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Emergence of the Anthropocene: A History of the Dynamics of the Environmental Effects of Human Activity and Technology

Since the Neolithic revolution, human activity and the technologies implemented have been in contradiction with the natural environment, through the intrinsic generation of negative effects, such as predation, pollution, destruction of natural spaces, etc. This depredation of the environment has grown in parallel with the development of technological power and the quantitative expansion of human activity. All this culminated in an ecological crisis, which became fully apparent in the final third of the 20th century. A historical analysis of these relationships over the course of history is enlightening for understanding and modeling the relationships between the ecological crisis and the development of human activities, of their transformative power, and of the growth in their scale.

1.1. In the beginning, humanity integrated into the biosphere

The first phase of the development of human activity evolved in a symbiotic relationship with the natural environment, similar to that of other animal species, since it consisted of "taking" from nature: gathering, hunting and fishing. This harvesting of the natural environment was necessarily moderate and balanced, as humans were not in a position to replenish the resources they had depleted, but had to await the natural renewal of the resources. The proof lies in the fact that, throughout this initial period known

as the Paleolithic, this "hunter-gatherer" society was a nomadic one; they were constantly on the move to find the abundance of resources that these groups had consumed by exploiting their hunting and gathering territories.

This society was already technically active, notably through the generation of hunting tools: stone weapons, thrusters, bows and arrows, bolstering the efficiency of these human activities. These Paleolithic societies appear to have been societies of relative abundance (Sahlins 1972), of high dietary quality and diversity, with a vitamin and mineral content higher than that of the average American in 1990, and with a population that had a very high level of physical development (Magny 2019).

This activity remained within the absolute quantitative limit of natural potential. This initial society, a social organization based on kinship[1] and a technology that was already evolving (Leroi-Gouran 1971), maintained humans in the hunting and gathering relationship with nature. The low intensity of this hold on nature, along with the basic technology that supports it, prevented human societies from degrading it through excessive exploitation that was supported by destructive technology. The hunter-gatherer, for example, was not involved in polluting and environmentally destructive activities; it could almost be said that they remained essentially a large predatory mammal, and therefore an integral part of the ecosphere.

1.2. The first period of artificial human activity: from the Neolithic to the Industrial Revolution

1.2.1. *The Neolithic revolution*

A major revolution, known as the "Neolithic revolution", took place approximately around the year 10,000 BCE, intensifying between the year 9,000 BCE and the year 5,000 BCE, with foci appearing in the "fertile crescent" of the Middle East, China and Indonesia, Central and Latin America and tropical Africa, before spreading to the rest of the planet approximately around the year 1,000 BCE.

1 Far from Hobbes' naive theses of initial chaos and Freud's primitive horde, Paleolithic societies "...were from the outset rather peaceful and relatively 'egalitarian' societies where a certain abundance reigned and which appeared to be in harmony with their environment" (Magny 2019, p. 45). These elements of harmony can be explained by balanced access to resources and the impossibility of private accumulation of wealth.

The Neolithic revolution marked a break with the subsistence modes of human society of the Paleolithic era, based on hunting and gathering, with the emergence of the new techniques of agriculture, animal husbandry and handicrafts (year 6,500 BCE). The intensive use of fire gave rise to a powerful and rapid technical evolution with the development of metallurgy, first bronze and then iron, approximately around the year 1,000 BCE (Childe 1963).

This evolution was a response to the massive geo-climatic mutation at the end of the Great Ice Age, and to the disappearance of large wild herds, the main resource of hunter-gatherer populations, leading them to seek control over the production of their subsistence by developing agriculture and animal husbandry. This led to the "invention" of techniques for working the land and storing agricultural output, for domesticating animals and raising livestock, techniques that increased the efficiency and security of subsistence production; or, like pottery, promoted the safe preservation of food products. The Neolithic is characterized as being the first period of intense technological innovation, leading to the development (in what has been called the Upper Neolithic) of large-scale, sedentary, organized and hierarchical human societies, models of which are the Mesopotamian and Egyptian societies (Demoule 2015).

