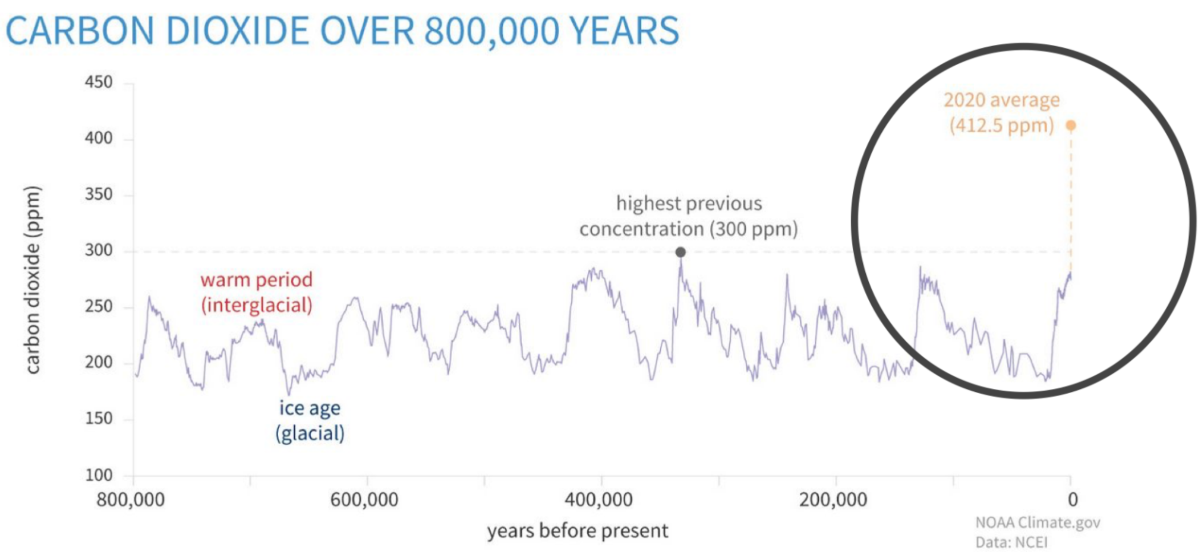
Figure 1.8 Schematic figure of the long-term carbon system involving the exchange of carbon between the atmosphere, ocean and terrestrial systems on geological timescales. Carbon is transferred from the atmosphere to ocean sediments via chemical weathering, where acidic rain reacts with silica rocks, forming calcium and carbonate ions washed out to sea, which precipitate and form calcium carbonate sediments: $CO_2 + CaSiO_3 \rightarrow CaCO_3 + SiO_2$. Subduction of ocean crust below continents leads to eventual melting, releasing carbon dioxide contained within any organic carbon or calcium carbonate in the sediments through volcanic emissions, hydrothermal vents or mantle plumes. For a detailed discussion of the chemical and geological processes, see Berner (1999); drawn by K. Lancaster.



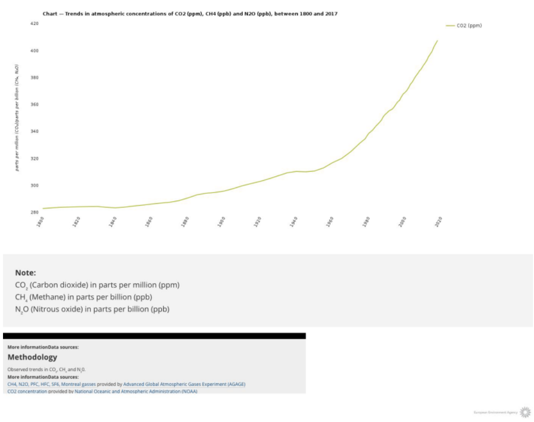
3.4. Anthropogenic activities and carbon cycle

3.4.1. Disruption of the carbon cycle-causes

a)Observation of disruption of the carbon cycle



Atmospheric carbon dioxide concentrations (CO2) in parts per million (ppm) for the past 800,000 years. On the geologic time scale, the increase to today's levels (orange dashed line) looks virtually instantaneous. Graph by NOAA Climate.gov based on data from Lüthi et al., 2008, via the NOAA NCEI Paleoclimatology Program.



"Recent increases in global averaged temperature over the last decade already appear to be outside the normal variability of temperature changes for the last thousand years. A number of different analyses strongly suggest that this temperature increase is resulting from the increasing atmospheric concentrations of greenhouse gases, thus lending credence to the concerns about much larger changes in climate being predicted for the coming decades." (Wuebbles, 2001)

b)Source of the disruption

« Human-related emissions from fossil fuel use have been estimated as far back as 1751. Before 1863, emissions did not exceed 0.1 GtC/year. However, by 1995 they had reached 6.5 GtC/year, giving an average emission growth rate slightly greater than 3% per year over the last two and a half centuries. Recent growth rates have been significantly lower, at 1.8% per year between 1970 and 1995. Emissions were initially dominated by coal. Since 1985, liquids have been the main source of emissions despite their lower carbon intensity. The regional pattern of emissions has also changed. Once dominated by Europe and North America, developing nations are providing an increasing share of emissions. »

« Physical processes and feedbacks caused by land-use change, that may have an impact on the climate, include changes in albedo and surface roughness, and the exchange between land and atmosphere of water vapour and greenhouse gases [see section 4, chapter 7]. [...] Land-use change may also affect the climate system through biological processes and feedbacks involving the terrestrial vegetation, which may lead to changes in the sources and sinks of carbon in its various forms [see chapter 3)]. » (IPCC, 2001)

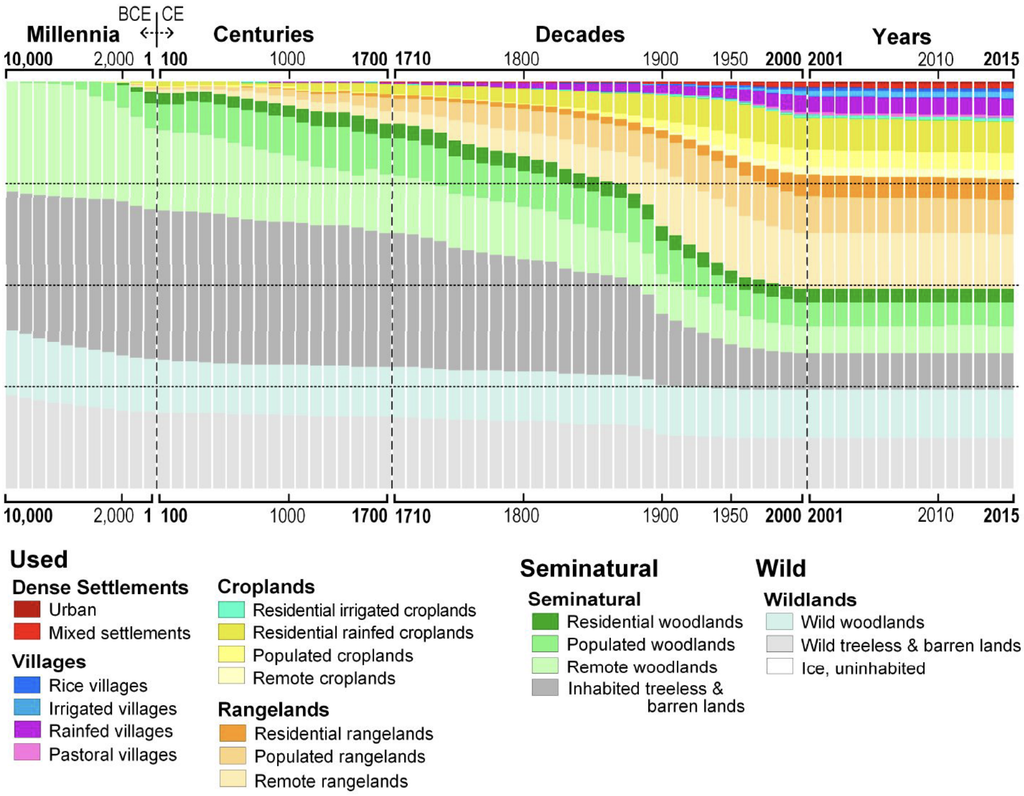


Figure 3. Changes in anthrome areas from 10,000 BCE to 2015 CE for all time intervals in the Anthromes 12K dataset. Relative global areas are indicated using stacked bars, which add up to the total global land area, not including Ice, uninhabited, which showed no significant changes over time.

c)Media

https://pod.utt.fr/video/4142-carboncycle-video8mov/

3.4.2. Disruption of the carbon cycle-environmental issues

a)Consequences on the Earth System

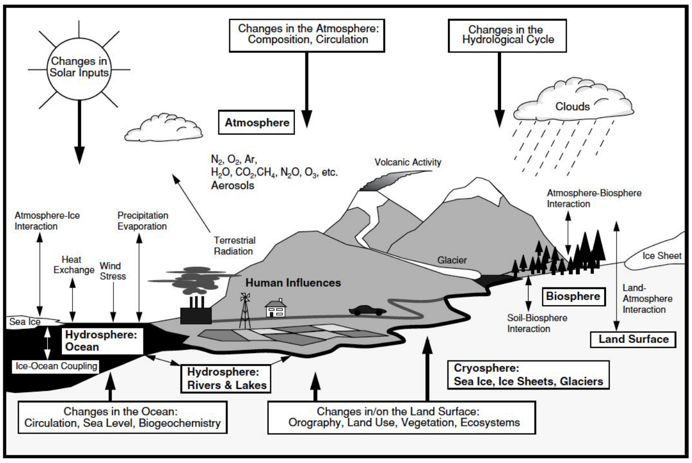
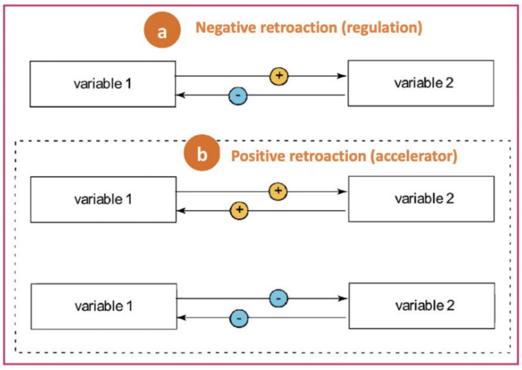


Figure 1.1: Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows).

Figure: Schematic representation of negative (a: regulating effect on the system) and positive (b: runaway effect on the system) feedback loops.

An arrow with a "+" indicates a positive correlation between the two variables, and an arrow with a "-" indicates a negative correlation.



b)Feedback loops

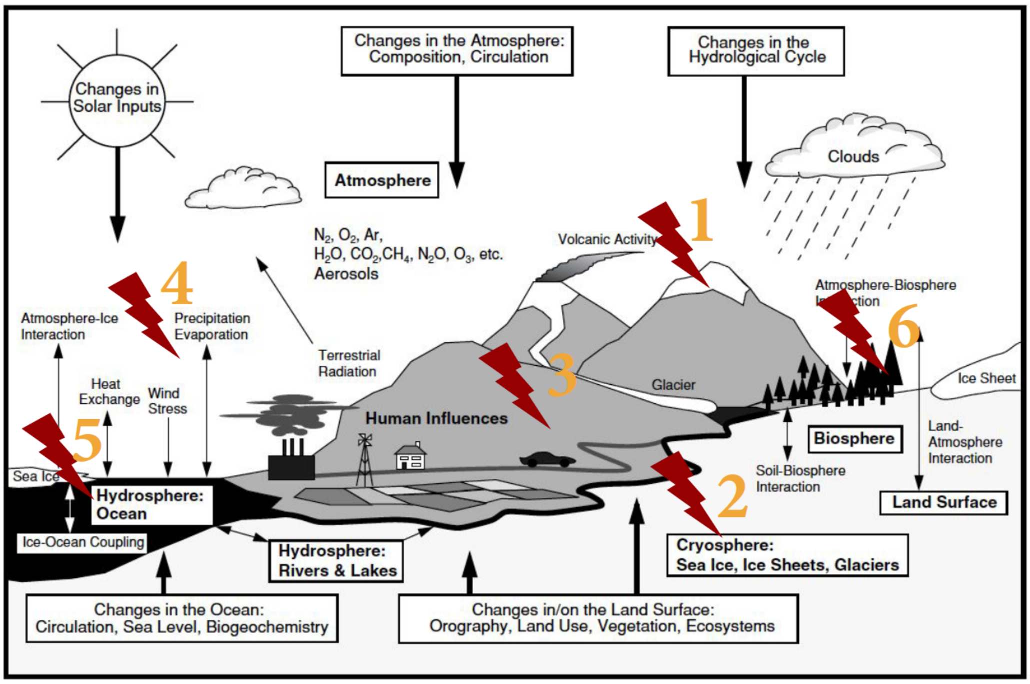


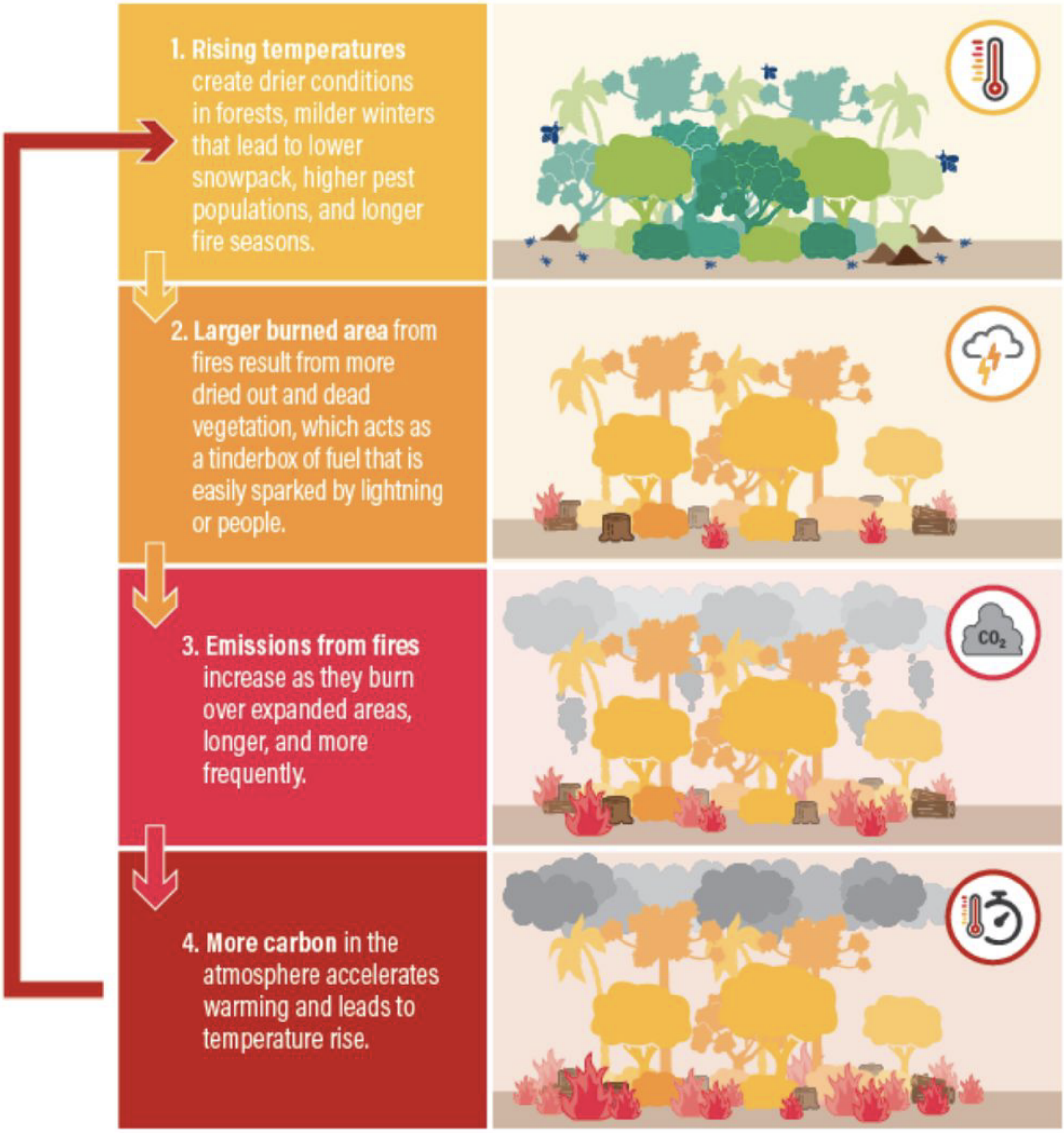
Figure 1.1: Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows).

Tatiana Reyes, Paul Robineau, Lou Grimal, Claudine Gillot, Kunzhang GUO

Feedback loop 1

Feedback loop 2

Feedback loop 6



Source: Global Forest Watch.
20.09.15

GLOBAL FOREST WATCH
WORLD RESOURCES INSTITUTE

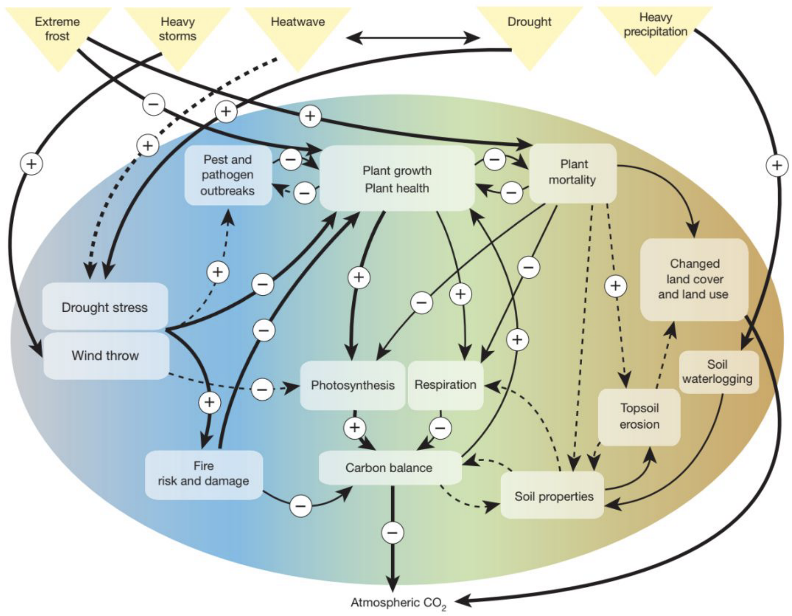
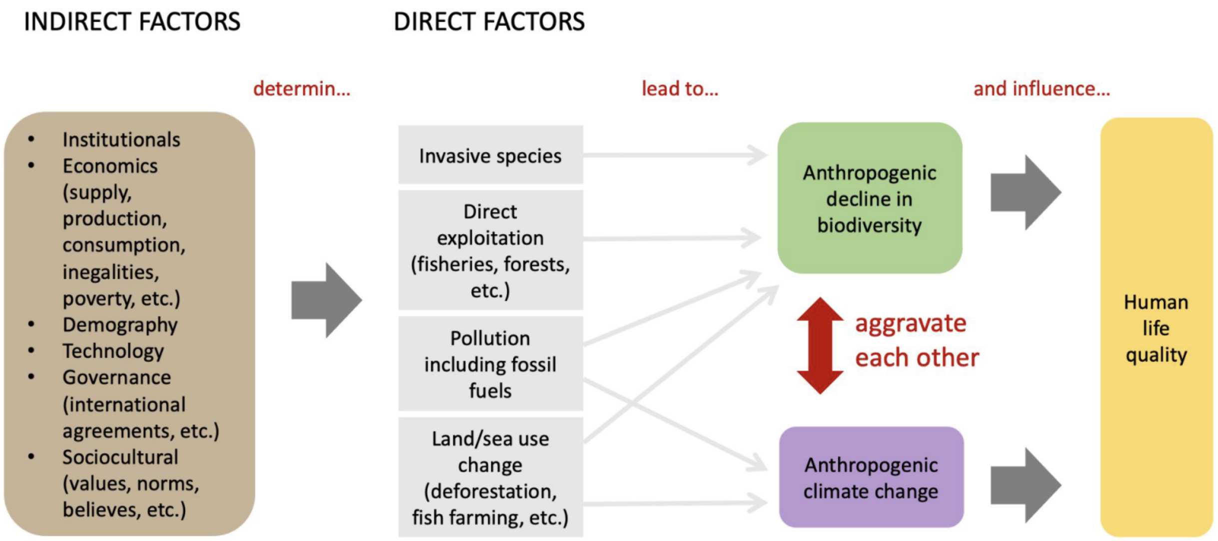


Figure 1 | Processes and feedbacks triggered by extreme climate events. The extreme events considered are droughts and heatwaves, heavy storms, heavy precipitation and extreme frost. Solid arrows show direct impacts; dashed arrows show indirect impacts. The relative importance of the impact relationship is shown by arrow width (broader arrows are more important).

