ENVIRONMENTAL THERMODYNAMICS

INTRODUCTION

The environment is the external surroundings of a system (from Fr. *en-vironner*, to circle). A system is a complex assembly of coupled components showing a common behaviour, which the observer takes as an integral entity; examples may range from a computer mouse, to the internet; from a room to a city or the whole planet; from a cell to an individual or the world population.

We restrict the term environment to the physical world, sometimes including other human beings, but not including intellectual human creations. The environment may be sometimes restricted to the omnipresent atmospheric air, but more complex environments (natural or artificial) must often be considered. Our Earth environment is basically governed by a radiation balance between the absorption of solar energy and the emission of terrestrial radiation towards outer space. This irreversible radiation flow drives all Earth processes, from atmospheric and ocean circulation, to biomass synthesis and life. Solar radiation directly or indirectly governs the thermal environment, the lighting, vegetation, precipitations, air pollution, etc.

Thermodynamics has focused since its beginning with Carnot in 1824 on the interaction system↔environment, where the system paradigms were the steam engine and the refrigerator (i.e. producing motion from heat, and producing cold from heat, respectively). It was the school of Brussels with Prigogine in 1964 that opened the scope of thermodynamics to self-organizing and biological systems, including not only the possible states of a system, but the kinetics that drive non-equilibrium systems from one state to the other. Main life ingredients may be: an appropriate thermal environment (e.g. at 300 K), a good material medium (water, liquid at 300 K and 100 kPa), and suitable polymerizable molecules with self-organization capabilities (organic compounds).

The sum of system and environment, what in thermodynamic parlance is called the universe, here is nature as a whole (humans and the environment). Our aim here is at analysing the interactions between humans and the environment, from a thermodynamic point of view.

The interactions between humans and the environment

Basically, we aim here at analysing the interaction between humans (at individual and global levels) and their environment. Humans are living beings, i.e. organic systems capable of growing by themselves and replicating by using matter and energy from the environment (and information stored in their genetic code). Life is a process of perpetuation, achieved at individual level by feeding from and fighting against, the environment, and at species level by reproduction because nature has find globally more efficient to die and start anew after a while (an individual life span). We do not pay attention here to internal life processes (e.g. human metabolism), in spite of the influence it has on the material and energetic exchanges with the environment (e.g. why and how is body temperature so finally regulated).

The natural environment on Earth is to be understood by default (although artificial environments like those found in closed vehicles may better show the needs), and our basic goal here is to better understand these two kind of processes:

- The effects of the environment on humans (changes in composition of air, water, soil, energy sources; climate change; natural disasters, plagues...).
- The effect of humans on the environment (local pollution, global pollution; impact on other people, on fauna and flora, on soil, water, air, on landscape and climate, on historic heritage...).

The environment, as the surroundings where humans live in, may be the traditional open-air terrestrial ambient, or several new environments that we have created or dared to go to, so that it can be classified as:

- Terrestrial environment: atmosphere, hydrosphere, lithosphere, biosphere; or in whole, the ecosphere, where we live (Gr. οἶκος, house; we may think of ecology as the house knowledge, and economy as the house keeping). Notice that we use here biosphere as synonym for biota (i.e. plant and animal life) spanning in a very thin layer around the sea-level surface (a 100 m thickness already contains most of its mass); but the term biosphere was introduced in 1801 by Lamark as the place where life on Earth stands and all adjacent interacting systems, i.e. our ecosphere. The ecosphere interacts with Outer Space and the Earth Mantle. Occasionally the anthroposphere is separated from the biosphere, or even a technosphere is introduced to pinpoint added anthropogenic impact on our ecosphere (perhaps we should add another geological epoch after the Holocene: the Anthropocene.
- Confined environments (as opposed to the free terrestrial one): space environments (including planetary environments), submarine environment (including diving), deep mines environment...

Life on Earth has slowly evolved during millions of years by finding new ways to take advantage of the environment. We should understand how nature solves system↔environment interactions, either to mimic it in our engineering solutions (e.g. seawater desalination by evaporation, waste disposal in landfills), or to find different solutions (e.g. desalination by reverse osmosis, aviation by jet propulsion instead of wing flapping like birds).

In general, environmental science is the study of the interactions of the system with its surroundings, i.e. the analysis of the environmental forces acting on the system, and the system response, i.e. the behaviour of the system, and the environment (which cannot be taken as infinite and imperturbable, at least at the terrestrial scale). Environmental engineering is a multidisciplinary field that combines the biological, chemical, and physical sciences with the field of engineering, what is sometimes called industrial ecology.