However, this great period, with the emergence and widespread use of artificial technology, began to generate environmental pollution. This was also the case through the demographic growth it brought about, what paleo-demographers call the "agricultural demographic transition": from four to six million people at the end of the Upper Paleolithic, to 20 million by 5,000 BCE, to reach, in the historical period, the considerable level of 100 million inhabitants. This demographic growth was mostly concentrated in the limited, enclosed spaces that were the great "hydraulic" empires of this period, concentrated in the basins of major rivers, beyond the two best-known of Mesopotamia and Egypt, the basins of the great Chinese rivers and the Indus.

These human and animal concentrations gave rise to the first major health problems, caused by the deterioration in water quality due to contamination by human and animal excrements, which led to endemic pollution and even epidemics. Ecological imbalances, caused by agricultural densification, manifested themselves, as already expressed in the Bible's "plagues of

Egypt". The transformation brought about by human activity initiated an early stage of a depredating process, that we are now witnessing in its full development: the increase in greenhouse gas content, with a very marked rise in the concentration of methane in the atmosphere, as a consequence of the introduction of rice cultivation as early as 5,000 BCE[2].

A new mode of agricultural production, already geared towards maximizing productive efficiency, was based on species selection in both crop and livestock production, consisting of relinquishing nature's diversity in order to base human subsistence on the limited number of "productive" plant and animal species that human societies were then capable of selecting. This process of species selection led to a direct reduction in biodiversity, which intensified over the course of development. It also promoted a diet that led to a series of deficiencies in metals, minerals and vitamins.

This was already an example of industrial pollution of food: "[...] the use of millstones to grind cereals mixed abrasive elements with flours which, over time, threatened teeth and oral health"[3]. In addition, the effects of work: arthrosis, joint wear and skeletal deformities, visible today on Neolithic skeletons. "Overall, Neolithic people were smaller and more slender than Paleolithic hunter-gatherers, with brain volume losing an average of 200 cm[3,4]." Therefore, one of the first effects of this new mode of production and consumption was a relative deterioration in human integrity itself, in terms of health and even morphology.

The development of human societies has also led to the onset of aggression on the biosphere, which began in the Upper Paleolithic and culminated in the great sociotechnical systems of antiquity: after Mesopotamia and Egypt, Rome, China, etc.

What emerged in this period was a technology already powerful and transformative, with the desired end goal of productive efficiency, without regulation of its negative effects on the natural environment. This technological development was already based on a conception of the world in which humans were "outside nature" and saw themselves as its master

2 See Gemene and Rankovich (2019, p. 24).
3 See Magny (2019, p. 55).
4 *Idem* p. 57.

(Whyte 2019). This conception was going to structure – on a massive scale – the type of sociotechnical forms that would lead to the Anthropocene.

1.2.2. *5,000 years of slow human expansion*

About 5,000 years before the Common Era, historical human societies such as the Mesopotamian, ancient Egyptian and Chinese, had reached an already powerful economic development[5], based on large-scale productive activity, supported by advanced technology, differentiated in a complex division of labor and a hierarchy of powers and wealth. On the Indo-European continent, this process went from the Greek principalities, already confronted with the Persian Empire, to Egypt, which had been extending and developing its civilization for almost 3,000 years, to the Roman Empire, which integrated all the societies of the Mediterranean area into a single whole; this generated, like China in its own area, the first forms of "World Economy"[6].

These societies developed large-scale agriculture, a massive and diversified craft industry, high-level military, hydraulic and construction technologies, and the ability to transform natural spaces by diverting watercourses, often over long distances, to supply towns with drinking water or irrigate agricultural areas. Hydraulic technology provided the capacity to harness energy, still little used in antiquity, but which took off from the second half of the Middle Ages onwards (Gimpel 1975), forming the basis of an already significant industrial development.