Feedback loop 6 : focus biodiversity

- Climate change = main cause of biodiversity loss
- Preserving biodiversity = mitigating climate change
- /!\ technological solutions to mitigate climate change can have negative impacts on biodiversity
- Same causes: our socio-economic way of life



Anthropocene Atlas, Gemenne

Interesting source : https://ipbes.net/sites/default/files/2021-06/20210609_workshop_report_embargo_3pm_CEST_10_june_0.pdf

c)Media

https://pod.utt.fr/video/4143-carboncycle-video9mov/

3.4.3. Disruption of the carbon cycle-social issues

a)Social impacts

- Migrations
- Wars

El-Hinnawi (1985): « *those people who have been forced to leave their traditional habitat, temporarily or permanently, because of a marked environmental disruption (natural and/or triggered by people) that jeopardize their existence and/or seriously affects the quality of their life* ».

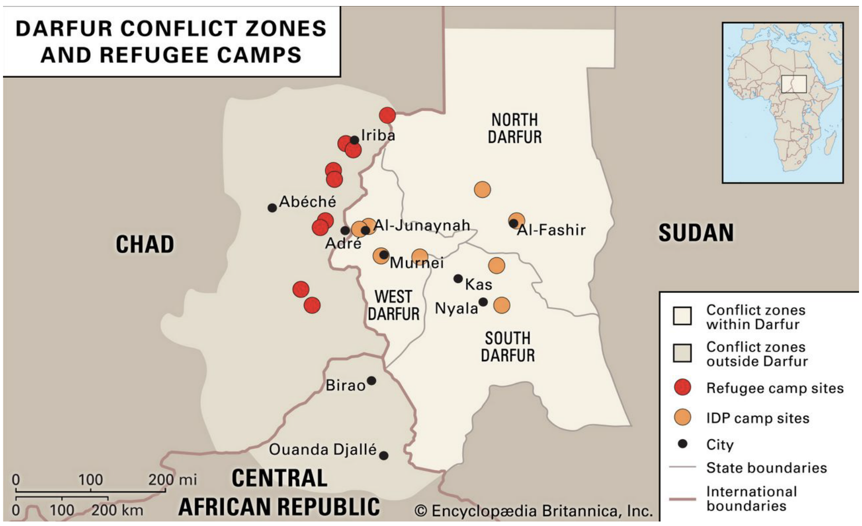
Table 4: Typology of Potential Migrations

Direct Climate Changes	Indirect Climate Changes	Type of Movement	Time Span
Gradual climate change	Chronic disasters such as drought, degradation	Seasonal labour migration. Temporary circulation	Seasonal
Gradual climate change	Chronic disasters-drought/ degradation	Contract labour migration	Yearly
Sudden or gradual climate change	Natural disasters/ severe drought/ Famine/Floods	Forced/distress migration	Temporary
Sudden or gradual climate change	Extreme Temperatures/ Sea Level Rise	Permanent migration	Lifetime

(Partially adapted from Kothari, 2002:20)

Définition Climate Refugees

- 1951 Refugee Convention: refugee = from political persecution (UN)
- “Climate Change Displaced People” : people whose habitat is threatened or is already at risk of being extinguished due to climatic change (Hodgkinson et al., 2009)
- “Climate refugees” or “forced climate migrants”



Britannica, The Editors of Encyclopaedia. "Darfur". Encyclopedia Britannica, Invalid Date, https://www.britannica.com/place/Darfur. Accessed 15 September 2021.

The complex ethnic distinctions in Darfur are perhaps less important than the contrast between agriculturalists and pastoralists. The relationship between the two is governed by competition for land and water resources, which can be affected by short- and long-term climate change (whether random, cyclical or greenhouse-induced), both in terms of absolute availability and geographical extent of the resources.

Jeffrey Mazo (2009) Chapter Three : Darfur : The First Modern Climate-ChangeConflict, The Adelphi Papers, 49:409, 73-86, DOI: 10.1080/19445571003755538

Définition Armed Conflicts

3 elements (Sakaguchi, 2017):

1. There are correlation between climate change and violence but no robust conclusion.
2. There are weak empirical support to the link between climate change and violence
3. Methodologies used in the different students have an impact on results

« Migration is generally considered to be the intermediate stage which links environmental degradation and disasters to conflict (Homer Dixon, 1991 and 1994) »

(Assessing the Impact of Climate Change on Migration and Conflict, Raleigh)

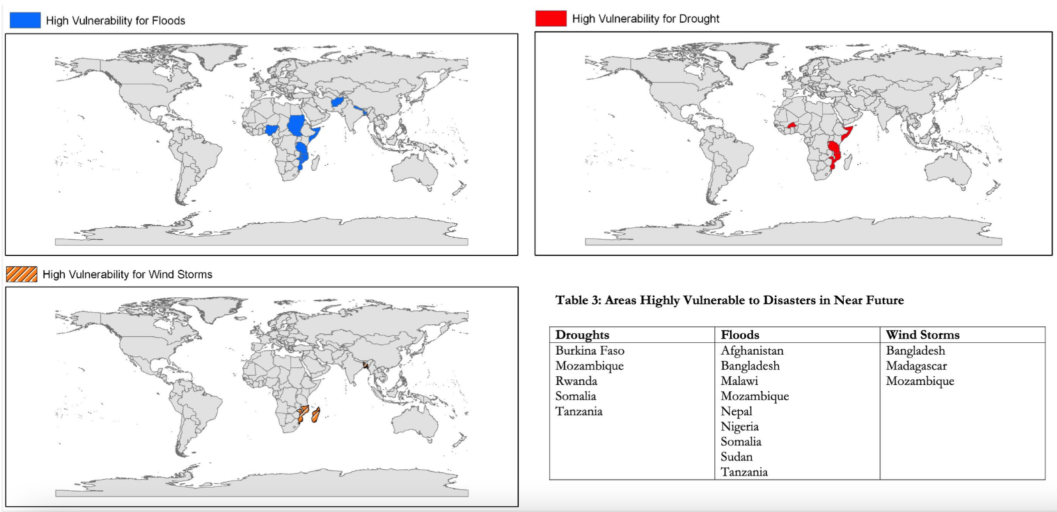


Table 3: Areas Highly Vulnerable to Disasters in Near Future

Droughts	Floods	Wind Storms
Burkina Faso	Afghanistan	Bangladesh
Mozambique	Bangladesh	Madagascar
Rwanda	Malawi	Mozambique
Somalia	Mozambique	
Tanzania	Nepal	
	Nigeria	
	Somalia	
	Sudan	
	Tanzania	

b)Media

https://pod.utt.fr/video/4144-carboncycle-video10mov/

3.4.4. Conclusion

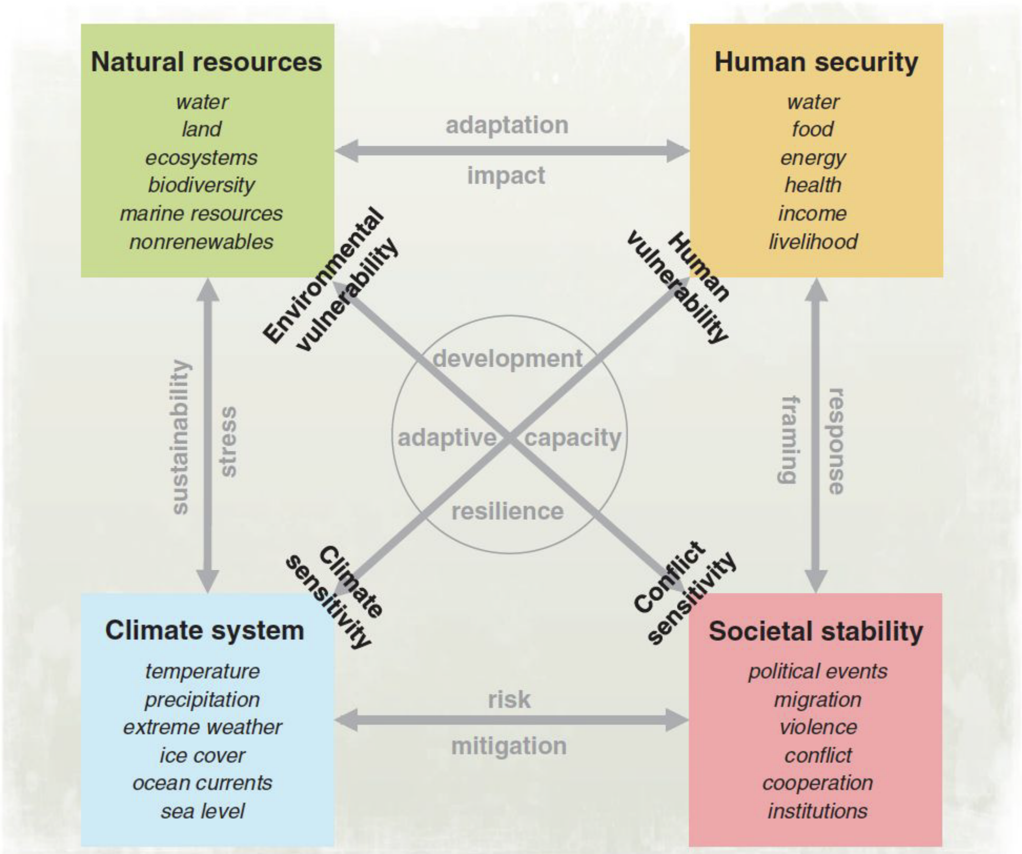


Fig. 1. Analytical framework of linkages between the climate system, natural resources, human security, and societal stability [based on (*28*)].

Scheffran, 2012 based on Scheffran, 2009

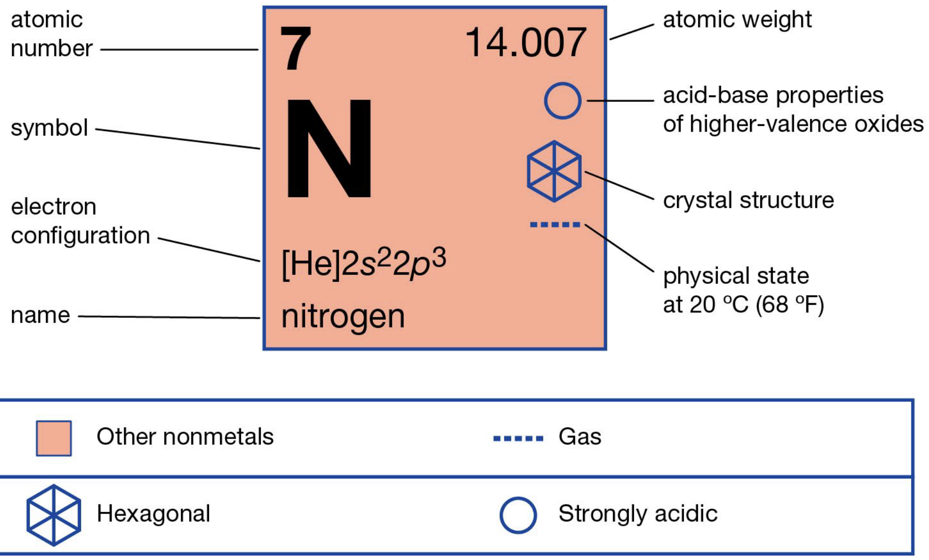
4. Nitrogen Cycle

Summary

1. Introduction
2. Natural nitrogen cycle
3. Anthropogenic nitrogen cycle
4. Outflows and nitrogen cascade
5. Environmental Impacts

4.1. Introduction

Nitrogen



Atmosphere's composition :

Dinitrogen N_2 78%

Oxygen O_2 20%

Argon Ar 9%

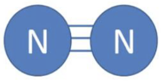
Carbon dioxyde CO_2 0,40% *

Water vapor H_2O 0-3%

Cox, Arthur N., éd. 2002. Allen's Astrophysical Quantities. 4 e éd. New York : Springer-Verlag. https://doi.org/10.1007/978-1-4612-1186-0.

* "Vital signs: Carbon Dioxide". NASA Climate. May 2020. Retrieved 5 June 2020

Dinitrogen molecule



N_2, the large amount of energy required to break the nitrogen-nitrogen triple bond makes this structure stable, which is why N_2 is the most abundant in air.

Nitrogen reservoirs

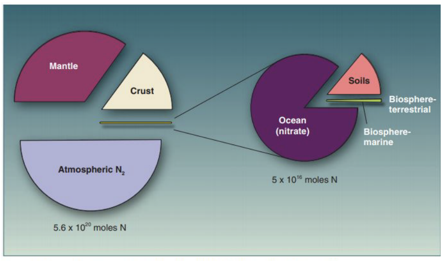


Fig. 2. The size of nitrogen reservoirs on Earth is highly variable. (*44*, *64–67*).

Canfield, Donald E., Alexander N. Glazer, et Paul G. Falkowski. 2010. « The Evolution and Future of Earth's Nitrogen Cycle ». Science 330 (6001): 192-96.

https://doi.org/10.1126/science.1186120.

Nitrogen compounds

Molecule	Name	Oxidation state
		Reduced
C-NH_2	Organic-N	
NH_3, NH_4^+	Ammonia, Ammonium	-3
N_2H_4	Hydrazine	-2
NH_2OH	Hydroxylamine	-1
N_2	Dinitrogen	0
N_2O	Nitrous oxide	+1
NO	Nitric oxide	+2
HNO_2, NO_2^-	Nitrous acid, Nitrite	+3
NO_2	Nitrogen dioxide	+4
HNO_3, NO_3^-	Nitric acid, Nitrate	+5
		Oxidized

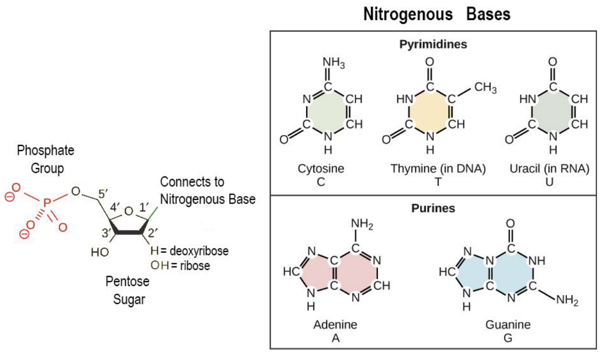
More electrons ↑ / Fewer electrons ↓

Current Biology

- Ammonium NH_4^+
- Nitrite NO_2^-
- Nitrate NO_3^-

4.1.1. Why nitrogen is important to life ?

Hint : DNA

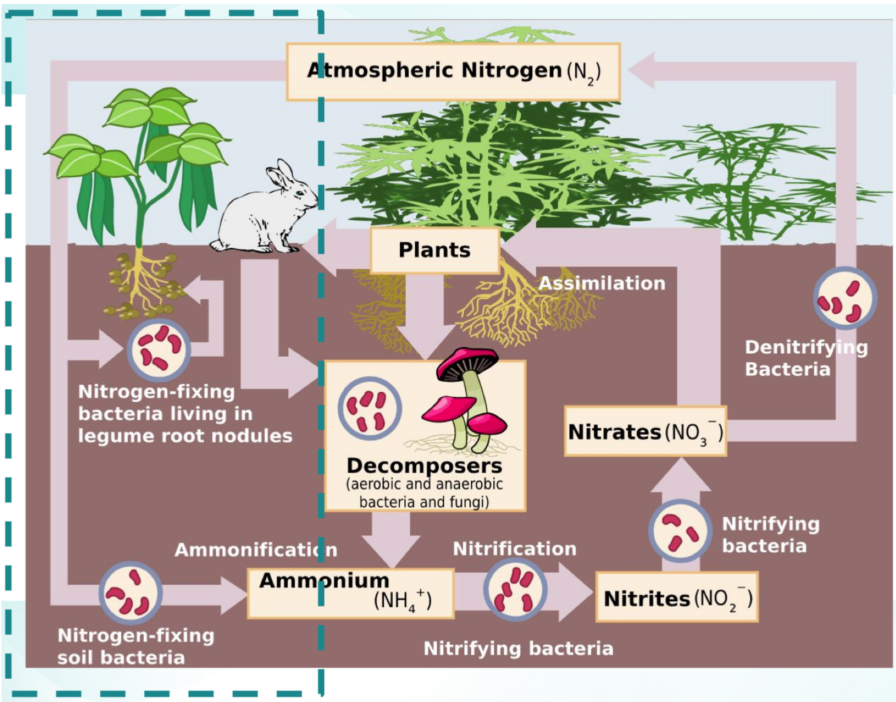


4.1.2. Medias

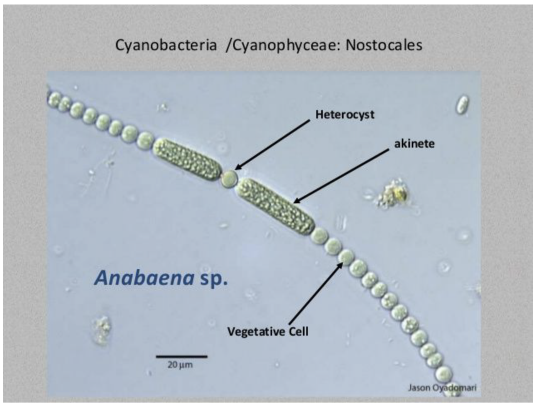
[cf. EV14_NitrogenCycle_Video1.mp4]
[cf. EV14_NitrogenCycle_Video1.mp3]

4.2. Natural nitrogen cycle

4.2.1. Biological fixation

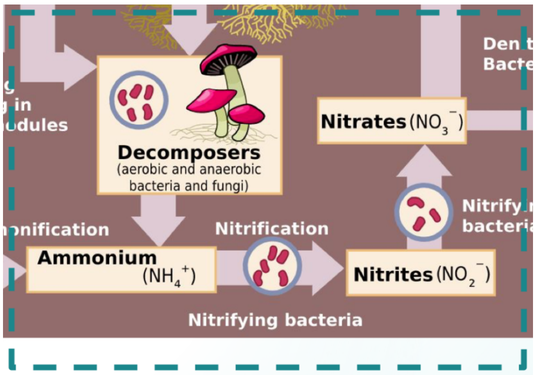


Actinomycetes



Cyanophyceae

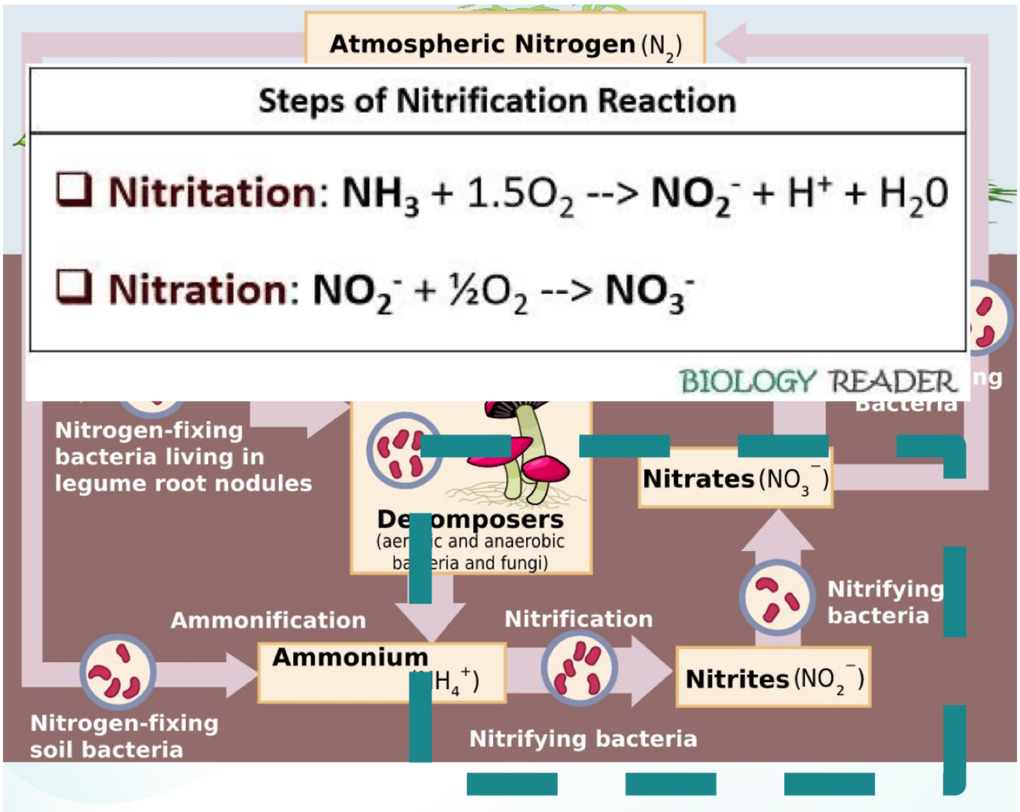
4.2.2. Mineralization



Aerobic and anaerobic conditions.