For living systems, particularly when people form part of the system (besides being the observer), it may be difficult not to get entangled with philosophical questions of 'what are we here for?', 'should we care for unknown people?', 'are wild animals friend or foe?', 'where needs end, and wishes start?', 'what is public and what is private?', 'can we change the world?', should we?'…

Humans in nature

It is a fact that humans are part of nature and rely on the environment for living (from birth to death): food, air, water, shelter... But it is also a fact that we humans are the main characters in our description of this world, if only because we are the narrators. Thence, we cannot content with just adapting ourselves to nature, as done by other animals and plants (and predicated in ancient oriental philosophy); we aspire to transforming nature to take advantage of it, to creating new environments (human progress), and in so doing we are encountering problems that we have to solve for our survival (at individual and global levels).

Human progress is the improvement from survival to intellectual activities, going from nomadism to sedentariness (with the change in food provision), from weather inclemency to space heating and air conditioning, from watch out water wastes to public water supply and sewage, from accident and illness harshness to health care, from over-the-hill ignorance to global instantaneous two-way communications, from learning the hard way (from mistakes) to formal compulsory education in accumulated knowledge...

Thermodynamic laws dictate that to sustain any activity without stopping, all systems (living or not) have to disperse energy, i.e. take in valuable energy from the environment and dispose of it as heat of lesser worth. The environmental problem of life is thence that living beings need continuous valuable resources, and convert them to polluting waste. It is basically due to the continuous solar radiation input and background radiation output that life is supported on planet Earth.

We humans have a long history on Earth, and we know that the environmental problem has been naturally solved in the past without too much concern from our side (as for other living beings), although, in many occasions, the dominance of the environment (e.g. access to raw materials) has brought societies to conflict and open war (control of the environment has always been a key political issue: territorial sovereignty). It is then important to be knowledgeable about our relationship with the environment, for curiosity, advantage, and exigency.

Public awareness and environmental attitudes

Environmental science in the past was first a descriptive subject (Geography), and later a topic of interest to naturalists studying Earth Science and ecology, but since the last quarter of the 20th century it has become a popular subject, when we took global conscience that human activities globally affect the environment, threatening the future of humankind (in the past, people were just concerned with environmental impact on humans, not the other way around, because the environment was assumed infinite and immutable). The milestone in this public-awareness change can be set at the 1st Earth Summit in Rio, in 1992.

From the United Nation Organisation down to small cities and private firms, most establishments have environmental programs: http://www.unep.org/, http://www.eea.europa.eu/, http://www.marm.es/... The UN has established a set of Days, Weeks, Years and Decades to help focus the world on issues of global interest; some of them are shown in Table 1.

Table 1. Some United Nations celebration dates.

22 March	World Water Day
23 March	World Meteorological Day
22 April	Earth Day*
5 June	World Environment Day
8 June	World Oceans Day
4-10 October	World Space Week
16 October	World Food Day
2008	International Year of Planet Earth
2009	International Year of Astronomy
2010	International Year of Biodiversity
2011	International Year of Chemistry
2012	International Year of Cooperatives
2013	International Year of Water
2014	International Year of Crystallography
2015	International Year of Light

*Earth Day is not a UN celebration, but it is in widespread use since 1970.

We are becoming conscious that natural resources should not be wasted (neither human resources); at least this is so in appearance (each individual person has some degree of hypocrisy to feel better and give better impression to the others). We are aware that wealth and welfare cannot only be measured in economic terms (cash money, income, and patrimony: you worth what you own) but also on other goods and services outside the market system and less quantifiable magnitudes: clean-air, fresh-water, noise-free, proximity of public services (schools, hospitals, communications), proximity of work, shopping, leisure... Non-government organisations (NGO), guided by humanitarian principles (sanitary, economical, ecological), have proliferated and are promoting international development.