Throughout this period, especially in the Roman Empire, and again from the 16th century onwards, there was a powerful development in land transport, with the construction of a gigantic road network combined with the slow progress of the towed cart. This maritime activity was taken up again and amplified by European expansion in the 16th century, inaugurating transoceanic trade and, in a way, starting to generalize trade on a global scale.

5 Technological development has led to increased productivity, so that the entire population is no longer required to search for sustenance, and the generation of a surplus has led to the complexification of society and the birth of both states and exploitation.
6 A concept coined by Fernand Braudel.

The technologies of this entire period did not have the power to generate significant transformation of the environment, and in particular massive degradation of the ecosphere, as was the case of energy technologies, which were still based on harnessing the natural energies of water, wind, animal and human power. However, it is the mass scale already reached by some of these activities that gave human technology a capacity on its own scale to significantly degrade these ecospheres. We can already mention the massive pollution caused by urban concentrations since Roman times, as well as the continuous deforestation of the southern part of the Roman Empire, which reappeared in Europe in the 18th century, due to the high demand of wood for construction, shipping, heating and the proliferation of thermal baths. Nevertheless, it was metallurgy that, as early as the ancient period, reached a level of production that would not be recovered until the beginning of the Industrial Revolution.

The first effects of the transformation linked to European technological development, insofar as it generated military supremacy over all the civilizations with which the West came into contact from the end of the 14th century, were those induced by the decisive destruction of the societies and populations of a large part of Latin America; this led to the disappearance of 80 million people, itself at the origin of the disappearance of agriculture over vast areas in favor of a return of the forest, which generated a climatic cooling in the 17th century, estimated at -1°C[7].

Long before the Industrial Revolution of the 18th century, which marked the bifurcation of the dominance of anthropogenic modification of the biosphere, the evolution of pre-industrial societies led to marginal degradation of the environment, already generated by the implementation of aggressive technologies, such as metallurgy, but above all, already and still locally by the effects of the abundance and concentration of human activity. Local and specific cases of limits reached reveal the ecological collapse of civilizations, such as the ecological destruction of Easter Island and the disappearance of the Mayan society; and later, the collapse of the Khmer empire of Angkor, through ecological depletion and deregulation, drought, local global warming and land exhaustion, generated by over-exploitation of

7 This is according to a 2018 University College of London (UCL) study published in the journal *Quaternary Science Reviews*.

the environment, which was made possible by a powerful agro-hydraulic system[8].

Therefore, the "vanished civilizations" of the technological level of the empires of early history demonstrate the fatal ecological crises that excessive scale and local concentration of human activity, aggressive technology and the ecological transformations they induced, can lead to.

1.3. The Industrial Revolution of the 18th century, the start of the Anthropocene

It was with the "English Industrial Revolution" that the qualitative, and quantitative, change in the technology and scale of nature's transformation took place. This transformation is traditionally dated with the invention and development of the steam engine, in particular, its most developed form – James Watt's thermodynamic pressure engine of 1782[9]. This machine inaugurated and generalized the first form of artificial energy transformation based on combustion, which led to the large-scale use of coal as the first fossil fuel. The steam engine originated from the functional need to extract water from mines that had become deeper and more extensive, to the point of saturating the possibilities of traditional hydraulic extraction. At this point, the steam engine represented the ideal energy-generating device, enabling large-scale industrial development and extraordinary growth in new modes of transport. The latter massively stimulated the use of new metallic materials, notably cast iron and iron, then steel, leading to a series of major innovations in metallurgy, another "fire technology" (Mantoux 1959).

At the end of the 18th century in England, a technological system was formed, based on three new, interrelated technologies that maintained their innovative momentum: a revolutionary energy technology: the steam engine,

8 See: https://www.pourlascience.fr/sd/anthropologie/pourquoi-les-mayas-ont-disparu-2486.php [Accessed February 18, 2022].