4.2.3. Assimilation by plants

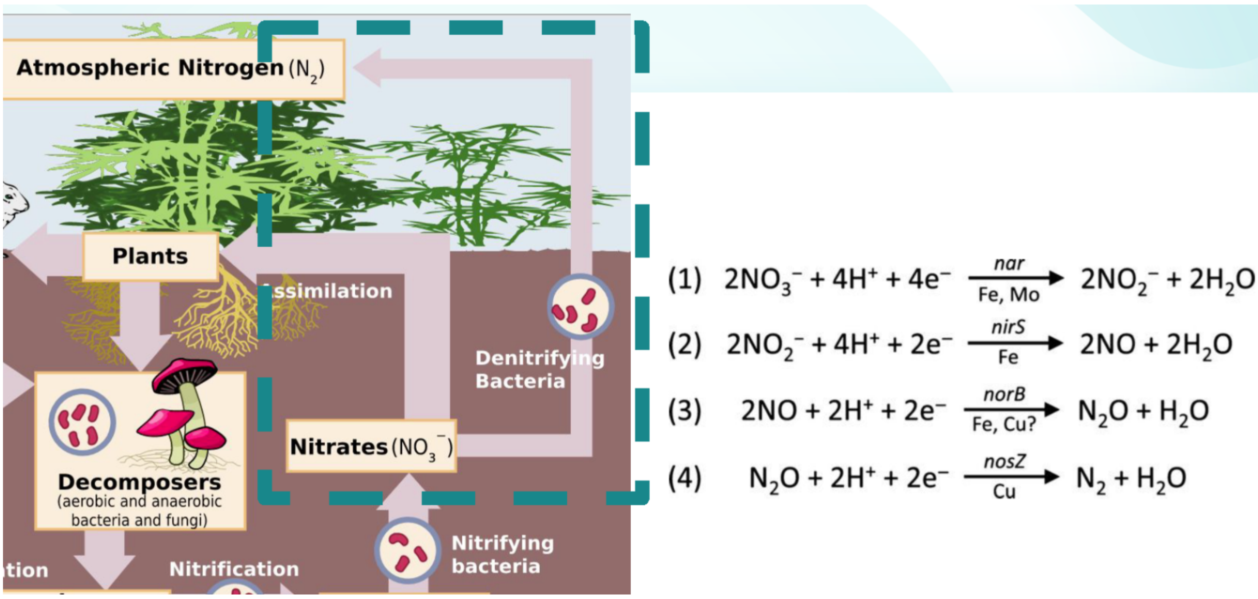
4.2.4. Nitrification



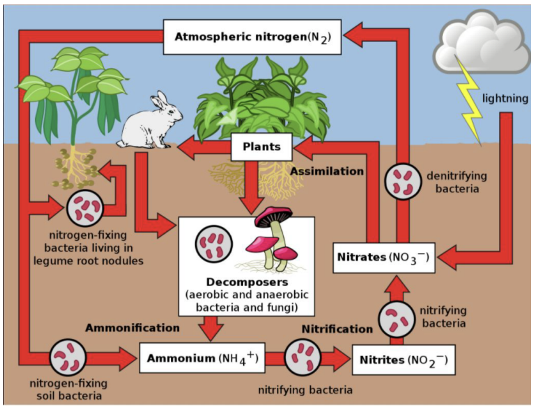
Takes place under aerobic conditions.

The activity of the microflora is optimal for pH 6.9 to 9 and temperatures between 20 and 36 °C.

4.2.5. Denitrification



4.2.6. The role of lightning



1. Energy from lighting breaks apart N_2 into N and O_2 into O.
2. They bond to form nitrogen oxides (NOx).
3. They react with rain water to form nitrates.

4.2.7. QCM

1) What is the name of the process that oxidizes ammonium (NH_4^+) to produce nitrite (NO_2^-) and then forms nitrate (NO_3^-)?

- Denitrification
- Biological fixation
- **Nitrification**

2) Thanks to their roots, plants are able to absorb atmospheric nitrogen (N□).

- True
- **False**

3) What are the functions of nitrogen on the planet ?

- Participate in photosynthesis
- **Produce the nitrogenous bases of DNA**
- Doing cellular respiration
- Transporting Oxygen (O_2) molecules
- **Making proteins**

4.2.8. Medias

[cf. EV14_NitrogenCycle_Video2.mp4]
[cf. EV14_NitrogenCycle_Video2.mp3]

4.3. Anthropogenic nitrogen cycle

Nitrogen use in manufacturing & processing

Blanketing :

Nitrogen gas can be used to flush wine bottles both before and after filling.

https://www.generon.com/nitrogen-for-wine-sparging-bottling-blanketing/

Nitrogen generator in Beverage processing & packaging

On the picture : Juice cartons on packaging production line

https://www.peakgas.com/Articles-and-News/article/basic-nitr ogen-facts-uses-and-onsite-gas-generation

The most important use is for fertilizer

Starter fertilizer can enhance growth and yield by improving access of immobile nutrients

https://www.mississippi-crops.com/2020/03/20/top-five-management-strategies-to-improve-corn-profitability/

Nitrogen and fertilizer

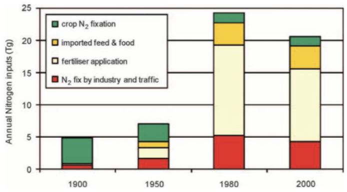


Figure SPM.1 Estimated trend of anthropogenic reactive nitrogen inputs to the European Union (EU-27) [5.1] (1 Tg equals 1 million tonnes).

The natural process of fixation of atmospheric nitrogen has been amplified by man through an increasing use of industrial fixation of atmospheric nitrogen.

The Haber-Bosch process

Video to watch :

https://www.youtube.com/watch?v=o1_D4FscMnU

The modern nitrogen cycle

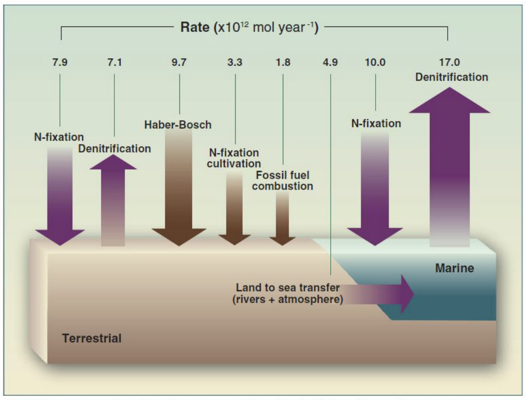


Fig. 4. Rates of nitrogen flux in the modern nitrogen cycle depend on the efficiency of the transformations between reservoirs. Arrow size reflects relative size of the flux. The dark brown arrows represent anthropogenic inputs (*25, 45, 46, 52, 53, 68, 69*).

NH4+ production : 9,5 x 10^12 mol

Fossil fuel combustion : 1.8 x 10^12mol

Anthropogenic sources contribute double the natural rate of terrestrial nitrogen fixation.

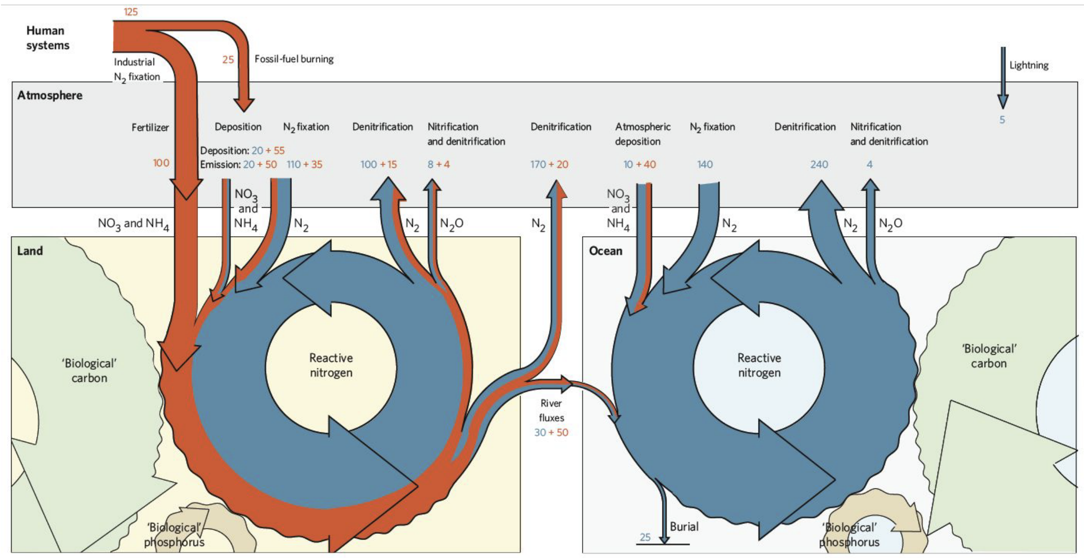


Figure 1 | Depiction of the global nitrogen cycle on land and in the ocean. Major processes that transform molecular nitrogen into reactive nitrogen, and back, are shown. Also shown is the tight coupling between the nitrogen cycles on land and in the ocean with those of carbon and phosphorus. Blue fluxes denote 'natural' (unperturbed) fluxes; orange fluxes denote anthropogenic perturbation. The numbers (in Tg N per year) are values for the 1990s (refs 13, 21). Few of these flux estimates are known to better than ±20%, and many have uncertainties of ±50% and larger[13,21].

Nitrogen and the agro-food system

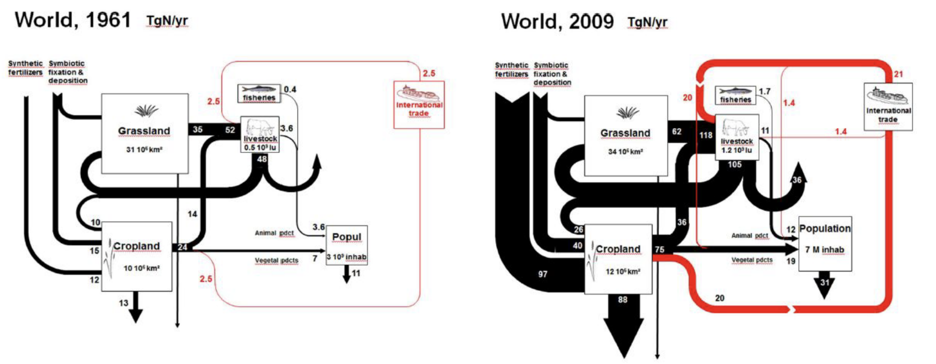


Figure 1. Generalized representation of N transfers through the world agro-food system (GRAFS) in 1961 and 2009.

Why does livestock farming produce large quantities of nitrogen-rich effluents ?

4.3.1. Conclusion

QCM

1) What is the Haber-Bosh process?

- A process that transforms air into fertilizer.
- **A process to fix atmospheric dinitrogen in the form of ammonia.**
- A process that converts ammonia into nitrate.
- **A process that permit to have available nitrogen in sufficient quantity to allow its industrialization.**

2) What are the anthropogenic sources of the nitrogen cycle?

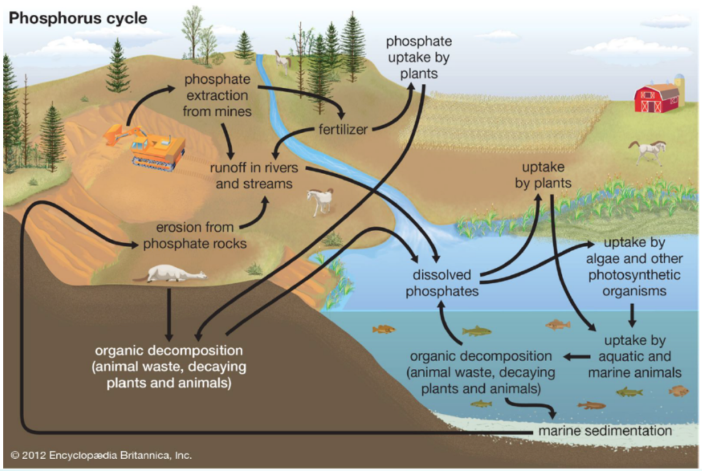
- **Fossil fuel combustion**
- **Industrial fixation**
- Deforestation
- **Crops and livestock**
- Building construction

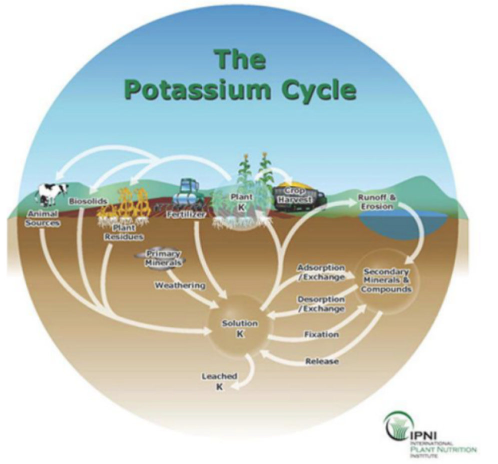
4.3.2. Medias

[cf. EV14_NitrogenCycle_Video3.mp4]
[cf. EV14_NitrogenCycle_Video3.mp3]

4.4. Outflows and nitrogen cascade

Introduction

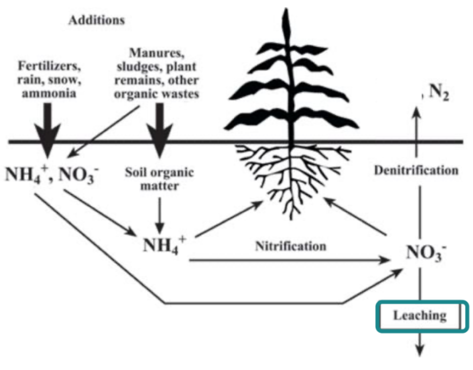




What is on of the main difference between phosphorus, potassium and nitrogen ?

Nitrate goes from the biosphere to the environment by nitrate leaching, gaseous emissions.

Nitrate leaching



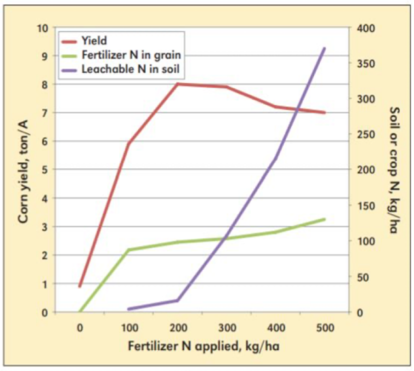


Figure 4. Nitrogen fertilizer added beyond the capacity of crops to recover it increases the risk for nitrate leaching. Broadbent and Rauschkolb, 1977.

Nitrate leaching is highly dependent on rainfall, soil type and soil nitrogen content.

Video to watch

https://www.youtube.com/watch?v=-6e_iF9d2F0

Ammonia volatilization

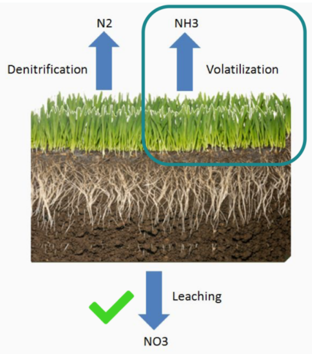
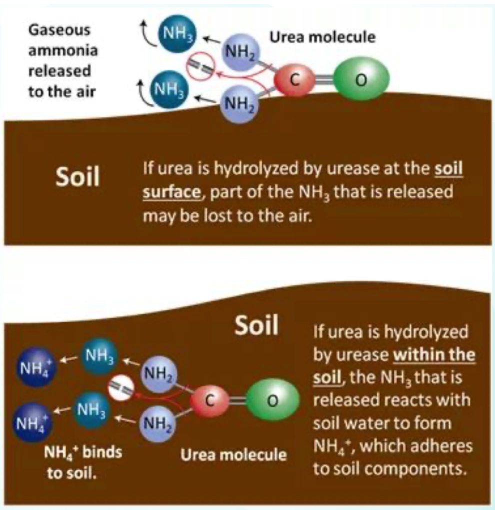


Figure 1. Agriculture emission challenges

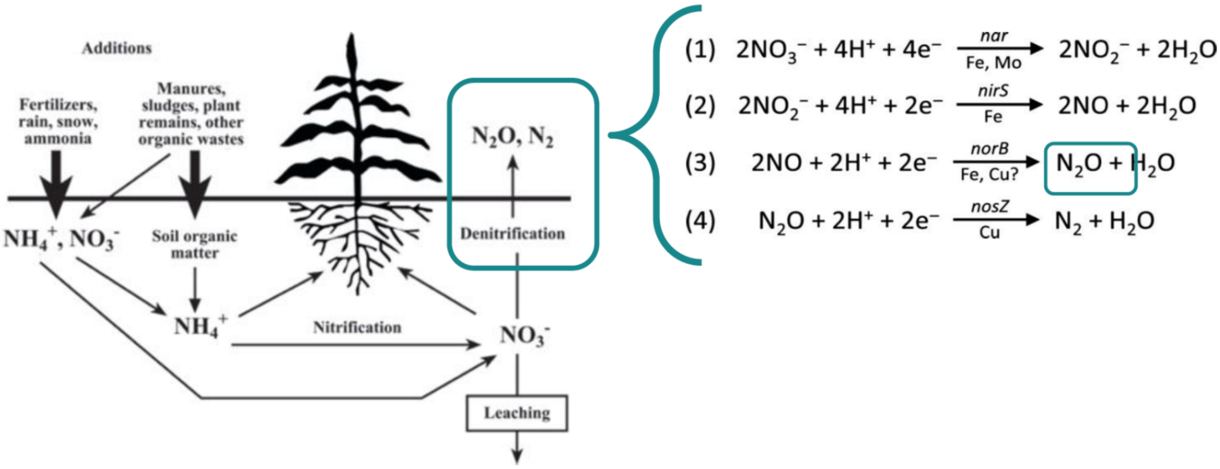
The presence of ammoniacal nitrogen in a solution in contact with air systematically leads to the volatilization of ammonia.

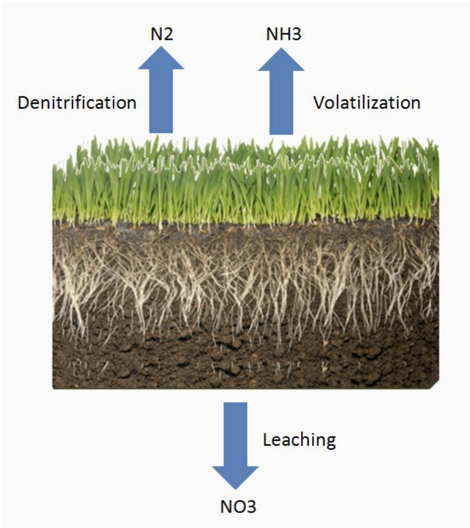
Volatilization depends very strongly on the physical and chemical conditions of the environment.

- the nitrogen content of the substrate in contact with the air ;
- the proportion of nitrogen present in the form of ammonia ;
- the contact surface between the solution containing ammoniacal nitrogen and the atmosphere ;
- the dispersion of the air in contact with the emission zone.