We are aware that ownership is not absolute because restrictions on user rights must be imposed by our social belonging; i.e. the owner should not waste his resources (water, food, artwork) if it causes a public loss. Responsibility is being extended: tobacco industry, pharmaceutical industry, maritime industry, professional actions (doctors, architects, engineers...), all are subjected to social scrutiny. But many old attitudes that hinder environmental actions still prevail:

- Selfishness (caring only about yourself). Many people think that individuals ought to do what is in their self-interest and nothing more. Selfishness is rooted in life: self-preservation; indeed, environmentalism and conservationism might be viewed as egoism at humankind level, too the preservation of the species. A lot of people believe that we are the masters of the world and what we find is ours (Judaism, Christianity and Islamism are rooted in a-world-to-humans given by our father God, whereas Hinduism, Taoism and Buddhism advocate more for a-world-with-humans given by mother nature. Related to selfishness is unconcern about tomorrow (many people live by the day); we have solved our problems, let the new generations solve theirs.
- Free market. Time has shown that individual initiative is more productive than social initiative, for both, owners or users. Thus, capitalism (business aiming at private profit), and individual management (privacy, property), should be encouraged, but while not damaging social interests as with monopolies and transnational companies that tend to render global economy not controllable by national institutions. For instance, a few countries hold most of the present energy sources, with most countries in the world being energy-importers; if energy-problems are not solved at world level, conflict and war are the rule. Regulations cannot come from the force of the stronger, not even from a local majority; security, justice and peace should be dealt with at humankind level.

We take for granted that we have to share resources at the family unit, and we accept income tax (often reluctantly). It is time to think of the whole human population as our relatives, and willingly share with them our common environment, starting to share our knowledge about it.

Environmental science and engineering

The study of the environment is an interdisciplinary subject that integrates physical, chemical, and biological sciences; some of the fields of interest are:

- Physics: Meteorology, Climatology, Hydrology, Oceanography, Oceans-atmosphere system, Earth's energy budget, Noise and electromagnetic pollution, Ionizing radiation...
- Chemistry: Constitution of environmental matter (air, water, soil, selected chemicals...); materials and energy balances: coal (heavy industry, massive transport), oil (light industry, personal mobility, tourism); sustainable logistics: water quality management, air pollution, safe food, solid and hazardous waste disposal...
- Biology: Microbiology, Botany, Edaphology, Zoology, Sociology, Biodiversity.

We intend to restrict the study here to physico-chemical interactions between humans and the environment from a thermodynamic point of view; a rather incomplete perspective since biological aspects are only marginally considered here, and the ultimate goal of environmental science is to predict the interactions of human systems with the available environment. Thence, a more appropriate title of these presentations might be 'Thermodynamics of the atmosphere and the ocean', since, besides not paying attention to biota and human society in particular (no mention of microbiology and disease spreading), little attention is paid to the land and soils (no mention of farming), and the focus is more on characteristics of the environment than on actual interactions. Typical topics in ecology, like population dynamics (e.g. prey-predator models), are out of scope here, in spite of its essential role. We exclude also most working-environment effects: noise, lighting, ergonomics (human-machine interaction), etc.

A global scale is favoured here most of the times (i.e. the whole human population on Earth, the whole Earth, its atmosphere, its ocean...), although some data for the interactions of a typical individual person are presented too. Environmental effects at the micro-scale (e.g. how bacteria interacts with its environment, or a red cell with blood plasma), and living organisms that have develop under extreme conditions (of temperature, pressure, composition, radiations...), are not mentioned at all.

The 'thermodynamics' modifier implies that the focus is on energy dissipation and its effects on matter, and from the scientific point of view; i.e. not on social aspects, economic aspects, legal aspects, or even other physical or chemical aspects (acoustic impact, electromagnetic interference, radioactive pollution, and so on). However, it is important to keep in mind that social, economic, and legal aspects are foremost to any viable environmental solution; scientific and technical analyses give just advise (but sound; predictive; reliable advice).

An engineering approach is also followed here aiming not only at knowing how things work, but also how we can alter their working to our convenience. To this purpose we need:

- Models of how actually things work (changing from old myths to physical theories).
- Measuring instruments that allow an undisputable quantification of the goodness of models to represent the real world.
- Education of our society not only to be aware of problems and known answers, but to advance.
- Machines to transform things to our advantage (from raw materials or resources to products), without too much impact on other resources (the environment).

Although environmental studies can already be found in the most ancient cultures, its widespread interest blossomed with the space era in the 1960s ("The supreme reality of our time is...the vulnerability of our planet", John F. Kennedy's Speech of 28 Jun 1963; "We choose to go to the moon in this decade." John F. Kennedy's Speech of 12 Sep 1962 at Rice University, Texas).