9 The concept of the Anthropocene was coined by Nobel Prize-winning chemist Paul Crutzen (2002), who proposed that this new geological Age marked by the dominance of human action should begin "[...] in 1784, the date of James Watt's patent on the steam engine, symbolizing the beginning of the Industrial Revolution and the 'carbonification' of our atmosphere by burning coal in the lithosphere" (Bonneuil and Fressoz 2016, p. 17).

iron metallurgy: the first massive industry producing transformed materials, both supported by mining industries, traditional in the case of iron, but revolutionary in the case of coal, and the first massive – and now almost exclusive – source of fossil energy (Landes 1975). This is how the first cluster of vectors of the Anthropocene ecological crisis came into being. It already combined the beginning of the accumulation of carbon emissions, the massive extraction of fossil fuels – which had been preceded by another massive problem, deforestation largely linked to the first development of combustion technologies – and the large-scale release of toxic industrial by-products from the metallurgical and already chemical industries (Jarrige and Le Roux 2017)[10]. This ecological problem of industrial origin was combined with the pollution of agricultural origin, linked to the beginnings of mechanization and the over-exploitation of the environment by intensive agriculture[11].

However, the major factor marking the entry into the Anthropocene was a change of scale, in which these effects appeared, through the development of major transport networks, the general industrialization of the Western world, and the particular form of globalization that was widespread colonial expansion. The development of technologies that pollute or aggressively affect the biosphere, combined with the level of massification and spatial generalization of these transformations, are the three factors of the Anthropocene.

1.4. The peak of the Anthropocene

1.4.1. *The Second Industrial Revolution amplified the ecological crisis*

This first wave of technological and economic development was superseded in the final third of the 19th century by what came to be known as the Second Industrial Revolution. By breaking with its technical foundations, this revolution compensated for the exhaustion of the first wave's capacity for technological progress. This new technological system (Aït-El-Hadj 1992), based on steel and metal technology, mechanics,

10 Particularly in the soda ash industry, using the Leblanc process (Fressoz 2012).
11 With the beginnings of the so-called "metabolic fracture", see Chapter 4.

electricity, chemistry and fossil fuels, reinforced and amplified the trends of the First Industrial Revolution.

1.4.1.1. *Widespread use of combustion as an energy source*

The first change involved combustion-based forms of energy transformation, based around the new steam turbine and internal combustion engine systems. These forms of energy production contributed to the generalization of combustion as a source of energy production from fossil fuels, with the consequent massive production of greenhouse gases, nitrogen oxides and fine particles.

By the 1950s, combustion gas pollution had become critical in the major industrial metropolises of the developed world. A paroxysmal episode was London's "great smog" of December 4, 1952, which forced all industrial and transport activities to cease for four days, during which time this critical pollution led to the deaths of 12,000 people[12]. This massive pollution by combustion gases and particles was already abundant and widespread in all major cities and industrial zones of the developed world at the time[13].

This cluster of pollutants – greenhouse gases, fine particles and sulfur-containing gases – is produced by the combustion of energy devices dating back to the 19th century: heating and steam engines running on coal and hydrocarbons to produce electricity, relayed and amplified by the internal combustion engine of road transport. This pollution became considerable, with the explosive growth in automobile transport, for example, rising in France from 3.28 million motor vehicles in 1953 to 15.92 million in 1974 (Pessis et al. 2015). This widespread use of motorized transport in developed countries, extended to a global scale, makes it one of the three biggest contributors to air pollution.

1.4.1.2. *The limits of an extractive system: the energy crisis*

Over the same period, oil took a growing share of primary energy production, rising from 1 million tons in 1870 to 2,237 million tons in

12 See: https://en.wikipedia.org/wiki/Great_Smog_of_London [Accessed July 22, 2020].
13 This widespread use of combustion in domestic heating, for example, led to coal consumption rising from 131 Mtoe in 1870 to 1,387 Mtoe in 1970.

1970[14]. However, this was not a coal–oil energy transition, since, despite the huge growth in oil consumption, coal consumption continued to grow. This led to intense mining of fossil fuels, to the point of raising fears that oil resources would eventually run out.