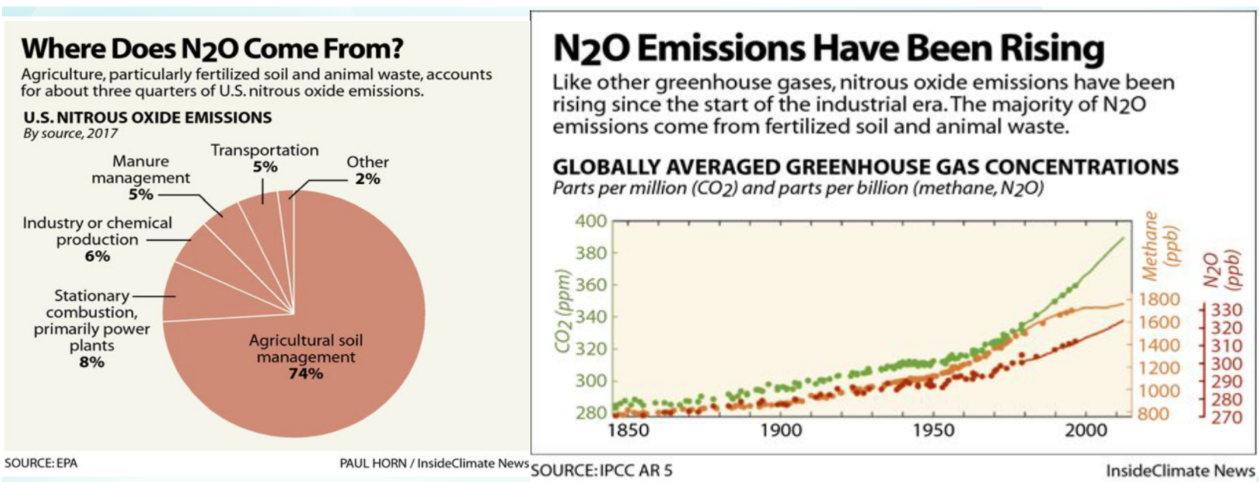
Nitrogen oxides and nitrous oxide emissions





The parameters which are likely to intervene to regulate the proportion of nitrous oxide formed during denitrification are :

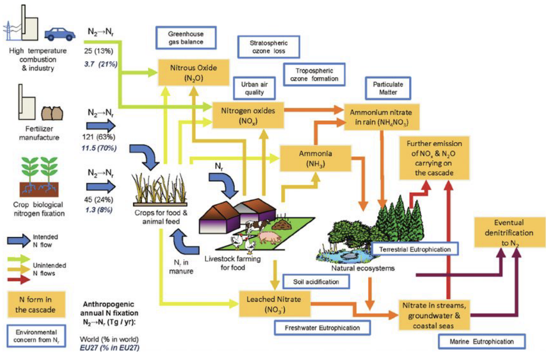
- the pH of the environment ;
- the nitrate concentration ;
- the soil aeration, often characterized by the water saturation rate ;
- the availability of reducing agents.



In addition to nitrous oxide emissions, there are nitric oxide emissions, rather observed in dry environments, and associated with nitrification situations.

Nitrogen oxides, mainly NOx (NO_2 and NO) and nitrous oxide (N_2O) are emitted during nitrification and/or denitrification reactions, **both in the field and in livestock buildings** (bedding, effluent storage areas).

The nitrogen cascade



Simplified view of the nitrogen cascade, highlighting the major anthropogenic sources of reactive nitrogen (Nr) from atmospheric dinitrogen (N_2), the main pollutant forms of Nr (orange boxes) and nine main environmental concerns (blue boxes). Estimates of anthropogenic N fixation for the world (Tg /yr for 2005, in black) are compared with estimates for Europe (Tg /yr for 2000, in blue italic). Blue arrows represent intended anthropogenic Nr flows; all the other arrows are unintended flows.

QCM

1) Nitrogen is characterized by a great ability to leave the soil-plant-animal cycle

- **True**
- False

2) Nitrate leaching losses increase when fertilizer applications are in excess of the crop need.

- **True**
- False

3) What is the physical and chemical condition of the environment on which the volatilization of ammonia depends?

- **the nitrogen content of the substrate in contact with the air.**
- **the proportion of nitrogen present in the form of ammonia.**
- the proportion of nitrogen present in the form of nitrate.
- **the contact surface between the solution containing ammoniacal nitrogen and the atmosphere.**
- the soil aeration.
- **the dispersion of the air in contact with the emission zone.**

4.4.1. Medias

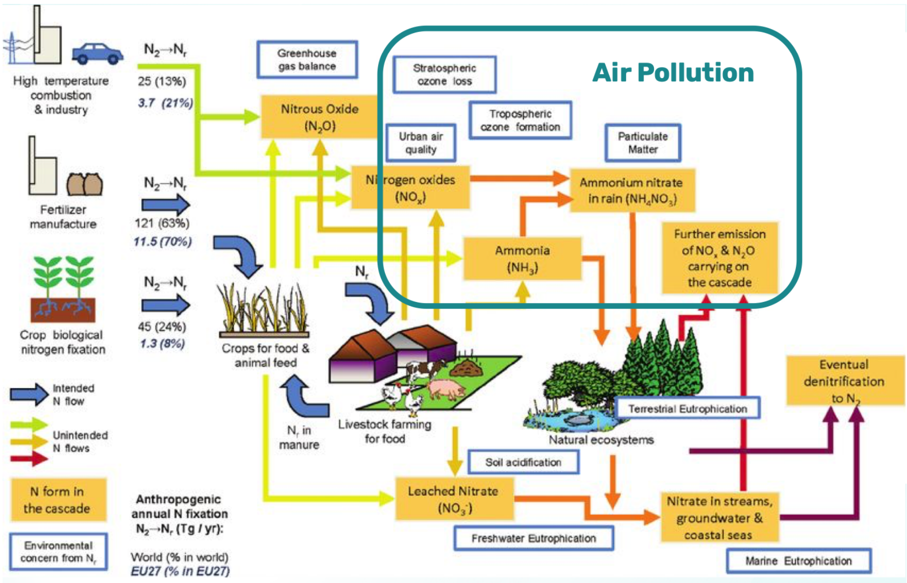
[cf. EV14_NitrogenCycle_Video4.mp4]
[cf. EV14_NitrogenCycle_Video4.mp3]

4.5. Environmental Impacts

Video to watch : The impact of nitrogen pollution[1]

https://www.youtube.com/watch?v=ZvKXHQM6soo[2]

The nitrogen cascade



Small reminder :

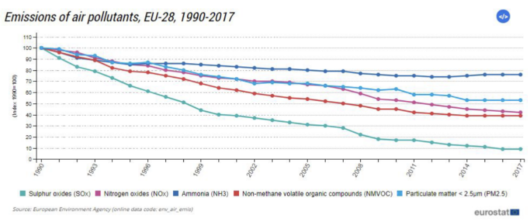
This cascade of unintentional flows of reactive nitrogen is accompanied by a cascade of harmful consequences for the environment, the climate and human health.

When reactive nitrogen returns in the form of inert atmospheric nitrogen dioxide, it has potentially crossed several compartments in several forms in excessive quantities, and thus contributed to different environmental impacts on all of our planet.

Air pollution

Table 18.1 The role of N containing compounds and ozone in air pollution effects. The threats to ecosystems from N deposition are discussed in Grizzetti *et al.*, 2011 and Dise *et al.*, 2011 (Chapter 17 (threats to water)) and Chapter 20 (threats to biodiversity))

	Effects			
Compounds	**Human health**	**Ecosystems**	**Materials**	**Visibility**
Nitrogen dioxide	X		X	X
Ammonia		X	X	
Particles NH_4^+/NO_3^-	X		X	X
Ozone	X	X	X	
N deposition		X (acidification, eutrophication)		



Regulations :

- Air quality standards
- The Convention on Long-Range Transboundary Air Pollution (LRTAP Convention)

Table 18.5 Overview of nitrogen related health impacts

Pollutant	Health impacts and routes	Health impacts
NO_x	Inhalation - direct impacts of NO_2 - impacts via O_3 - impacts via PM	Asthma, respiratory disorder, inflammation of air ways, reduced lung functions, bronchitis, cancers
NH_3	Inhalation: - direct impacts (negligible) - impacts via PM Odour	See NO_x Small as odour contribution by NH_3 is modest
N_2O	Health impacts from global warming, often enhanced by eutrophication	Enhancement of vectors for infectious diseases (malaria) and frequency of infestations (HAB*, insects)

* Harmful Algal Bloom

[1] https://www.youtube.com/watch?v=ZvKXHQM6soo
[2] https://www.youtube.com/watch?v=eJOGGvH9xkg

4.5.1. 1. Health impacts

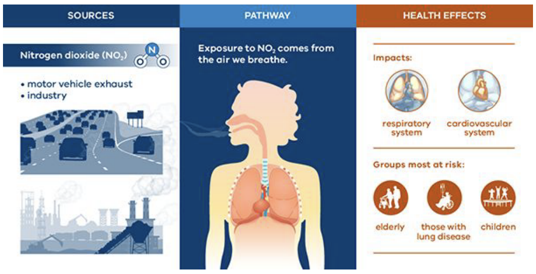
Ammonia

NH_3 - Health effects of ammonia are indirect through contribution of NH_4^+ to particulate matter (PM).

Ammonia emissions significantly contribute to the formation of secondary particulate matter in the atmosphere (~ 20% by mass).

The main source of ammonia in the atmosphere is agriculture.

Nitrogen dioxide (NO2)



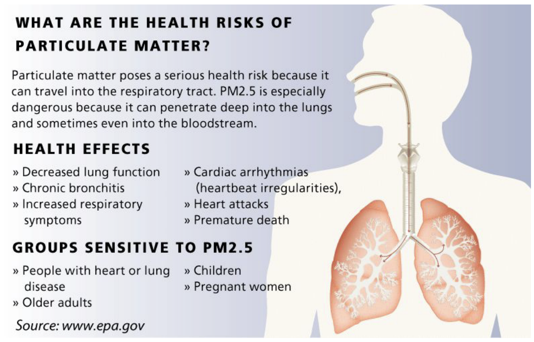
It is a toxic gas that has adverse health effects both in the long term (chronic) and short term (acute).

Data from Europe suggested that long-term concentrations of nitrogen dioxide or nitrogen oxides (NO) were associated with an increased risk of all-cause mortality.

Nitrogen dioxide is strongly related to particulate matter.

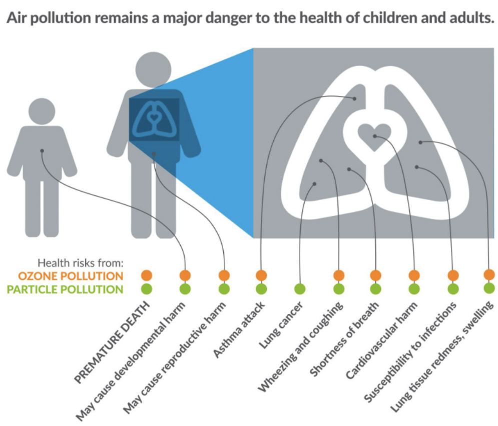
https://www.epa.vic.gov.au/for-community/environmental-information/air-quality/nitrogen-dioxide-in-the-air

Particulate matter (PM)



NO_2 and NH_3 - Reactive nitrogen contributes to particle mass and to the adverse health effects caused by the PM.

Ozone



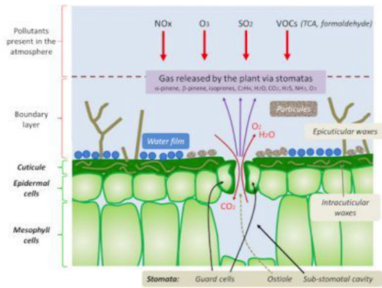
NO_2 and NH_3 - Reactive nitrogen contributes to particle mass and to the adverse health effects caused by the PM.

https://www.lung.org/research/sota/health-risks

4.5.2. Ecosystems

Ammonia

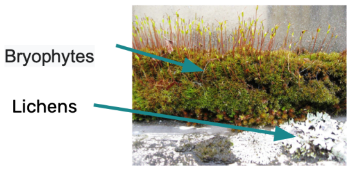
	Effects
Compounds	**Ecosystems**
Nitrogen dioxide	
Ammonia	X
Particles NH_4^+/NO_3^-	
Ozone	X
N deposition	X (acidification, eutrophication)



Atmospheric ammonium is absorbed by the leaves of plants. More precisely through the stomata, where gas exchanges take place.

Atmospheric ammonium is absorbed by the leaves of plants. More precisely through the stomata, where gas exchanges take place.

Before reaching the leaf, the pollutant will first have to pass through the "boundary layer".

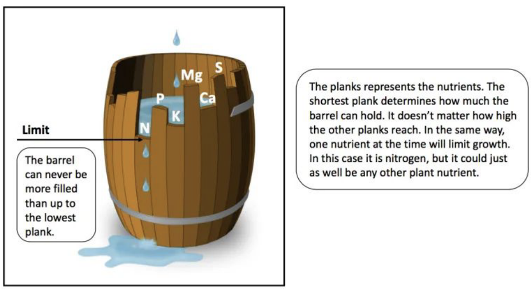


Lichens are very affected by atmospheric pollution because they not have a impermeable cuticle.

Lichens and bryophytes are an important part of the ecosystem integrity.

https://www.irishtimes.com/news/science/the-trouble-with-ammonia-1.3721098

Liebigs Barrel Illustrates the Law of the Minimum



Ammonia acts as a macro-nutrient and at low exposure levels plants respond by increasing their biomass production.

Because plant growth is often limited by the supply of nutrient nitrogen, and so any increases in growth may lead to negative effects on community composition.

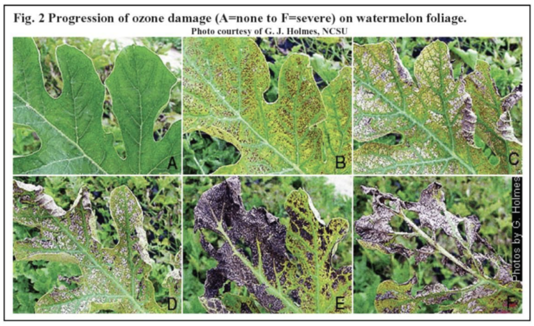
The fertilisation effect can at higher exposure levels lead to secondary long-term adverse effects including increased susceptibility to abiotic (drought, frost) and biotic stresses.

Oxides of nitrogen

Oxides of nitrogen can have a fertiliser effect, but can also be toxic to plants, depending on concentrations.

At low concentrations typical of ambient conditions, nitrogen oxides is more phytotoxic than nitrogen dioxide.

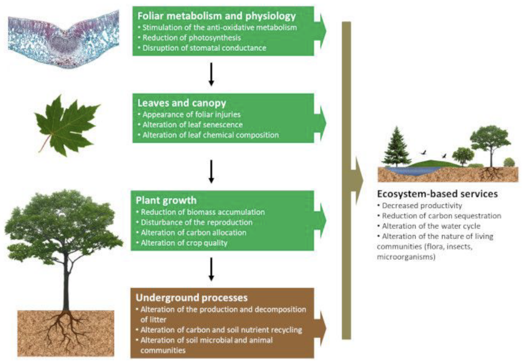
As for ammonia, the growth stimulation was also considered as potentially adverse for (semi-) natural vegetation owing to potential negative effects on community composition.



Today ozone is considered to be the most important gaseous pollutant causing effects on vegetation.

Besides visible injuries on leafs and needles, ozone also causes premature leaf loss, reduced photosynthesis and reduced leaf, root, and total dry weights in sensitive plant species.

https://extension.umd.edu/learn/air-pollution-effects-vegetables



Today ozone is considered to be the most important gaseous pollutant causing effects on vegetation.

Besides visible injuries on leafs and needles, ozone also causes premature leaf loss, reduced photosynthesis and reduced leaf, root, and total dry weights in sensitive plant species.

This leads to significant decrease in productivity of some agricultural crops and to reduced forest production.

Effects of ozone on vegetation: from plant cells to ecosystems. [Source: © J.P. Garrec]

Effects on materials

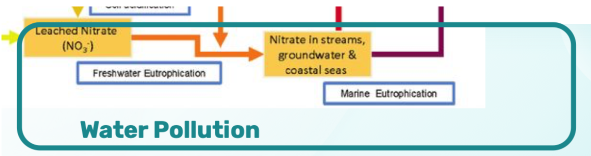
Table 18.1 The role of N containing compounds and ozone in air pollution effects. The threats to ecosystems from N deposition are discussed in Grizzetti *et al.*, 2011 and Dise *et al.*, 2011 (Chapter 17 (threats to water)) and Chapter 20 (threats to biodiversity))

	Effects			
Compounds	**Human health**	**Ecosystems**	**Materials**	**Visibility**
Nitrogen dioxide	X		X	X
Ammonia		X	X	
Particles NH_4^+/NO_3^-	X		X	X
Ozone	X	X	X	
N deposition		X (acidification, eutrophication)		

Corrosion of materials was originally mostly associated with air pollution by sulphur dioxide; however know that nitric acid (HNO3), ozone and particulate matter also contribute significantly to the negative effect of air pollution on materials.

The lifetime of technological products is shortened because of air pollution.

4.5.3. Water Pollution



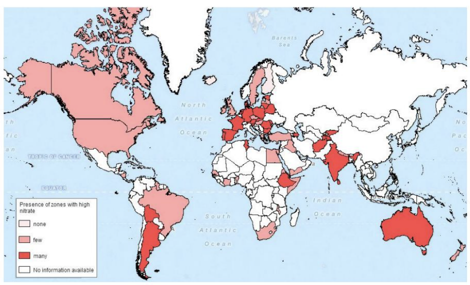
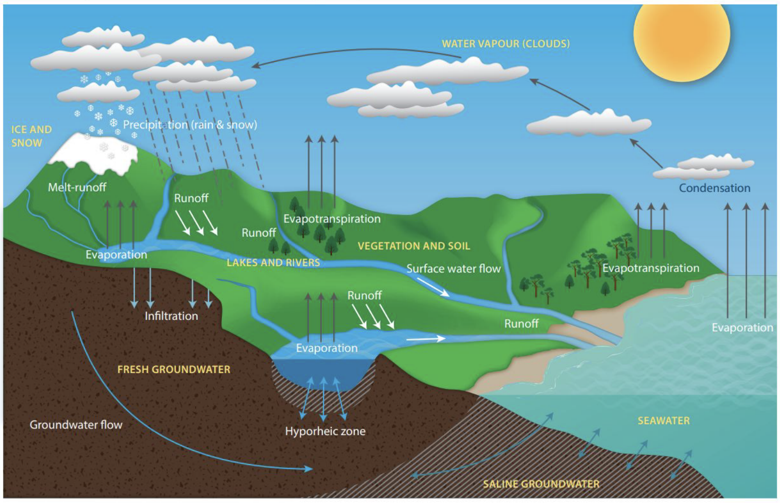
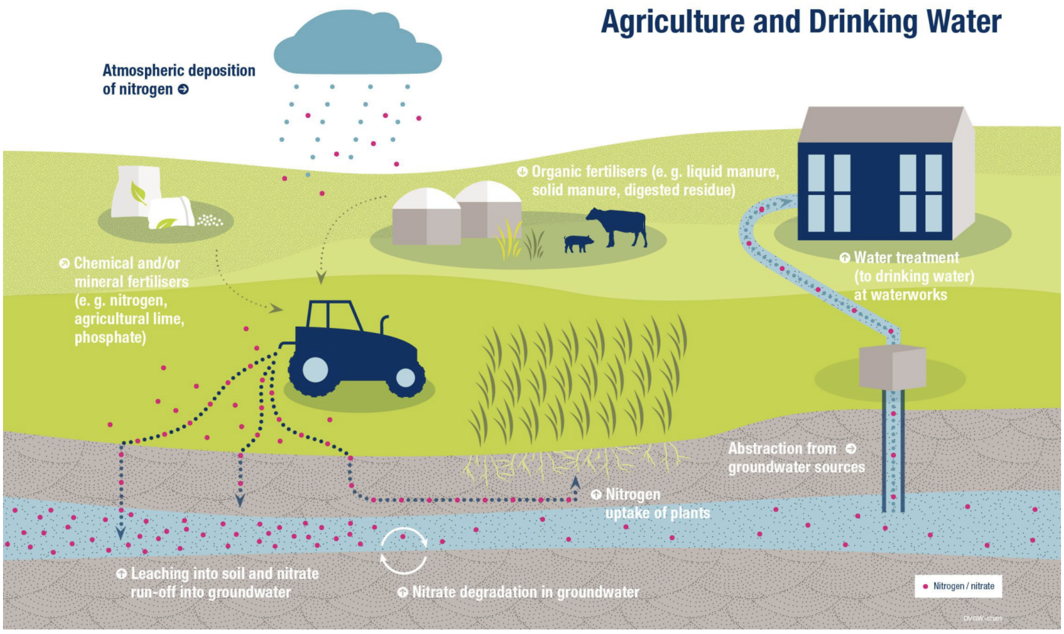


Figure 2 Global map with the presence of zones with high nitrate in groundwater (source: IGRAC, 2012)

The water cycle – also known as the hydrological cycle



How does nitrogen get into drinking water?



https://www.dvgw.de/english-pages/topics/water/nitrates-and-drinking-water/

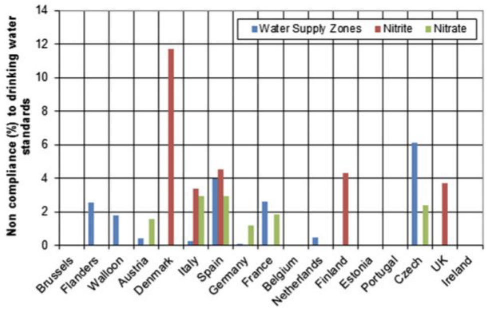


Figure 3.2 Noncompliance for EU legal standards for nitrite and nitrate in drinking water (exceedance in more than 1% of all samples taken) between 2000 and 2004 and the associated proportion of Water Supply Zones (WSZ). *European Commission: the quality of drinking water in the European Union, 2002–2004. Synthesis report for EU Directives 80/778/EEC and 98/83/EC; 2007. [http://circa.europa.eu/Public/irc/env/drinking_water_rev/library?l=/drinking_synthesis/report_2002-2004pdf/_EN_1.0_&a=d].* For color version of this figure, the reader is referred to the online version of this book.