HUMAN NEEDS AND QUALITY OF LIFE

Human needs can be categorised in several priority levels (Maslow's pyramid): physiological, emotional, and transcendental needs. We deal here just with the physical needs of respiration, drinking, feeding, waste removal (mater and heat), and energy and materials sources to satisfy basic services like space heating/cooling, illumination, transport, communications, and so on.

Air, water, and food (and energy up to the 18th century), were naturally renewed. Most mineral sources (and fossil and nuclear energy) are not renewable in the sense that they were concentrated aeons ago and we transform and disperse them on making use of them. At present, the amount of energy products in mass terms equals all other human consumptions: the world average is 2 kg/(person·day) of coal, plus 1.5 kg/(person·day) of crude oil, plus 1 kg/(person·day) of natural gas, i.e. 4.5 kg/(person·day) of technical energy products, against another 4.5 kg/(person·day) of metabolic products: roughly 3 kg/(person·day) of water, plus 1 kg/(person·day) of oxygen, plus 0.5 kg/(person·day) of food.

There are different time frames in satisfying human needs. The most urgent need is for breathing (to the next minute). We might be wearing ancillary equipment to cope with a short-of-air emergency, but we think it is not necessary in everyday life (although there are numerous faints and intoxications in badly-ventilated areas like in crowded shows or garages). There are only a few provisions, as oxygen masks in airplanes and submarines, fire-fighting personnel, special workers, and so on. Air-pollution in large urban areas is becoming a serious threat to health. Other short-term needs (to the next hours) may be shelter against natural harshness or incoming threats (e.g. cold or rain), water and food, waste disposal, electricity, etc. Medical assistance in case of accident is also needed in the short term. Nowadays, transportation to/from home/work (and the energy required) is also a short-term need in some societies (e.g. fuel for our car). We need security of supply, otherwise fear may bring panic. We in industrialised societies are totally dependent on the electrical grid and the two fuels at hand (oil-derivatives and piped natural gas), and the only backup we have is a regional security storage for fuels. We are not prepared for an energy blackout; we rely on having these two sources (but space-heating boilers need both); fortunately, thermal inertia maintains thermal control for a few hours (heating, refrigeration). It is worth here to recall that for a third of the world population, this short-term horizon is the only one, lacking proper water-supply, proper food, electricity, and so on.

Beyond satisfying basic needs, people ambition more well-being, including a standard of living according to their geographical and time membership (e.g. nowadays, air conditioning is an assumed service in developed societies, whereas it was a minority luxury in our last generation, and it is so in underdeveloped societies). There are many parameters to quantify the standard of living: per capita gross domestic product, life expectancy, level of employment, inflation rate, hours of work required to purchase a certain good, number of emblematic goods (e.g. cars) per capita, etc.

But humans aspire to higher levels in well-being where the 'quality' of life is pinpointed, more than simple material wealth: health-care services, education, infrastructures, political and religious freedom, other human rights... On more subjective grounds is the 'happiness' of living, a mental state of well-being based on contentment with own resources and achievements, and on finding positive aspects in ordinary events instead of complaining for imperfections.

Human progress in search of better quality of life, however, has always been accompanied by side effects that tend to oppose the benefits:

- Lighting and space heating started to be associated to smoke and fire risk.
- Cheap manufacturing of goods has put an end to repairing (requires handicraft), leading into the 'use and throw' unsustainable economy.
- Present agriculture high-yield (in crops and cattle efficiency) is associated to herbicide and pesticide pollution, crowded animals in farms, and great energy consumption.
- Personal mobility has brought with it large mortality figures.
- Living in large cities with plenty of services, forces you to breathe polluted air in return.
- The more sophisticated and dependent we get, the more exposed and hurt we become to malfunctions (just imaging a sewage problem in a city dwelling).

Our environment: the four elements

The environment is the world around us, which provides for our life support requirements (a life or death question), and for all additional commodities we might fancy (raw materials, landscapes, landfills…); there is nothing more beyond ours and our environment (in thermodynamic parlance, the sum of the system plus the environment is the universe).

In classical thermodynamics, the environment is the surroundings that has an influence on a given system, the usually system being some gas within a cylinder, and the environment loosely defined as 'a thermal reservoir'. But in environmental thermodynamics the emphasis is more on the outside, and the systems are so varied (one person, a community, one industry, an industrial sector, an ecosystem, humanity as a whole), that it is often not explicitly mentioned. Although there may be far-reaching influences (from the Earth's core, from the Moon and other celestial bodies), we only deal here with two extensions for the environment: the whole Earth's ecosphere, and the immediate local environment in contact with a person.