1.4.1.3. *Massive waste development, a waste society*

This phase of development also marked a turning point in the field of pollution, in the sense of toxic and destructive effluents, materials and substances discharged into the air, land, water and sea, and even the urban environment. Pollution is set to grow and become more widespread as a result of two factors. Technological intensification, in this second technological system, has produced a general movement to replace traditional organic products by mineral substances in the chemical field as a whole; the generation by the new industrial chemistry of increasingly active – and therefore increasingly harmful – products, with the widespread use of strong acids, such as hydrochloric, sulfuric[15], and nitric acids. The invention of the Haber–Bosch device in 1909, which synthesized ammonia to fix nitrogen in large quantities at low cost, led to the mass production of nitric acid, ammonium salts and nitrates for the manufacture of urea and ammonium nitrate[16], and nitrogen fertilizers, a powerful new device for capturing nitrogen for agricultural fertilization. However, this "nitrogen forcing" action, while positive in terms of its contribution to agricultural yields, is also highly disruptive to the natural environment, with its undesirable effluents generating plant proliferation and eutrophication of wetlands. This "chemization" of human activity is also based on the massive use, at higher concentration levels, of heavy metals such as mercury, lead and arsenic, and the development of energy chemistry such as petrochemicals and coal chemistry.

The consequences of this pollution were amplified by the mass effect generated by the scale reached by industrial activity and its rapid growth over the 20th century, indicators of which include a nine-fold increase in energy consumption and a 40-fold increase in industrial production over the period. As a result, this century has been dubbed the "toxic century".

14 See: https://www.encyclopedie-energie.org/consommation-mondiale-denergie-1800-2000-les-resultats/ [Accessed July 22, 2020].
15 See Jarrige and Le Roux (2017, p. 331).
16 The originator of a new generation of high explosives, such as nitroglycerine and TNT.

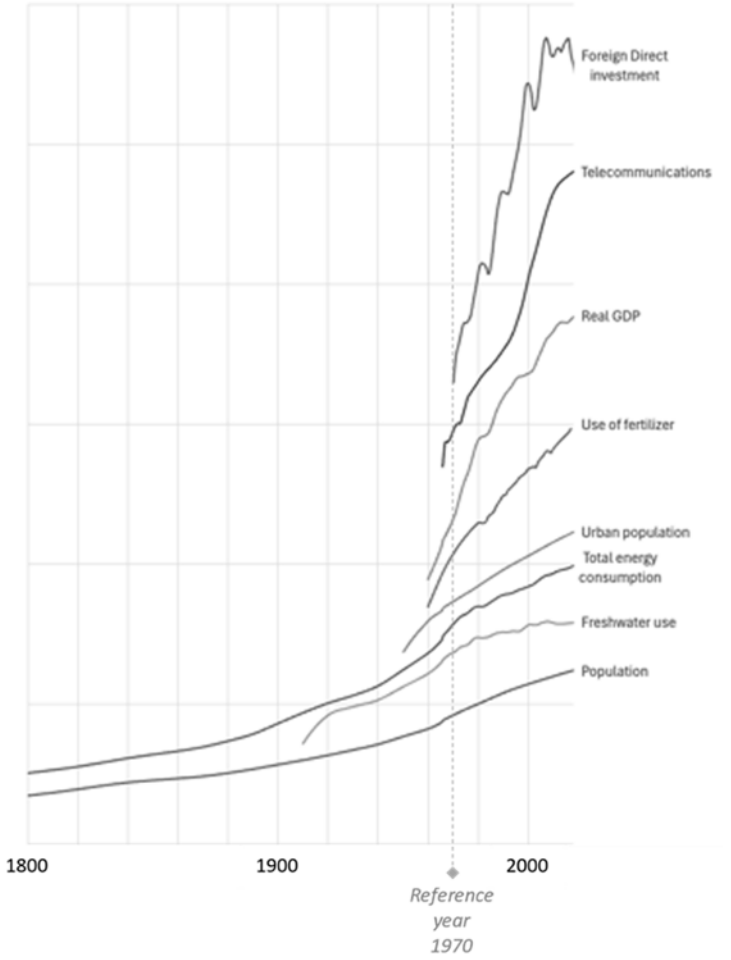

Figure 1.1. *Economic and technological growth statistics showing the bifurcation of growth from 1970 (data from Our World in Data, World Bank Data, UNCTAD, and Gemene et al. (2019)). For a color version of this figure, see www.iste.co.uk/ait-el-hadj/environmental.zip*