The regulatory level is usually met for public water supplies, which are routinely monitored.

In the EU, noncompliance to the nitrate or nitrite standards in large public supplies is reported regularly but rarely exceeds □% of the sample population.

Bryan, Nathan S., et Hans van Grinsven. « The Role of Nitrate in Human Health ». In Advances in Agronomy, 119:153-82. Elsevier, 2013.https://www.sciencedirect.com/science/article/abs/pii/B9780124072473000032?via%3Dihub[1]

[1] 2013.https://www.sciencedirect.com/science/article/abs/pii/B9780124072473000032?via%3Dihub

Effects of nitrogen rich drinking water on human health

Nitrate itself is generally considered to be harmless at low concentrations.

Nitrite, on the other hand, is reactive especially in the acid environment of the stomach where it can nitrosate other molecules including proteins, amines and amides.

Eutrophication

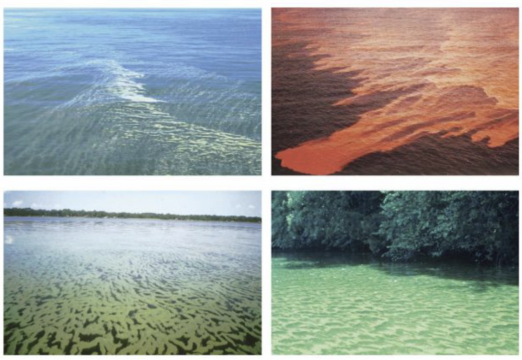


Fig. 1. Examples of estuarine and coastal phytoplankton blooms symptomatic of nutrient-driven eutrophication. Upper left: a bloom of the nitrogen-fixing blue-green algae (cyanobacteria) *Nodularia* spp., *Aphanizomenon flos aquae* and *Anabaena* spp. in the Gulf of Finland, Baltic Sea (photograph courtesy of P. Moisander). Upper right: red tide dinoflagellate bloom, in coastal Japan (Courtesy of ECOHAB Program). Lower left: a mixed cyanobacterial bloom comprised of nitrogen fixers (*Anabaena* spp.) and a non-nitrogen fixing nuidance species, *Microcystis aeruginosa*, in the St. Johns River, a tidal estuary in Florida, USA. Lower right: a mixed algal bloom dominated by non-nitrogen fixing cyanobacteria (*Microcystis aeruginosa*, *Oscillatoria* spp.) and green algae (chlorophytes) in the upstream oligohaline segment of the Neuse River Estuary, NC.

- Is one of the most common alterations of continental and marine waters.
- Result in an exacerbated productivity of aquatic ecosystems due to an excessive nutrient inputs.

Factors controlling eutrophication can be summed up as a combination of some or all of the following interacting factors:

- An excess of nutrients
- A long water residence time
- A sufficient amount of light
- A favourable temperature

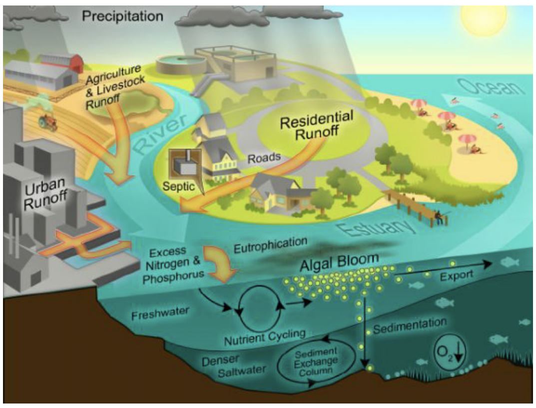
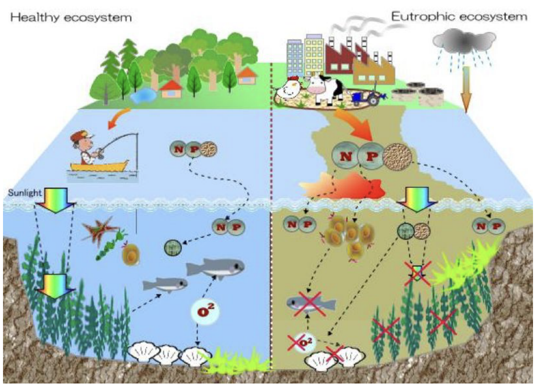


Fig. Functional linkages between hydrology, anthropogenic nutrient inputs, eutrophication (phytoplankton blooms), and hypoxia/anoxia

in estuarine and coastal aquatic ecosystems.

Paerl, Hans W. « Assessing and Managing Nutrient-Enhanced Eutrophication in Estuarine and Coastal Waters: Interactive Effects of Human and Climatic Perturbations ». Ecological Engineering 26, no 1 (janvier 2006): 40-54.



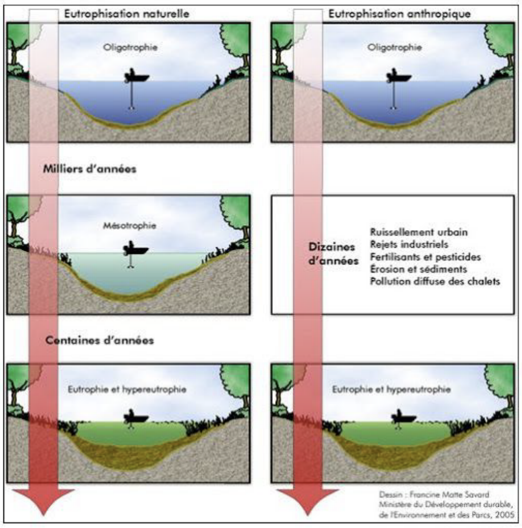
1. The increase in nutrients leads to a strong increase in primary productivity.
2. The new limiting factor becomes light.
3. The light penetration decreasing by self-shading as the biomass produced increases.
4. Development of more competitive species, which affects a change in primary producer communities, which changes the ecosystem and affects biodiversity.

https://www.unenvironment.org/nowpap/what-we-do/prevent-and-reduce-pollution/eutrophication

Video to watch

Eutrophication and dead zones | Ecology | Khan Academy

https://www.youtube.com/watch?v=AxaWXWd2pw4

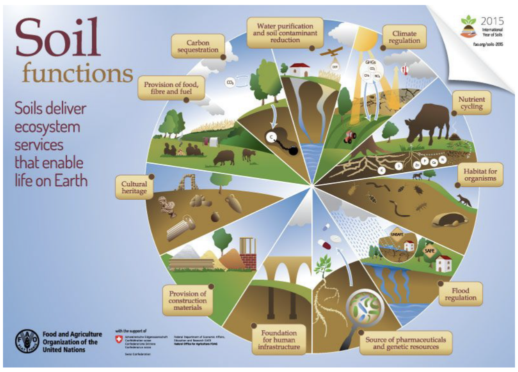


- A natural eutrophication phenomenon.

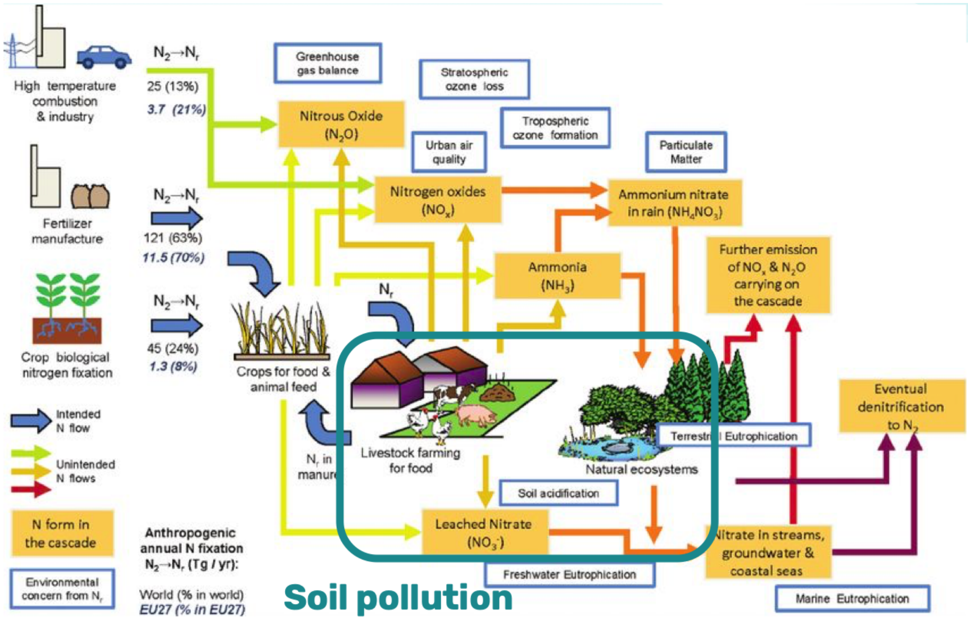
The difference between natural and anthropogenic eutrophication is time.

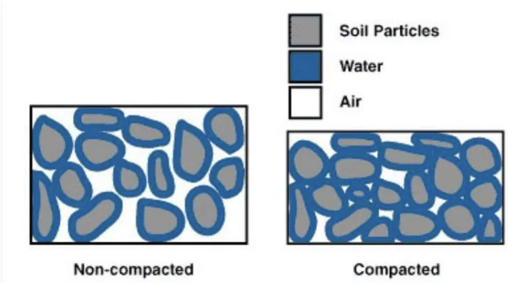
4.5.4. Soil pollution

Soil quality and functions



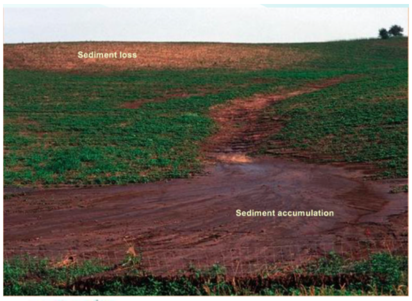
Effect of soil degradation on nitrogen

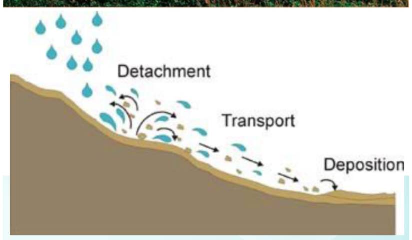




- the effects of soil compaction.

https://civilblog.org/





- the effects of erosion.
  1. Loss of productivity and sediment accumulating due to erosion sometimes can be seen in the same field as showing in this photo.
  2. Rain enhances the translocation of soil through the process of splashing. Individual raindrops detach soil aggregates and redeposit particles. The dispersed particles may then plug soil pores, reducing water intake. Once the soil dries, these particles develop into a crust at the soil surface and runoff is further increased.

  https://wiki.ubc.ca/

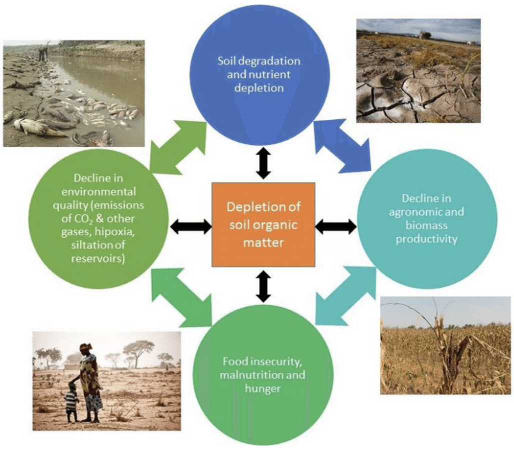
- the effects of salinisation.

  High salt concentrations inhibit biological nitrogen transformations in soil, as well as nitrogen fixing capacity by legumes.

  https://www.quora.com/

- the effects of soils contamination.

  https://www.worldatlas.com/



- the effect of organic matter decline.

  Figure. The vicious cycle of depletion in soil organic matter-decline in

  crop yield-food insecurity-soil

  Vicente Vicente, José. « Soil organic carbon sequestration in Andalusian olive groves: effect of the managements on soil organic carbon dynamics », 2017.

Effect of nitrogen on soil

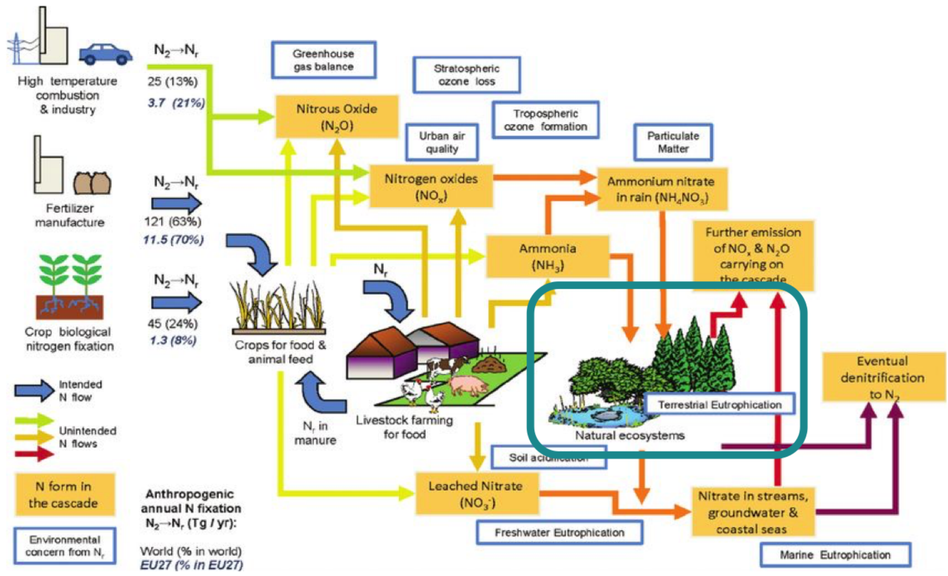
Table 21.1 Effects of N on soil parameters of natural soils, their mechanisms, and the ecosystem response

Soil parameter	Mechanism	Ecosystem response	Literature
C/N ratio	Narrows at sites with high N availability, due to the incorporation of surplus N in soil organic matter.	Plant species richness ↕ Decomposition of SOM ↕ Microbial biomass ↑	(Von Oheim *et al.*, 2008) (Friedel *et al.*, 2008) (Dumortier *et al.*, 2002) (Berg, 2000)
Inorganic nitrogen concentration	Nitrogen deposition is close to or exceeds ecosystem N demand. Input of inorganic N increases soil solution concentrations.	Plant productivity ↑ Leaf/needle N content ↑ Litter decomposability ↑ Plant species richness ↓ Vascular plants in wetlands ↑ Microbial N immobilisation ↓ Nitrogen leaching ↑ Soil N_2O/NO emissions ↑	(De Vries *et al.*, 2006b) (Corré *et al.*, 2007) (Kreutzer *et al.*, 2009) (Gundersen *et al.*, 2006) (Stevens *et al.*, 2006)
Acidification and soil buffering capacity	Nitrification of deposited NH_3/NH_4^+ leads to H^+ formation. In the course of the acidification process base cations are leached.	Nutrient availab. (Ca/Mg) ↓ Al/Mn toxcity if soil pH<5.5 ↑ Biodiversity ↓ Microbial activity ↓ Root growth ↓ Nitrogen leaching ↑ DOC leaching ↓ Soil N_2O/NO emissions ↑ Wetland CH_4-emissions	(Matzner and Murach, 1995) (Raubuch and Beese, 2005) (Bowman *et al.*, 2008) (Gauci *et al.*, 2005) (Evans *et al.*, 2008)
Soil C stocks and SOC stratification	Surplus N decreases fine root biomass and, thus, reduces belowground litter production, but increases aboveground plant production and litter fall.	Total soil C stocks ↑ Forest floor C stocks ↑ Mineral soil C stocks ↕	(Högberg, 2007) (De Vries *et al.*, 2006b) (Hyvönen *et al.*, 2007, 2008)
Soil aggregation	N can increase litterfall and improve litter quality and, thus, positively affect soil fauna and the formation of organo-mineral soil aggregates by e.g. earthworm activities	Soil aeration ↑ Water infiltration ↑	(Lavelle *et al.*, 2007)

4.5.5. Nitrogen as a threat to biodiversity

a)What is biodiversity ?

Video to watch :
https://www.youtube.com/watch?v=GK_vRtHJZu4&t=36s



Ecosystems can be defined by both their sensitivity and their

vulnerability to a stress such as enhanced nitrogen deposition.

The major impacts of nitrate deposition on terrestrial ecosystem

diversity are through :

- eutrophication,

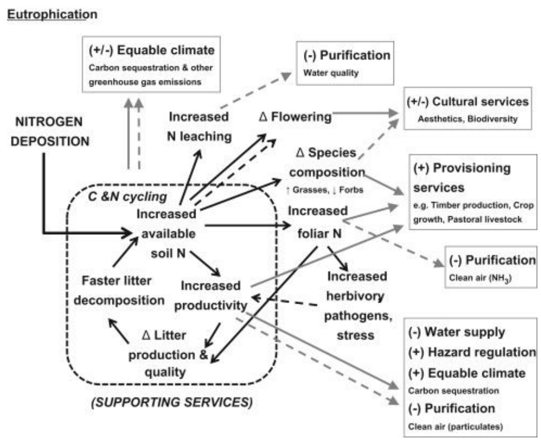
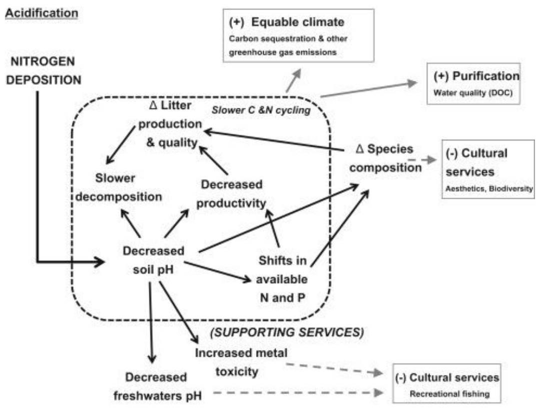
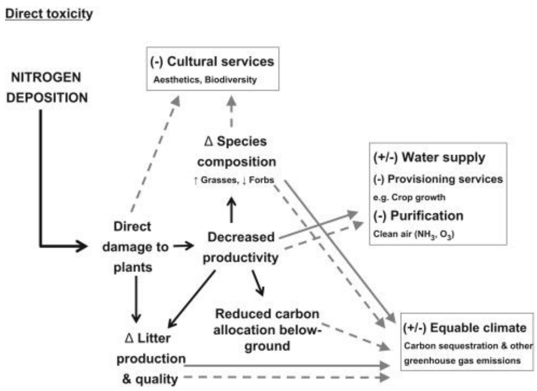


Fig. 1. Process-based impact pathway for eutrophication. Black arrows indicate process-based links, grey arrows show links to ecosystem services, where + and – indicate the nature of relationship and examples are given in small type. Solid arrows represent positive relationships and dashed arrows negative relationships. The dotted line box encompasses processes linked to C and N cycling (=Supporting Services). Impacts on species composition are generalised to increases in graminoids and decreases in forbs, but in reality are much more complex.