The ecosphere can be roughly quantified as: the atmosphere ($5.1\cdot10^{18}$ kg of a gas mixture of N_2, O_2, and minor, but important, gases, notably H_2O), the hydrosphere ($1.7\cdot10^{21}$ kg of a liquid mixture of H_2O, salts, and other minor, but important, solutes, notably O_2), the lithosphere crust ($20\cdot10^{21}$ kg of a solid mixture of silicates, oxides, carbonates...), and the biosphere ($2\cdot10^{15}$ kg of living matter, mainly near the ocean surface).

In order to analyse our exchange of matter and energy with it, we must understand the properties of the environment, which started to be scientifically analysed in the 19th century, and was first made manifested in our first trip off Earth in 1969 (Fig. 1).

Fig. 1. Earth view from Apollo 11 spacecraft (1969).

Leaving aside extra-terrestrial space and the Earth interior, our nearest environment can be split, following the classical four-element theory, in the following subsystems:

- Air, the atmosphere, the tightest life-supporting media (we die after a few minutes without). We need fresh air to breath and provide the oxidiser (O_2) used in metabolism, and we also make use of air as a cooling medium (temperature conditioning and heat sink). According to UNEP, some 2 million people prematurely die every year because of air pollution. Besides air availability and composition, air temperature, and all other meteorological phenomena, ordinary (like rain and wind) and extraordinary (like draughts and storms), have a strong influence on people's way of living. We have advanced a lot on weather forecast (present rate of success for 3 day prediction is about 90%), but nearly nothing in weather control (we still beg for rain, or for sunny days).
- Water, the hydrosphere, sometimes including solidified water (the cryosphere), mostly used as a solvent and carrier for matter and energy transport inside our body. Water has a deeper role for us because living matter is basically water (an aqueous solution with some macromolecules, enclosed in permeable membranes formed by macromolecules too), and, focusing on the thermodynamic aspects, water is the only substance present in its three phases (solid, liquid, and gas) in our environment. The water cycle is the main controller of matter and energy flows on Earth, providing plentiful of distilled water for direct human use and plant growth, and controlling Earth radiation budget. According to UNEP, nearly a third of the world population (i.e. some 2 thousand million people) suffers from polluted or scarce water supply.
- Land, the lithosphere (or its most external part, the crust, or even the most superficial layer, the soil or earth), so fundamental to land animals like us, which feed mainly from land flora and land fauna. From land we take most of our raw materials and energy, including the food to act as reducer in our metabolic energy release, and as building matter in our growth. And to land we throw most of our dump (and our own remains). Cultivated soil, pastures and forests cannot be further increased on Earth, although great improvements in the production of food and goods through efficient farming and forestry has been achieved with modern machinery, fertilizers and pesticides, but not without a corresponding stress in energy consumption and environmental impact (contamination of soils and ground waters, acidification, salination, and desertification). Mining, urbanization, transport infrastructures, landfill sites…, all of that is needed, and all of that is degrading the natural environment. To the whole mass of the Earth must be attributed also the omnipresent gravitational force field.
- Fire, what today we associate with energy (the '*vis viva*' or '*élan vital'*, from Sun irradiation (or alike, as in combustion). In a sense, energy is what makes the world go around, what keeps us alive, what controls air-, water-, and land- processes, what generates and regenerates environmental conditions, and what helps inert matter to form living matter. The large increase in average energy use per capita in the last two centuries in industrialised countries, has greatly increased the living standard of most citizens there, but energy utilization is also the main responsible for local and global environmental impact, energy sources are being depleted worldwide, and poor people (the largest portion of world population) is without the local advantages of cheap manufacturing and plenty servicing, and with the global problems of scarcity and pollution.

Human ecology

Ecology (from Gr. *οικοζ*, house) is the study of the relationships between living organisms and their environment, as coined by German biologist E. Haeckel in 1866. According to Charles Darwin (*On the Origin of Species*, 1859), the environment determines natural selection of organisms and species. James Lovelock suggested in the 1960s that life on Earth provides a cybernetic, homeostatic feedback system operated automatically and unconsciously by the biota, leading to broad stabilization of global temperature and chemical composition. With his initial hypothesis, Lovelock claimed the existence of a global control system of surface temperature, atmosphere composition and ocean salinity. His arguments were:

- The global surface temperature of the Earth has remained constant, despite an increase in the energy provided by the Sun.