1.4.1.4. *The destructive effects of intensive agriculture and the metabolic revolution*

This pollution also accompanied agricultural activity on a massive scale, and was specific to this activity, engendered in particular by the "metabolic

fracture"[17] (Valiorgue 2020), which led to external fertilization – in particular, by fertilizers that rapidly became chemical, and were disturbing ecosystems. For example, azotic forcing and, above all, the large-scale use of phyto-sanitary products and, in particular, the protection of vegetation by pesticides (highly toxic chemical products[18]) are a factor in the collapse of biodiversity, from the destruction of bees to the decimation of birds that consume pesticide-encapsulated seeds. The generalization of intensive agriculture, notably with the "green revolution" of the 1960s, was in the process of extending this disequilibrium and degradation, all the more so as it created, through the degradation of terroirs and the destruction of ecosystems, the stimulus for an amplification of the "chemization" of this agriculture.

The technical and economic conditions of this intensive mechano-chemical agriculture, through the destruction of ecosystems by widespread clearing and deforestation, the drying up of wetlands, the exhaustive monoculture on bare land, generated the growing need for this aggravated use of fertilizers and pesticides. The concentration of animal husbandry, the overexploitation of +water and the artificialization of part of the soil exacerbated these destructive effects.

Intensive livestock farming contributed to this ecological degradation, through its effects of concentration, over-use of resources, particularly water, and the massive production of methane through ruminant digestion, one of the factors that contributed to the increase in greenhouse gases.

The forms of human activity in agriculture, a productivist, artificialist model in this recent and paroxysmal phase of their growth and generalization, thus represent a major contribution to ecological degradation.

This period marked a massive technological leap, building up transformed and new technologies that have considerably multiplied the power of transformation and production, but which at the same time

17 The metabolic divide refers to the situation that has arisen with the massive urbanization process transferring agricultural consumption to cities, thus depriving agriculture of the reuse of organic residues from agricultural consumption as fertilizers, which constituted a balanced circuit for traditional agriculture and the ecosystem in general. These residues then become waste, adding to this type of pollution.

18 DDT, first used as a disinfectant during World War II, was a popular agricultural pesticide in the 1950s.

generated a considerable increase in their degradation of all kinds with regards to the Earth system.

This unitary action of human technologies was amplified in the same period, by the period of the strongest economic growth in history, bringing this degradation of the environmental system to a previously unknown level, a level and pace that are now considered critical, as the ecological crisis of the Anthropocene began.

1.4.2. *The peak of the contemporary technological system and the ecological crisis*

1.4.2.1. *An energy crisis and a new technological revolution*

This growth was such that, in the mid-1970s, it led to an energy, oil and major economic crisis, which called into question the very foundations of development, with what came to be known as the "oil crisis" of 1973–1981. It also introduced the first awareness of ecological issues, and in particular of the limits of natural and fossil resources, making the pace of economic development catastrophic in the long term (Club de Rome 1972).

The energy crisis coincided with the first awareness of the resource limits of global development, particularly in the field of energy. This led to the first planetary analysis of the ecological limits of global economic development, with the work of the Club of Rome, known as the Meadows Report, published under the title "Limits to growth[19]"; this highlighted, using dynamic modeling, that unlimited growth in activity would in all cases lead to a collapse in growth, living standards, food availability and population growth by 2100, even under assumptions of pollution control and unlimited natural resources. This was the basis for the first policies that could be described as "ecological" at the time, massively focused on energy savings, mainly in response to the oil crisis.