- acidification,

  Fig. 2. Process-based impact pathway for acidification.



- direct foliar impacts,

  Fig. 3. Process-based impact pathway for direct toxicity (incorporating NOx and NH_3 effects).

- exacerbation of other stresses.

Jones, L., A. Provins, M. Holland, G. Mills, F. Hayes, B. Emmett, J. Hall, et al. « A Review and Application of the Evidence for Nitrogen Impacts on Ecosystem Services ». Ecosystem Services 7 (1 mars 2014): 76-88. https://doi.org/10.1016/j.ecoser.2013.09.001.

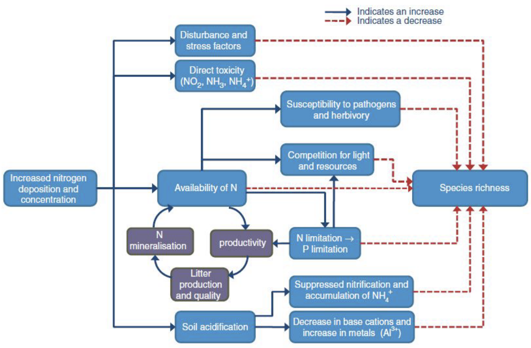


Figure. Schematic of the main impacts of enhanced N deposition on ecosystem processes and species richness. Stress is considered to occur when external constraints limit the rate of production of vegetation; disturbance consists of mechanisms that affect plant biomass by causing its partial or total destruction.

Sutton, Mark A., éd. *The European Nitrogen Assessment: Sources, Effects and Policy Perspectives*. Cambridge: Cambridge Univ. Press, 2011.

Example : Red-backed shrike

4.5.6. Medias

[cf. EV14_NitrogenCycle_Video5a.mp4]
[cf. EV14_NitrogenCycle_Video5a.mp3]

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5. Phosphorus

SUMMARY

1. Introduction
    1. Why do we talk about phosphorus ?
    2. How was phosphorus discovered?
    3. What is phosphorus ?
    4. Where is phosphorus ?
    5. Why and how humans use phosphorus ?
2. Phosphorus cycle
    1. The cycle
3. Anthropogenic phosphorus input
    1. Why phosphorus became toxic ?
    2. Why is it important ?
    3. Current phosphorus dependency
    4. Prospective of phosphorus demand
    5. A new war on phosphorus ?
    6. How can we ensure the safety of phosphate supplies?
    7. Sustainable management of phosphorus

5.1. Introduction

5.1.1. Why do we talk about phosphorus ?

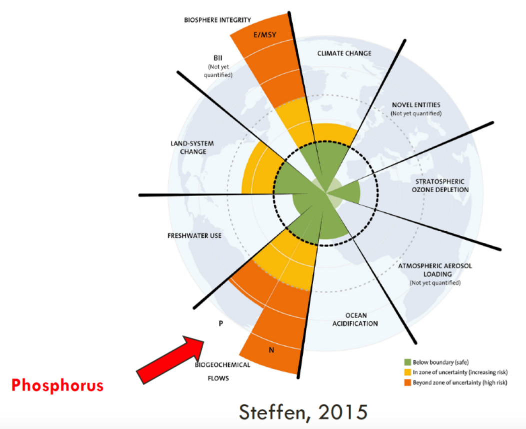
1 of the 9 planetary limits

1 of the 3 planetary limits exceeded

What is phosphorus ?

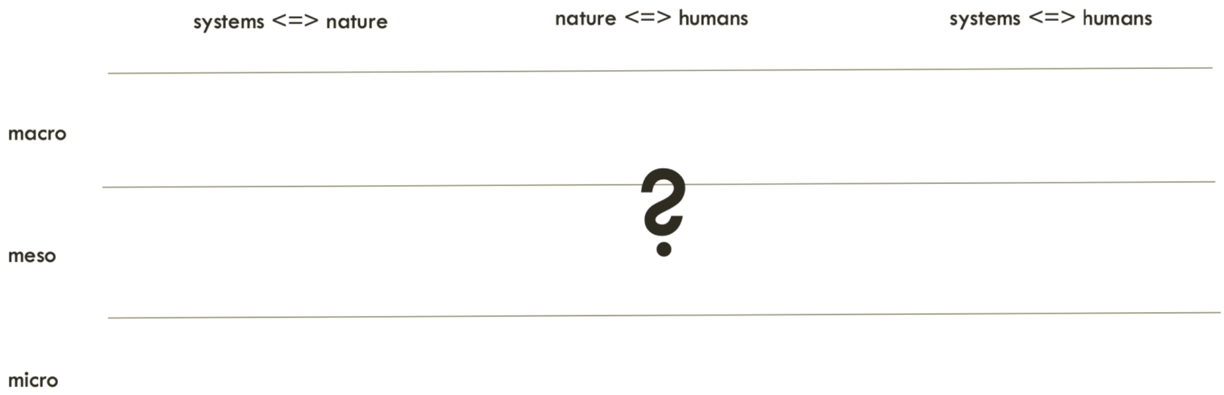
What is its cycle ?

In which human activities is it used ? How to return to a "normal" situation ?



Tatiana Reyes, Paul Robineau, Lou Grimal, Claudine Gillot, Kunzhang GUO

During the course, think about the different interactions between humans, nature and systems involving phosphorus.



5.1.2. How was phosphorus discovered ?

According to you, how did humans discovered phosphorus ?

A. By looking for the Philosopher's Stone

B. By doing caving (spéléologie)

C. By observing a carp population in a lake

A - Complete answer :

By looking for the Philosopher's Stone AND analyzing urine. Yes.

Who ? Hennig Brand

When ? 1669

Why ? By looking for the Philosopher's Stone

How ? By analyzing large quantities of urine

Properties :

- it is phosphorescent
- it ignites spontaneously on contact with air

1769 : Scheele discovery

(Gervy, 1970)

(Joseph Wright, 1771)

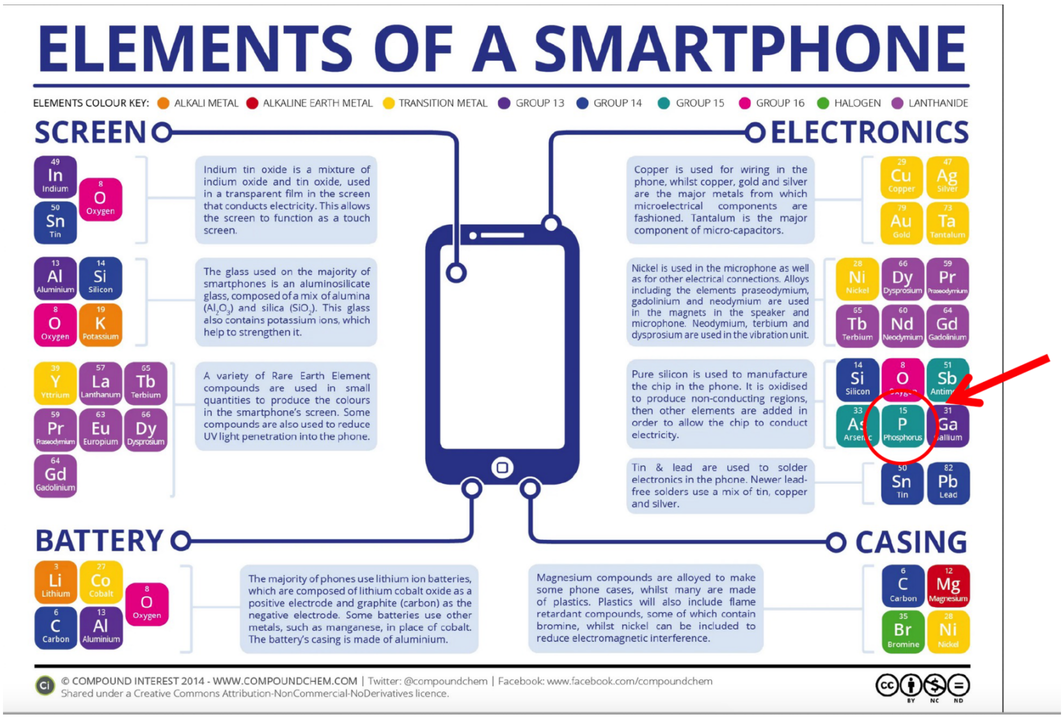
5.1.3. What is phosphorus ?

According to you, where can we find phosphorus ?

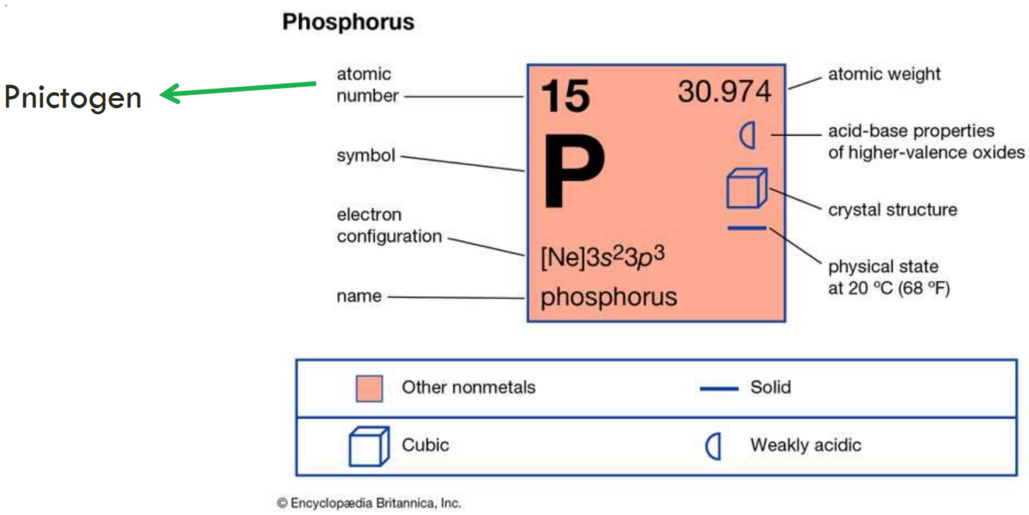
A. In our DNA

B. In our Smartphones

C. In our clothes

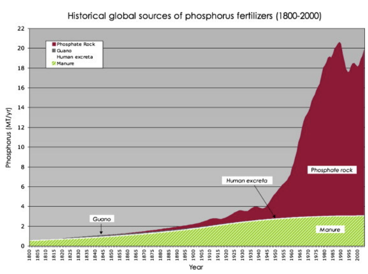


(Compound Interest, 2014)



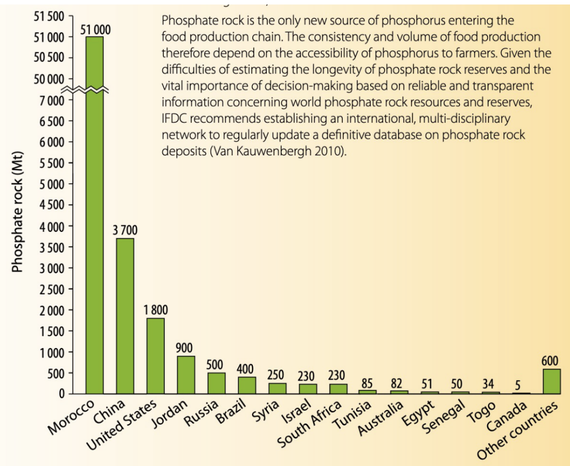
(Sanderson, 2018)

5.1.4. Where is phosphorus ?



(Cordell, 2009)

Country	Phosphate rock reserves, millions of tonnes
Morocco	5 700
China	3 700
South Africa	1 500
Jordan	1 500
United States	1 100
Brazil	260
Russia	200
Israel	180
Syria	100
Tunisia	100
Other countries	1 660
World total (rounded)	16 000



Phosphate rock is the only new source of phosphorus entering the food production chain. The consistency and volume of food production therefore depend on the accessibility of phosphorus to farmers. Given the difficulties of estimating the longevity of phosphate rock reserves and the vital importance of decision-making based on reliable and transparent information concerning world phosphate rock resources and reserves, IFDC recommends establishing an international, multi-disciplinary network to regularly update a definitive database on phosphate rock deposits (Van Kauwenbergh 2010).

Figure 3: Recent estimates of the distribution of world phosphate rock reserves, as reported by the United States Geological Survey (left) and the International Fertilizer Development Center (right). Most potentially viable phosphate rock reserves are concentrated in a few countries. *Sources: Jasinski (2010) and Van Kauwenbergh (2010)*

Note: The United States Geological Survey's Mineral Commodity Summaries 2011, published on 21 January 2011, revised the USGS estimate of world phosphate rock reserves to 65 billion tonnes. Its revised estimate of Moroccan reserves is 50 billion tonnes, based on information from the Moroccan producer and IFDC. The top ten countries in the 2011 report are Morocco, China (3 700 Mt), Algeria (2 200 Mt), Syria (1 800 Mt), Jordan (1 500 Mt), South Africa (1 500 Mt), the United States (1 400 Mt), Russia (1 300 Mt), Brazil (340 Mt) and Israel (180 Mt). Source: Jasinski (2011)

(Syers, 2011)

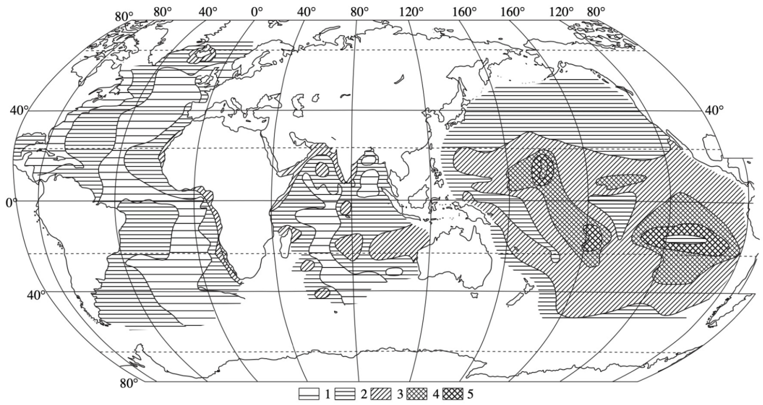


Fig. 1. Phosphorus distribution (%) in the upper sediment layer of the World Ocean, based on data from (Baturin, 1988; Baturin and Sevast'yanova, 1986; Baturin *et al*., 1995; Emel'yanov and Romankevich, 1979). (1) <0.05%; (2) 0.05–0.1%; (3) 0.1–0.2%; (4) 0.2–0.3%; (5) >0.3% (for the Indian ocean: (2) 0.05–0.08%; (3) >0.08%).

(Baturin, 2003)

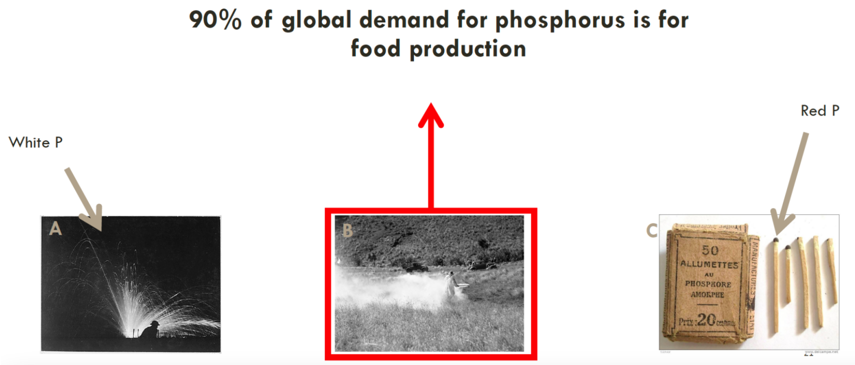
5.1.5. Why and how humans use phosphorus ?

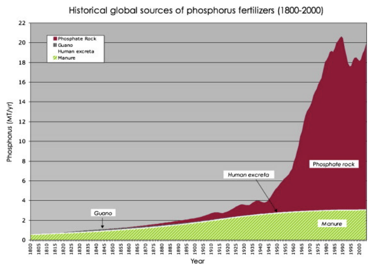
According to you, why do we use phosphorus ?

A. To create bombs

B. To create fertilizers

C. To create match scrapers (grattoirs pour allumettes)





(Cordell, 2009)

And HOW ?

Use of phosphates before their discovery :

1. Use of bones
2. Use of guano

According to you, what is guano ?

A. A plant that can be smoked

B. A typical Latin American outfit

C. A pile of excrement

Seabirds and bats dropping are full of phosphorus !

2 reasons to use guano :

- Both live in large colonies
- High concentration of phosphorus

5.2. Phosphorus cycle

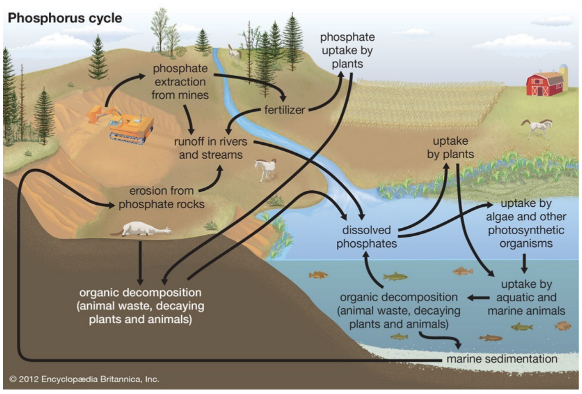
5.2.1. The cycle

According to you, what is not involved in the phosphorus cycle ?

A. Atmosphere

B. Oceans

C. Lacks



5.3. Anthropogenic phosphorus input

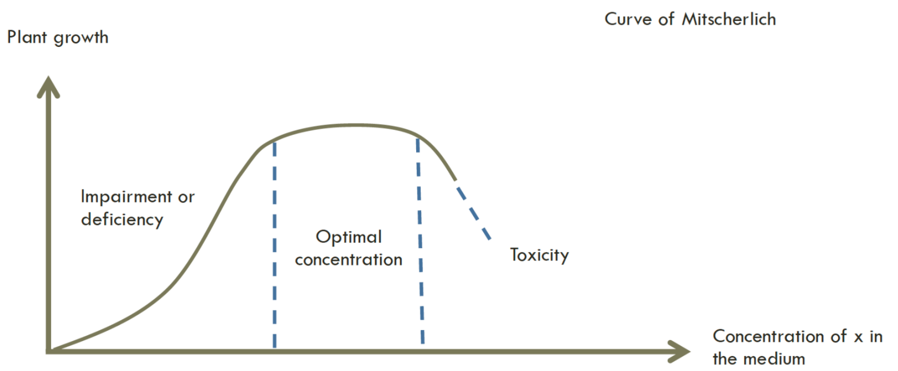
5.3.1. Why phosphorus became toxic ?

An ever increasing amount of phosphorus in ocean.

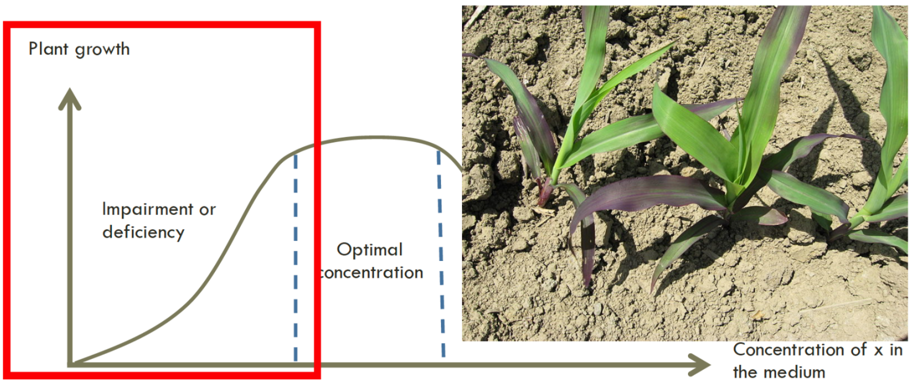
Table 2. Forms of present-day and preanthropogenic phosphorus supply into the World Ocean, Mt/yr (Compton *et al*., 2000)

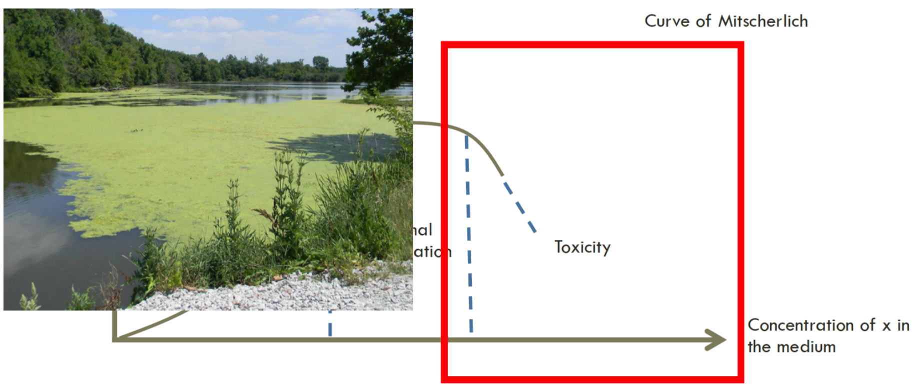
Phosphorus sources and species	Preanthropogenic supply	Present-day supply
1. River runoff		
Dissolved P:		
inorganic	0.3–0.5	0.8–1.4
organic	0.2 (maximum)	0.2 (average)
Suspended P:		
organic	0.9 (maximum)	0.9 (average)
inorganic	1.5–3.0	1.3–7.4
detrital	6.9–12.2	14.5–20.5
2. Eolian	1.0 (including 20% of reactive P)	1.05 (including 20% of reactive P)
Total	10.8–17.8	18.7–31.4
Reactive	3.1–4.8	3.4–10.1

(Baturin, 2003)

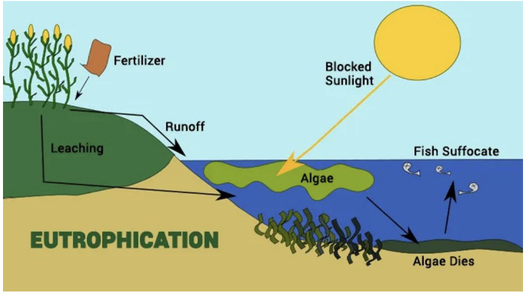


(Gaujous, 1995)





Eutrophication phenomenon



(Pinay, 2018)

Social consequences :

- Crystalization of social tensions
- Agricultural world, local elected officials and environemental protection associations
- DIfferent environement conceptions of public action, social responsability and scientigic knowledge

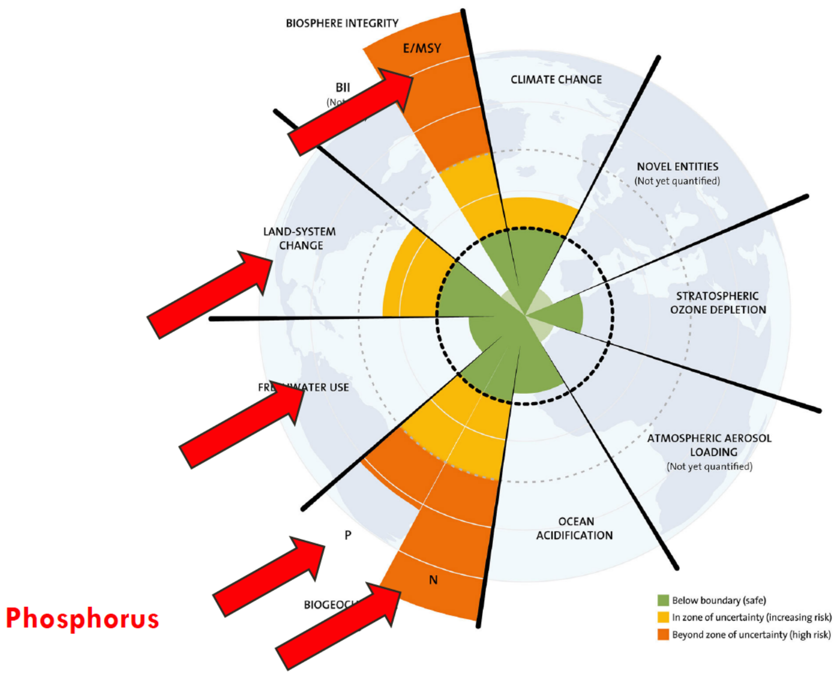
5.3.2. Why is it important ?

According to you, is this phenomenon reallyimportant ?

A. I guess, otherwise this course wouldn't exist

B. It is important but there are bigger issues

C. Not important, it is nothing in front of other issues



(Steffen, 2015)

5.3.3. Current phosphorus dependency

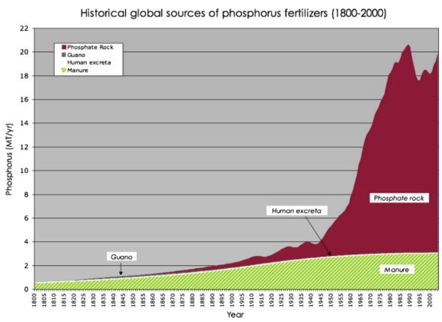
Rapid food demand to rapid population growth

Rectification of phosphorus deficiency of soils

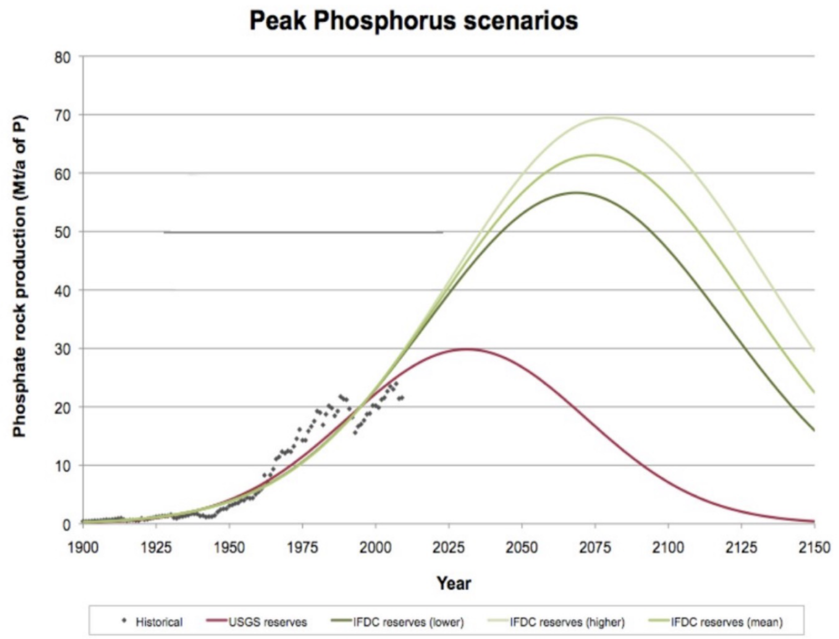
Saving people from starvation

« 90% of global demand for phosphorus is for food production, currently around 148 million tonnes of phosphate rock per year (Smil, 2000a, Smil, 2000b, Gunther, 2005) »

(Cordwell, 2009)



Phosphorus peak



Cordell et al, 2009; 2011

Figure 1. Peak phosphorus curve, indicating that production will eventually reach a maximum, after which it will decline. Red line indicates the original 2009 analysis based on USGS reserve data (Cordell, Drangert & White, 2009), while the green curves were updated with IFDC 2010 phosphate rock reserve data.

(White, s.d.)

5.3.4. Prospective of phosphorus demand

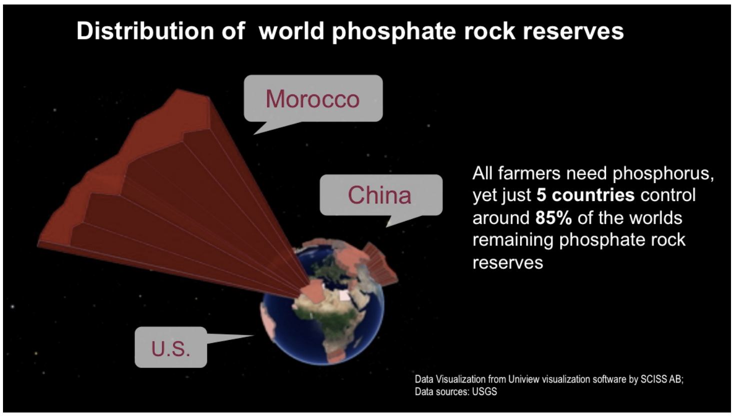
« Following more than half a century of generous application of inorganic high-grade phosphorus and nitrogen fertilizers, agricultural soils in Europe and North America are now said to have surpassed 'critical' phosphorus levels »

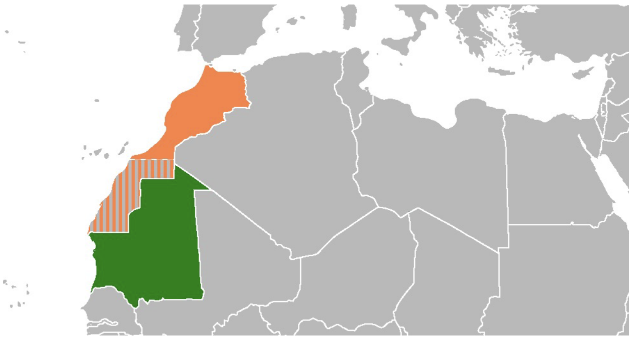
« Consequently, demand for phosphorus in these regions has stabilized or is decreasing. »

« However in developing and emerging economies the situation is different. Global demand for phosphorus is forecast to increase by around by 3–4% annually until 2010/11 »

=> high demand and an approaching peak...

5.3.5. A new war on phosphorus ?





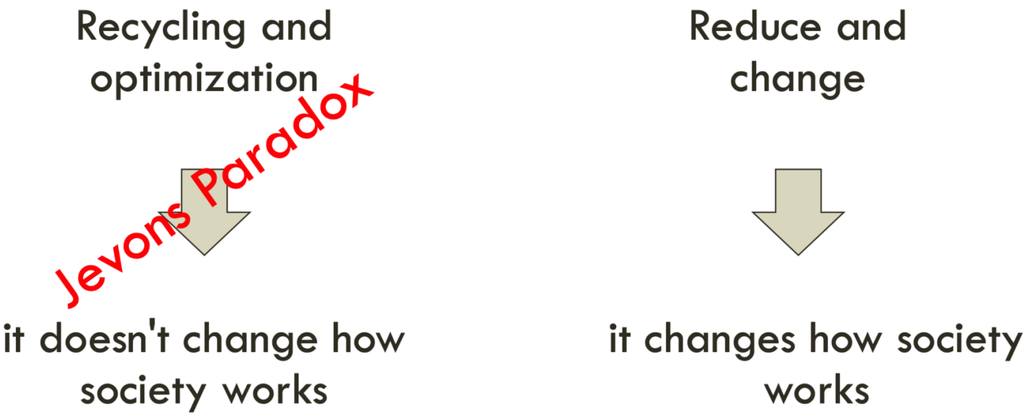
(Wikipedia, s.d.)

5.3.6. How can we ensure the safety of phosphate supplies?

Phosphorus security goals might therefore include:

1. "Increase number of people fed per tonne phosphorus input, or, reduce total phosphorus demand while maintaining food/agricultural output;
2. Reduce dependence on phosphorus imports (to reduce vulnerability to geopolitical dynamics and thereby increasing long-term access to phosphorus);
3. Ensure healthy soils (no phosphorus-deficiency, no phosphorus accumulation, balanced nutrition and presence of organic matter);
4. Ensure farmers needs are met (e.g., maintaining or increasing productivity; ensuring access to phosphorus fertilisers);
5. Reduce losses and wastage where avoidable;
6. Reduce eutrophication and pollution by preventing phosphorus from the food system from entering waterways."

- 4/5 phosphorus mined for food production never actually reaches the food on our forks
- Existence of a whole toolbox of phosphorus recycling and efficiency
- Low tech and high tech phosphorus recovery in the sanitation sector to changing diets



5.3.7. Sustainable management of phosphorus

Possible solutions for the management of phosphate nutrition of tropical crops in the context of ecological intensification :

1. Making better use of the diversity of the plant world and genetic resources
2. Greater use of species assemblages in time and space
3. Make more efficient use of mineral and organic inputs
4. Assessing the potential of microbial inoculants and bio-effectors
5. Maintain and promote the activity of the soil's macrofauna

   earthworms = ver de terre

(Hinsinger, 2015)

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6. Ecology

6.1. Introduction

6.1.1. What does “nature” mean ?

This is the first question I ask you in this class !!

Whats is "Nature" ?

A- a famous scientific journal.

B- the physical, geological, tectonic, meteorological, biological, evolutionary "forces" and principles that constitute the universe.

C- the biophysical environment, the habitat and the so-called natural environments.

D- the essence, the innate character, the set of fundamental properties of a thing or a being.

E- a synonym of universe or cosmos.

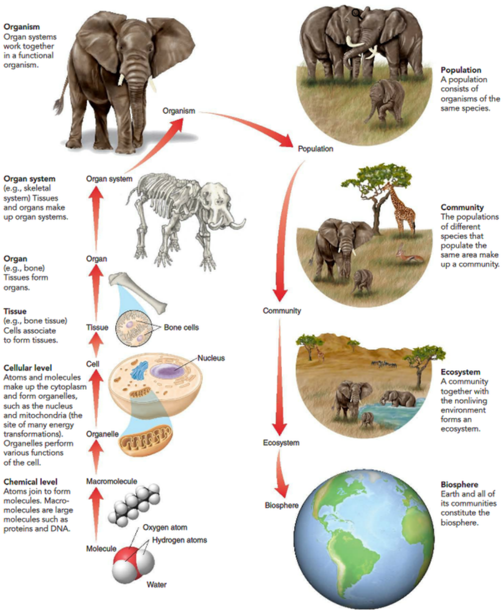
What do you think is a true answer ?

[cf. EV14-Ecology-v1.mp4]
[cf. EV14-Ecology-v1.mp3]

6.1.2. What is ecology ?

The term "ecology" was created by Heackel in 1866 to designate the science of habitat (from the Greek oikos = house, dwelling); it was a question of studying living beings no longer in breeding or laboratory but in their natural habitat. Nowadays, the definition tends to be more "systemic": it is said today that ecology is the study of the interactions between living organisms and the environment in which they live, and of living organisms among themselves, under natural or modified conditions.

Ecology is interested in the biosphere, and the biosphere is all the living beings on the planet, and all the environments they inhabit. The term ecosystem is used to characterize a sustainable interaction between organisms and an environment.



Ecology is also interested in biodiversity, which refers to the variety of life forms on Earth. This term is composed of the prefix bio (from the Greek βίος "life") and the word "diversity". It is assessed by considering the diversity of ecosystems, species and genes in space and time, as well as the interactions within and between these levels of organization.

Ecology can only be understood through evolution. It is based on observations on very varied time scales.

6.2. Ecosystem, it's structure and functions

[cf. EV14-Ecology-v2.mp4]

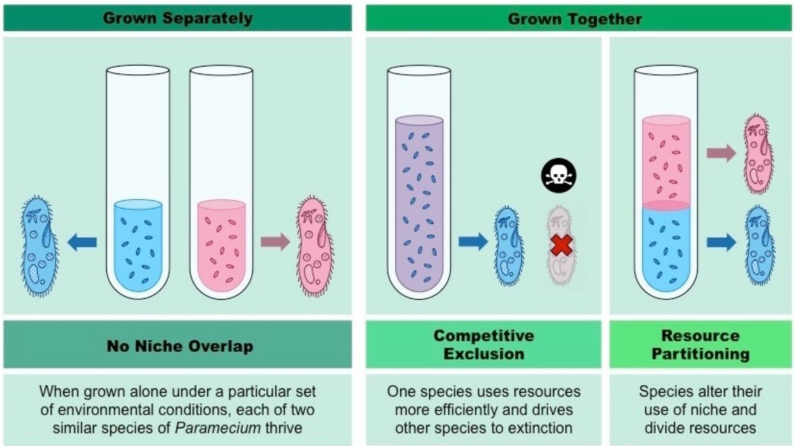
<!> The notion of an ecosystem is theoretical : it is multiscale, meaning that it can be applied to varying-sized portions of the biosphere, such as a pond, a meadow, or a dead tree. A smaller unit is called a microecosystem. An example of a microecosystem would be the species that have colonized a submerged rock. A mesoecosystem might be a forest, and a macroecosystem might be a region and its watershed.

6.3. Ecosystems, organized entities resulting from the action of ecological factors: the structure of ecosystems

[cf. EV14-Ecology-v3.mp4]
[cf. EV14-Ecology-v4.mp4]
[cf. EV14-Ecology-v5.mp4]
[cf. EV14-Ecology-v6.mp4]

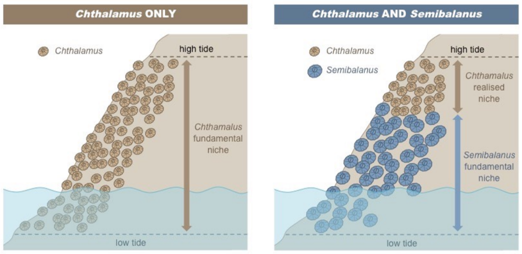
More about ecological niche :

In this picture you have an example of niche differention with bacteria.



Source of the image : bioninja.com

<!> Some species may not be able to occupy their entire niche due to the presence or absence of other species.



Ecologist Joseph Connell studied two species of barnacles - Balanus balanoides and Chthamalus stellatus - that have a stratified distribution on rocks on the Scottish coast.

In nature, Blanus species does not survive on the top of rocks because Balanus does not resist to desiccation (drying) incurred at low tide. Its niche is similar to its fundamental niche. However, Chthamalus species is usually concentrated on the upper rock strata. To determine the fundamental niche of the species, Connell he took back Balanus species from lower rock strata.

When Connel took back Balanus population from lower rock strata, Chthamalus population spread in this area.

The fact that Chthalamus had invaded this area, free from Blanus population indicates that the real niche of Chthamalus species is smaller compare its fundamental niche because of competitive exclusion.

6.4. Interactions between the populations of the biocenosis: the interspecific relations

[cf. Ecology _ ecosystems and interactions - Video 5.mp4]

Here you have an other video talking about Ecological relatioships : https://www.youtube.com/watch?v=rNjPI84sApQ

And here the video with parasitim examples : https://www.youtube.com/watch?v=NFa8-Hagg9Y

A symbiosis example

Symbioses of the mutualism type can be really important at the scale of ecosystems because they allow a rapid colonization of living environments.

Here is a example: symbiosis of coral algae.

https://youtu.be/JENUAv0w8Q4?t=7

Besides this ecological role, these symbioses are also very important for human health.

This is why we are going to have an overview of the human microbiota. The human microbiota is the set of bacteria, fungi and other microorganisms that live on the surface of the human being or inside.

Video : The Invisible Universe Of The Human Microbiome

https://youtu.be/5DTrENdWvvM?t=3

I also link you to a very interesting scientific conference on the subject (in french) : https://www.youtube.com/watch?v=1-6Z0JYsCQs&feature=emb_logo

To conclude

The species interactions discussed above are only some of the known interactions that occur in nature and can be difficult to identify because they can directly or indirectly influence other intra-specific and inter-specific interactions.

The role of abiotic factors adds complexity to species interactions and how we understand them.

That is to say, species interactions are part of the framework that forms the complexity of ecological communities. Species interactions are extremely important in shaping community dynamics. It was originally thought that competition was the driving force of community structure, but it is now understood that all of the interactions saw in the lesson, along with their indirect effects and the variation of responses within and between species, define communities and ecosystems.

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7. Humains needs and sustainility

Définition

“Strong sustainability: Among two main models of sustainability (weak and strong), strong sustainability captures the essence of irreversible, dynamic and hierarchical relationships between environment, society and economy while weak sustainability model creates a bias towards economy creating a detriment for environment and society. Therefore, businesses should strategize towards innovation with a strong sustainability approach and circumstances at institutional level should be created to support this.

- System thinking: Sustainability is a system property and not a property of individual system elements. Therefore, products, services, technologies and organizations cannot be regarded as sustainable on their own right but they may be elements of sustainable socio-technical systems. Therefore, design and innovation for sustainability should adopt a systems thinking approach as a reference to evaluate product / service concepts within which the system they will be produced / consumed.