19 Excellent presentation of this report, which is shown not as a forecast but as forward-looking, hypothetical modelling under Forrester's system dynamics modeling (see: https://jancovici.com/recension-de-lectures/societes/rapport-du-club-de-rome-the-limits-of-growth-1972 [Accessed March 10, 2022]).

From the 1980s onwards, this energy crisis gave rise to a major technological transformation, known as the Third Industrial Revolution, which was largely geared towards saving resources and reducing pollution; this is thanks in particular to the IT and biological revolutions, which became the technological foundations of this new technological system (Aït-El-Hadj 2017b). However, this awareness of the destructive nature of a system that was driving rapid and far-reaching technological expansion, driven by economic growth, globalization and the rapid development of emerging countries, did not prevent its rapid development, on an unchanged technico-economic trajectory – and even aggravated by globalization.

1.4.2.2. *The change in the scale of activity and the extension of the technological world*

This technological revolution will contribute to boosting economic growth, organizing a new global international division of labor, driving the massive industrialization of emerging countries, considerably increasing world trade, and generalizing the model of productivist agriculture through the intensification and generalization of the "green revolution" and the exploitation of areas that had remained natural. This, in turn, will lead to a considerable boost in energy production, particularly of fossil fuel origin, pressure on raw materials and an increase in the amount of land under cultivation; this would lead to the destruction of natural areas, particularly forests, intensified by the artificialization of land, and a considerable rise in transport activities of all kinds, linked to globalization, all of which generate massive pollution and diversified environmental degradation.

This increase in predatory environmental pollution is taking place despite improvements in the technical efficiency of industries, making them less polluting. Nevertheless, cumulative global pollution is rising steadily under the influence of four factors:

– the global spread of industrialization, which mechanically increases production and hence pollution;

– the growth in mining, which is taking place on increasingly less pure seams, requiring increasingly aggressive extraction processes;

– the development of mass consumption, which shifts pollution to the consumer sphere;

– the globalization of economic activity and industrial relocation, which tends to create new sources of pollution and displace them, notably through the expansion of transport.

These factors in the growth of ecological damage are in turn amplified by demographic growth[20], which increases the agricultural and urban needs of the population, particularly in emerging and poor countries, therefore accentuating the pressure to extend agricultural land, deforestation and soil artificialization.

1.4.2.3. *The ecological crisis of the Anthropocene*

It was the culmination of this process that, by the 1990s, led to an awareness of the major ecological crisis of the Anthropocene.

What are the components of this crisis? The first is that global warming has reached a measurable and already critical level as a major and radical environmental risk, generating not only climatic disruption but also degradation of the entire Earth system[21]. However, it is also the realization and formalization that all the direct degradations caused by our technological system, such as the disruption of the biosphere by chemical pollution or the accumulation of plastic waste, and contamination of the hydrosphere by water pollution and over-consumption, are in the process of amplifying each other.

The formalization of this crisis of the Anthropocene and its system dynamics, likely to lead to the collapse of the "Earth system" as a whole, shows the need for an ecological transition, and its "ways and means".

Long-term trends show that the ecological crisis that culminated in the Anthropocene is generated by the environmentally destructive action of current technologies used in human activity, but that it only reaches its critical level, i.e. to generate major, cumulative and often irreversible environmental degradation, through a mass effect particularly amplified by the gigantic economic growth of the 20th century.

20 At least for a few decades, as it appears that the trend is being reversed and polarized towards Africa in particular, with the rest of the world confirming a stabilization or even beginning a demographic regression (Bricker and Ibbitson 2019).

21 The Earth system is defined as the combination of lithosphere, atmosphere, hydrosphere and biosphere.

In the process of resolving this crisis, commonly referred to as the ecological transition, the need to reduce – if not cancel out – the environmentally destructive impact of previous technologies triggers a movement of innovation and technological renewal that is the first, easiest and probably quickest response to the ecological crisis. This leaves open the question of the quantity of activities and their growth, which, if they are to be kept in line with the demands of the ecological transition, require economic and social transformations that are far more complex, difficult and time-consuming to implement.