7.1. What are the needs we are talking about?

The need is defined by a feeling of deprivation, of a lack that the individual wishes to fill.We can distinguish several needs : fundamental / primary / absolute and secondary / relative which are defined in the different theories.The needs are characterized as follows : they can be unlimited and evolving. Needs change according to the context of society, environmental issues and the individual. The needs are the same but it is the way to meet them that changes according to the cultural, social, historical context ...

7.2. Human needs and sustainability

Even primary needs consume resources and produce polluting emissions. Humans will exploit and appropriate resources and transform them to meet their needs. This is not without consequences on the state of the planet (see course on planetary boundaries). It is within this framework that Malthus (1966) posited his principle of population, where he shows that there is an intrinsic divergence between the increase of population and that of subsistence. Subsistence increases more slowly than needs. Malthus believes that the earth will not be able to feed the entire population in the long term and therefore that population growth must be regulated.

Since the beginning of the 1970s, one of the ideas carried in ecological thought is that there are limits to growth, economic but also industrial, demographic, pollution, consumption (“ The limits to growth ” by Meadows et al. 1979 sponsored by the Club of Rome). The report showed that after decades of rapid growth, humanity must reach a threshold beyond which growth would be neither possible (due to planetary boundaries and finite resources) nor desirable. It is the work of Georgescu-Roegen (with " La décroissance " Georgescu-Roegen 1979- http://classiques.uqac.ca/contemporains/georgescu_roegen_nicolas/decroissance/la_decroissa nce.pdf) which poses the problem of the inevitable déplétion of non-renewable natural resources. One of the conclusions of this work was that the decades of growth was an exception in history and that this context was about to end. Consequently, it was urgent to anticipate this reduction before a decline. Ayres and Kneese in their writing “ Production, consumption and externalities ” (1969), present an approach that questions production methods but also consumption patterns by analyzing flows and therefore identifying the origin of emissions. In their work, the authors show the principle of conservation of the mass of flows in the economic system. In fact, part of the flow is transformed into a system and a larger part of the flow is emitted in the form of pollution.

It is the foundations of ecological economics that have given rise to reflections on sustainable development.

The Brutland report, united nations, defined in 1987, sustainable development by :

“ Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs”

In this definition, there are two essential notions : 1) needs and 2) the level of sustainability 1) How can we define the needs? What needs are we talking about ? Are these basic needs ? What is the difference between needs and wants ? Are our daily needs necessary ? The central question would rather be how to clearly define its needs with regard to the resources that we are going to consume or the programs that we are going to emit to produce in order to meet the needs. 2) The level of sustainability of the concept of sustainable development with two positions : weak and strong sustainability. In the concept of sustainable development, the concept of development includes structural change or a modification of the lifestyles of society (we are not talking about an economic model or growth) What type of sustainability : weak (we admit that technology can replace nature) or strong (we admit that nature is irreplaceable).

Here it is what is important is to decouple economic decrease and ecology, through new models which call into question the relationship with society. For example, social and solidarity economy approaches, sharing economy, The main question is : What kind of models are suitable to stay within planetary boundaries while meeting needs ?

7.3. The question which human needs compatible with a Sustainable development (SD) ?

As we have seen, most definitions of SD speak of human needs.

Sustainability is our ability to meet our needs while staying within ecological limits. Also, in one of the four principles of sustainability it is said that " in a sustainabile society, people are not subject to conditions that systematically undetermine their capacity to meet their needs)

7.4. How will its needs make it possible to achieve sustainability ?

There are several models of needs like Maslow's. See video : Maslow's Hierarchy of Needs Explained - https://www.youtube.com/watch?v=xT6BpFhPsfY

In this course we will be interested in the model of the economist Mandref Max Neef, he published a book in 1991 entitled “ Human scale development ” demonstrating that human needs are limited and classifiable.

Max neef **identified 9 main needs common** to all cultures and all historical periods ; What changes is the way we will meet these needs. The nine basic needs are

- Subsistence : we need food, water, shelter, 3
- Protection : a safe environment, social security,
- Participation : take part in decisions that affect us
- Idleness : being able to relax
- Affection : to have friends, to love and to be loved
- Comprehension : Learn, understand, meditate
- Creation : cook, create, invent
- Identity, having a sense of belonging, having an identity, knowing yourself
- Freedom : being free to choose how we want to live our life

Even if the needs were the same in all civilizations, the means of satisfying our needs for protection, subsistence, freedom are very different than in those times. Certain objects / contexts / people fulfill a need, such as the insurance contract which provides protection. Others are more synergistic and make it possible to meet several needs. For example, breastfeeding a baby can meet both the baby's need for subsistence, but also his needs for protection, affection and identity.

Max Neef highlights other ways of meeting needs : **destroyers**. Which claim to meet a need but prevent us from meeting several others. For example censorship which would meet the need for protection but prevent us from meeting other needs such as creation, freedom, identity, understanding.

The **pseudo-Filler** that will give a false impression to meet our needs (like fashion for identity).

Max Neef offers four categories to organize how we meet our needs : **being, having, doing and interacting**.

Watch the video : Fundamental human needs

https://www.youtube.com/watch?v=28GMoDzpvPQ

Explanation of the Max-Neef matrix : https://www.youtube.com/watch?v=jJTvd0Yg2hk

Max-Neef recommends that emerging countries must make themselves independent of the current economic model which is centered on consumption. Its countries must strengthen social identity and use resources efficiently. For this, Max Neef encouraged promoting social development. In addition, it differentiates social development and growth. And so he encourage development on a human scale.

7.5. How are its needs useful to move towards sustainability ?

First, When we try to reduce our contribution to impacts which also reduce the ability to meet the needs of other humans.

It is about following a process to guide our reflections. We can highlight our business, products and services by using Max Neef's Nine Fundamental Needs and how they are being met. Second, when we try to reduce an unsustainable practice, it allows us to take a step back on the product, namely its origin, to what need it meets, and to question whether we could meet the same needs in another way or with a less impactful product ? Is the product necessary to meet the need ?

For example, how can we rethink the organization of a festival, which should meet the need for participation, idleness, creation and identity. Would we have another way to meet its needs by reducing CO2 impacts, the use of resources and with less impact on local ecosystems ?

Asking this questions would make it possible to explore different solutions that are more compatible with socio-ecological challenges.

Can we develop new ways of meeting the needs for freedom, identity without overconsuming our resources, producing and consuming so many products and services. Can we meet the needs of idleness and freedom without going to the other side of the world ?

And if we find sustainable ways to meet our need, can we improve it to meet other needs synergistically and using fewer resources ?

In other words, being sustainable is our ability to meet our needs (by redefining the means to meet them) within planetary boundaries.

The 9 fundamentals needs of Max Neef can be very helpful in finding ways to meet them, using fewer resources and having a holistic view of the system. It allows us to give a new look at the system we are trying to change. This is essential to stimulate innovation and avoid superficial solutions.

It is important to link human needs and ecological economy. See the video : Ecological foundation of basic human needs - https://www.youtube.com/watch?v=iLediUlP24s

Satisfaction of needs through goods ? (Economic theory)

In the thought of the economic classical school, the needs are supposed to be known by the individual consumer and the producer, who is even rational to him.

In a supply and demand model, we imagine that the individual has defined his need. But the needs are shaped by the market.

In economics, the difference between natural need and artificial need does not arise. The economy is concerned with the way in which human activity will allow the satisfaction of needs through the production of goods.

There are several classifications of “goods”. (In design for sustainability goods are defined as products, systems, services and infrastructures).

Classification according to rarity

Free goods : available in large quantities and which do not need human labor (air)

Rare goods : economic goods that need human intervention to produce them

Classification according to nature

Material goods: physical aspect

Intangible goods : service, benefit

Classification according to their use

Produced goods : machines used to produce

Intermediate goods : raw materials

Final consumer goods: final products

Classification according to service life

Perishable goods: will disappear after the first consumption

Semi-durable goods : will gradually wear out

Durable goods : long use (housing)

Carl Menger 1840-1921 helps identify the conditions that transform needs into material good. He identified four main ones :

1. Humans must be aware of a current or future need
2. The object or the service must have objective characteristics which make it possible to satisfy the need.
3. The human must have knowledge of the objective characteristics of the object
4. The object must be available

The " economic " good exists when it is insufficient and causes scarcity is at the heart of the value of this good. The value is the importance that the individual attributes to this good according to the needs (Water in a mountain context and water in the middle of the desert)

“The word VALUE, it should be noted, has two different meanings […] One can be called 'use value', the other 'exchange value'. use frequently have little or no exchange value; conversely, those with the greatest exchange value frequently have little or no use value. water, but it acquires almost nothing: one can hardly get anything in exchange for it. A diamond, on the contrary, has almost no use value; but one can often obtain a very large quantity. other goods in exchange "(Smith 1776).

According to karl Max, the exchange value of a good is the amount of labor socially necessary for its production: "living labor" and "dead labor" (embodied in the means of production). By paying a salary, the capitalist becomes the owner of the labor-power, for the duration for which he bought it. The source of exploitation: the worker devotes more hours of labor to the service of the capitalist than is necessary to reproduce his labor power. Current dynamics predicted by Karl Max.

"If our values are fair, everything else (price, pollution, etc.) is fair" Georgescu- Roegen

In this context, it is important to quantify the intensity of our needs and the value that can be attributed to a tangible or intangible (knowledge, partnership, innovations..) asset. Here we will quantify the level of utility of an asset. Here we will talk about assets to include any element that would allow to have a value of the tangible (environmental impacts, etc) or intangible (knowledge, partnership, innovations, patrimonies,..) flows exchanged. To this, it is important to promote the distribution of assets for social justice. The surplus of a good or an asset is not visible (since it is abundant) for some individuals but it is essential for others (since it is rare in this community).

The question that can be asked is the following : **Objects, nature, people only have values because they are useful ? Exchangeable? Difficult to produce**?

Questioning the need by value would be a way to lead towards sustainability ?

What need are we trying to satisfy through the product? What desire? What ambition? What action should we take (and how much does it consume or emit) ? What transformation of the world is desirable? What will it be used for? Whose ? What absolute finality?

Any need must be judged on the basis of the means implemented to meet it.

Current products tend to be integrated into “super-systems” forming “technical eco-systems” or even a single “technical system” in which the user (and the designer) loses his autonomy.

7.6. Could one lead be to reappropriate the technique to promote the satisfaction of “ lean ”needs and regain one's autonomy ?

The commons : values of sharing and value of savings to promote the satisfaction of needs by promoting the empowerment of the individual.

The notion of common refers to a free and collective management of scarcity: a common is a resource shared, managed, and maintained collectively by a community; this establishes rules in order to preserve and perpetuate this resource while providing the possibility of the right to use it by all. These resources can be natural: a forest, a river; material: a machine tool, a house, a power station; intangible: knowledge, software.

7.7. And should we give a "value" to nature?

“Progress can be a great comfort. But beyond a certain threshold, it becomes uncomfortable and even unlivable. Unlivable at the existential level, because it gives the image of a dead world, dumb, disenchanted, asphyxiating in the long term. And unlivable at a more concrete level: by inducing climate change and a biodiversity crisis, this will make the world uninhabitable for humans in the decades to come. The question is therefore to relearn how to pay attention, to connect one's sensitivity to the multiplicity of life forms which inhabit an environment, which constitute it but in a discreet way, pollinators, soil fauna, forests… ”(Ed Begley Jr)

7.8. A brief reminder of the values of the sustainable development concept

We can dissociate the constituent values of SD from the associated values

The three constitutive values in the definition of sustainability are as follows

- Economy : productivity, employment, profitability
- Society : justice, education, health
- Ecology : protection of biodiversity, fight against climate change,

To this we add the values at the interface of each of its spheres which are: environmental justice, social justice, energy efficiency, etc.

To these constitutive values of the definition we can add fundamental associated values , which are not in the classic pattern of sustainable development.

Recognition of the existence of conflicts between the three spheres of SD but also between present and future generations : There will always be a posture that will give more importance to the social or ecological or economic sphere. It is important to recognize the existence of diversity and these different postures and the right of expression of the supporters of each of these spheres.

7.9. Reflexivity

It is essential to be able to question the definition of sustainable development in all these facets: Is it possible to reconcile development and sustainability ? How can we take into account future generations? Is it possible to reconcile the diversity of supporters (both those who advocate for the green economy and those who advocate degrowth) ? How to strengthen the ecological sphere in the reflections?

It is therefore fundamental to question sustainability in order to create a dynamic concept adapted to the evolving societal context.

7.10. Citizen participation

Sustainability cannot be achieved without the participation of each individual through these daily actions, the adoption of decentralized technologies, political participation, etc.

8. Digital technological case study

8.1. Documents

In those documents, you will find information to help you define what are the different interactions between this technological tool (smartphone), humans (individual and global scale), and nature (fauna, flora, biogeochemical cycles).

Please, do not read all the readings entirely. Even if you try, you won't be able to make it until the end of the semester (so don't try!). **You must search for the information you need intelligently :)**

- LCA Cellphones: here[1]
- Impact of smartphones on society: here[2]
- Impact of smartphones on individuals: here[3]
- Emotions around smartphone use: here[4]
- Smartphone components: here[5]
- Computers in human behaviors: here[6]
- Indium cycle impacts: here[7]
- Lithium mining: here[8]
- Lanthanum and Yttrium: here[9]

You can look for other sources of course to find information on smartphones.

8.2. What to do

You don't have any lecture for this week. You only have some practicle work to do with the previous lecture.

By project groups, try to build a little model of the interactions between humans, nature, and smartphones along all the cycle of the life of a smartphone. You need to provide a table (the famous table you now know well now!) with the different interactions.

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[1] http://www.designlife-cycle.com/cellphones
[2] https://drive2.demo.renater.fr/index.php/s/etpse5GfAj5Niwr
[3] https://link.springer.com/article/10.1007/s10639-019-09947-7
[4] https://drive2.demo.renater.fr/index.php/s/tm6QwrZDLWCoSQp
[5] http://www.compoundchem.com/2014/02/19/the-chemical-elements-of-a-smartphone/
[6] https://drive2.demo.renater.fr/index.php/s/dKF6TkcZd4KToik
[7] https://www.tandfonline.com/doi/full/10.1080/10643389.2010.498755?casa_token=ZAiFKVvxr3sAAAAA%3AteXyoscGUyKuQuKY3JQUwC-UQFdpuNcvLwOZQKMFWxipAFS_XIlK4wLAZZEbpw2CixZoSGCSNplw
[8] https://drive2.demo.renater.fr/index.php/s/5mnoy7xnKPTBny2
[9] https://drive2.demo.renater.fr/index.php/s/y7rSqCmrrm4LpzE

2 mandatory rules to respect :

- Make sentences while completing the table (because when you only put words, I cannot always guess what you mean). Your table has to be understandable.
- Put sources on the different elements you add to the table.

Here is an example of the table you need to fill in :

Technical system				S <=> N	N <=> H	S <=> H
Stages	Description	Cause / Consequence	Modeling scale			
First life cycle stage : Conception		Cause	Macro			
			Meso			
			Micro			
		Consequence / impacts	Macro			
			Meso			
			Micro			
...						

Table 1: human-system-nature interaction representation at different levels and along with all the life cycle of the technical system

Of course, in a few days, it is very hard to model every interaction between a smartphone, nature, and humans. The aim of this work is to force you to model a complex technical system interaction to oblige you to understand the model and be at ease with it.

9. Infrastructure case study

Understand the interactions between optical fibers, humans and nature

9.1. Documents

In those documents, you will find informations to help you define the different interactions between this technical tool (optical fibers), humans (individual and global scale) and nature (fauna, flora, biogeochemical cycles). You are encouraged to focus on the main use of optical fibers, which is communications.

Please, do not read all the documents entirely. **You must specifically look for the informations you need :)**

Note : Some elements in the socio-historical domain are only available in French, because I did not find equivalents in English, I'm sorry. But the titles could help you investigate in the direction pointed by it - you may find what I did not!

General elements

- Presentation of optical fibers principle (video): here[1]
- Presentation of optical fibers fabrication (video a bit outdated but gives an overall idea): here[2]
- Optical fibers (wikipedia article): here[3]
- Fiber-optic communication (wikipedia article): here[4]

Specifics on technical elements

- Life-cycle analysis (LCA) on optical fibers production: here[5]
- A bible on Sand mining: here[6]
- Germanium and its mineral commodity profile: here[7]
- Carbon footprint of networks: here[8]
- Ecological impact and sustainable developpment in FTTO (fibre to the office). Slides are really ugly, we're sorry: here[9]

Specifics on socio-historical elements

- Overall review of technial history of optical fibers: here[10]
- Optical fibers at end of last century (the telecom boom, bubble, bust): here[11]

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[1] https://www.youtube.com/watch?v=jZOg39v73c4
[2] https://www.youtube.com/watch?v=6CqT4DuAVxs
[3] https://en.wikipedia.org/w/index.php?title=Optical_fiber&oldid=989311477
[4] https://en.wikipedia.org/w/index.php?title=Fiber-optic_communication&oldid=989407989
[5] https://drive2.demo.renater.fr/index.php/s/QrZiCEA9j7moGNq
[6] https://drive2.demo.renater.fr/index.php/s/kbm87Ds4Sji9yzY
[7] https://pubs.usgs.gov/of/2004/1218/2004-1218.pdf
[8] https://www.arcep.fr/uploads/tx_gspublication/reseaux-du-futur-empreinte-carbone-numerique-juillet2019.pdf
[9] https://ecoinfo.cnrs.fr/wp-content/uploads/2015/01/2018-06-josy-ftto-ecoinfo.pdf
[10] https://drive2.demo.renater.fr/index.php/s/SB5BDqHKLJdozfR
[11] https://drive2.demo.renater.fr/index.php/s/2mMirqM4PrY4Kmj

- The global challenges imbricated within sand use : here[1]
- Geopolitics of the submarine network of optical fibers: here[2] & here[3]
- Economical activity linked to public investment in optical fibers: here[4]
- A bible on the sociology of the digital (at all scales!): here[5]
- Material socio-history of high frequency trading: here[6]

You can of course look for other sources of course to find information on optical fibers, but this should cover pretty much everything on the communication use of optical fibers. Good luck!

9.2. What to do

You don't have any lecture for this week. You only have some practical work to do with the previous lecture.

By project groups, try to build a little model of the interactions between human, nature and optical fibers along all the life cycle. It is a complementary point of view: last week, smartphones were a technical system with mostly complex internal structure and complex direct uses by individuals; this time, you'll work on a technical system with a quite simple internal structure and used mostly as an infrastructure for individual uses – which imply different HSN relations at different scales. You need to provide a table (the famous table you now know well!) with the different interactions.

2 mandatory rules to respect :

- Make sentences while completing the table (because when you only put words, I cannot always guess what you mean). Your table has to be understandable.
- Put sources for the different elements you add to the table.

Here is an reminder of the table you need to fill in :

Technical system				S <=> N	N <=> H	S <=> H
Stages	Description	Cause / Consequence	Modeling scale			
First life cycle stage : Conception		Cause	Macro			
			Meso			
			Micro			
		Consequence / impacts	Macro			
			Meso			
			Micro			
...						

[1] https://drive2.demo.renater.fr/index.php/s/roCcdDQB34wcjg9
[2] https://drive2.demo.renater.fr/index.php/s/HFQe84J8s896icp
[3] https://drive2.demo.renater.fr/index.php/s/kK3Wkw3RKi987We
[4] https://drive2.demo.renater.fr/index.php/s/DiLESwFPtY7GDnD
[5] https://drive2.demo.renater.fr/index.php/s/NdXcqzaDGffpxSg
[6] https://drive2.demo.renater.fr/index.php/s/AsEF2yHANWf9iBZ

Table 1: human-system-nature interaction representation at different levels and along all the life cycle fo the technical system

Of course, in a few hours/days, it is very hard (not possible!) to model every interactions between optical fibers, nature and humans. Therefore, the aim of this work is not to construct an exhaustive table but to exercize yourselves, get a better understanding of the modeling process and help you being at ease with it. The system here being different of what you might have encountered before (with other tutorials and your project), it might help you take a new perspective on your project. Once I reviewed your work, I'll publish examples of interesting HSN tables (from this year or the previous one) for everyone. I'll highlight interesting elements , in order to help you for the final parts of your project.

10. TD on waste

[cf. TD on waste collage.pdf]
[cf. La-Fresque-des-déchets-V8.8.pdf]