- Atmospheric composition remains constant, even though it should be unstable.
- Ocean salinity is constant, even though it should be increasing.

Human ecology focuses in our interactions with the natural and artificially-changed environment. Planet Earth is the only closed life support system we know today (at the International Space Station, only air, and more recently water, are recycled; food recycling will be a must in a Mars journey). Driven by just the energy flow from the Sun to the background space, Earth's surface provides a comfortable thermal environment, a gravitational attraction to keep water and air in place, a source of food supply by chlorophyll synthesis, and even the emergence of life itself.

By the end of the 20th century it has become evident that the evolution of the Earth system can only be understood by proper coupling of key dynamic processes in the atmosphere, the hydrosphere (including the cryosphere), the lithosphere, the biosphere, and the anthrosphere (it is but natural that we consider separately humans and the rest of living beings).

The ecological footprint is a measure of human demand on the Earth's ecosystems for a living. In 2005, the average biologically productive area per person worldwide was estimated as 21 000 m^2/cap (i.e. 2.1 gha/cap, global hectares per capita); at that time, world averaged ecological footprint was 2.6 gha/cap, USA footprint was 9.4 gha/cap, that of Switzerland was 5.0 gha/cap, while China's was 2.1 gha/cap. It is unjust that poor people have to suffer the major environmental problems, which are caused by more wealthy societies in the major share.

The science of the environment is Ecology, which studies natural ecosystems (at local or global scale). But we should go beyond a descriptive talk about ecosystems and the human impact on it, and try to develop mathematical models that allow predicting effects from causes, to avoid the 'trial and error' procedure, so ill-fated when applied to long-term global problems.

ENVIRONMENTAL PROBLEMS

Humans are living beings, and (as for any form of life) we need to connect with the environment for mass, momentum, energy, and information transfer (we take wealth in, and throw waste out). It happened, however, that by the end of the 20th century a scientific consensus has been reached on the negative impact of human activities at global scale, as the oncoming climate change, with far reaching threats. Knowing that the Earth will go around no matter how severely we may change our environment (even after our species disappears) should be of little comfort: we want to stay for long. Thence, it is but for our own sake that we should devote a proportionate effort to learn about and fight against those perils.

Humans are open thermodynamic systems that need taking energy and matter from the environment sources, and inevitably returning them as waste to the environment, modifying its state. Life is basically a biochemical process (mass and energy flows: nutrients, wastes, the trophic pyramid), where several biogeochemical cycles may be considered: water cycle, carbon cycle, oxygen cycle, nitrogen cycle (involved in protein composition), phosphorous cycle (involved in nucleic acid composition)... We only deal here with the physical aspects of our interaction with air, water, land, and the Sun (outer space in a broader sense).

The individual and family needs for resources access and waste disposal were solved in the past by roaming. When sedentariness began with the Neolithic Revolution around 8000 B.C., civil engineering had to be developed for water supply, sewage, and landfill management. When the settlement environment became hard to sustain the local population, migration to better lands was the escape solution. The problem grows with the amount of people suffering hardship. The present problem with the environment is that human population (and some people's per-capita consumption) has grown so much, that we can no longer take the Earth environment as infinite and free; we have gained conscience of its limitations and economic value, i.e. of the fact that the goods and services we get from the environment are becoming costly (in terms of health and not only money), and scarce (not only locally but worldwide); therefore, we must make an inventory of resources and disposal sites, and control their allocation according to priorities (it seems that we are squandering, in general, i.e. using too much of resources, and, what is even worst, generating too much of waste; at least in industrialised societies).

The environmental impact on humans

As any other living being, humans need to exchange matter and energy with the environment, taking in valuable resources (e.g. well-differentiated chemical compounds and concentrated energy), and throwing out contaminant wastes (e.g. mixed downgraded substances and heat). We may split this exchange in the following fluxes:

- Air revitalisation. Until the 20th century, the only need was getting rid of smoke and stinking odours, and the simple solution was ventilation (i.e. allowing a fresh air flow), or going away. With the advent of submarine, aircraft, and spacecraft vehicles, another more basic need arises: procuring fresh air (either from the atmosphere, or by in-situ generation), and maintaining an appropriate gas pressure.
- Water access and purification. Until the ocean sailing bloom in the 16th century, water supply was based on directly catching water from natural stores (rivers, lakes, or wells), and disposing the water waste through the soil (by natural infiltration), or down the supply river, or far in the same lake. On ocean vessels, seawater was made drinkable by distillation. In the 19th century sewage systems proliferated (it was not until the end of the 20th century that sewage treatment became the rule).
- Fertile soils. Soil is a mixture of mineral and organic materials mainly in solid state, but with gasses and liquids dispersed and dissolved. On a volume basis, a good quality soil may have 45% minerals, 25% water, 25% air, and 5% organic material (both live and dead). Fertile soils are rich in nutrients necessary for basic plant nutrition, including nitrogen, phosphorus and potassium. Soil depletion occurs when the components which contribute to fertility are removed and not replaced. Humans have considerably modified the soil for culture, including modifications in the water ways, and have modified the flora and fauna locally and globally, with extinction of many species, and breading of just a dozen or so domestic species (both crops and cattle).
- Energy sources. Human life changed a lot two centuries ago with the Industrial Revolution, when huge amounts of useful energy could be produced with heat engines, greatly expanding transport capabilities, manufacturing, and household appliances. But the associated problem is that we are following an unsustainable path in energy utilization, with >90% of our primary sources being non-renewable (fossil and nuclear fuels), and with major dangers (from sudden accidents to progressie poisoning).

We have managed to take advantage of solar energy to revitalise air and water in space stations by means of physico-chemical environmental control and life support systems (ECLASS), and we are investigating bioregenerative life support systems (BLSS), required for long autonomous space travel, like on a journey to Mars.

The human impact on the environment

In spite of the smallness of humankind in comparison with the environment (in terms of mass, momentum and energy; e.g. the whole world population has a body volume of 0.4 km^3, less than the capacity of a medium-size dam like Entrepeñas, Spain), there is scientific evidence that we are responsible for anthropogenic degradation of the environment, which, although it has been just local through the ages (who polluted suffered the consequences), now it has shown to be at a global scale, i.e. the consequences of our contamination impinge on all humans, and on future generations. In the last century, humankind has increased atmospheric greenhouse gases some 50%, has reduced tropical forest area in some 50%, and has become responsible for the major changes in biogeochemical cycles (phosphorous, nitrogen...).

At present, the major impact of humans on the environment goes around the need for energy production, followed by water and land use. And the way out from the threat of an unsustainable environment cannot be to limit human progress, i.e. to limit the consumption of energy and other raw materials, but to find out better ways in their utilization (e.g. not to stop fuel consumption because it is contaminant and scarce, but to develop cleaner 'fuels', like wind, hydrogen, or nuclear fusion). Nonetheless, it is wise to minimize the use of expensive resources (in acquisition and disposal cost), while we develop more favourable solutions.

Human activities most dangerous to the environment are:

- Large infrastructures: dams, ports, airports, railways, roads, canals...
- Large soil-use changes: urbanisation, new ploughing, irrigation, deforestation...
- Extractive and energy industries: mines, metallurgy, refineries...
- Chemical industries: fertilizers, ceramic, paper...
- Food industries: farming, fishing, aquiculture, food processing...
- Municipal water and waste management.
- Transport (due to its intrinsic mobility, and in many cases its decentralisation, it is difficult to allocate responsibilities and damages).

The distribution and abundance of living organisms (including humans) in ecosystems are limited by the availability of matter and energy and the ability of the ecosystem to recycle materials. Increasingly, humans modify ecosystems as a result of population growth, technology, and consumption, and many species are in danger of extinction (including humans).

Pollution types

Pollution is any alteration of the environment able to cause damage to humans (and, by extension, to other living beings of our interest, since we have little concern on a world without the human species; Earth will go on spinning). The alteration is usually by the presence of dangerous contaminants (artificially or naturally introduced), but also by changing proportions in natural constituents. Pollution types may be grouped by location (urban, industry, agriculture), by type of process (metabolic, combustion, nuclear, food industry...); by type of contaminant (inorganic, organic, nuclear, thermal...), by physical state (gases, liquids, solids), etc.

The danger to humans may be direct, indirect, or potential. Pollution is stronger than mere contamination, but it is difficult to draw the separation line (e.g. windmills cause visual contamination, i.e. alteration, but is it pollution?); both terms are currently used without distinction. The first mention of air pollution seems to be by Seneca in 61 AD: "… the stink from chimneys…".

Pollution may be classified according to its origin:

- Natural pollution: volcano eruptions, earthquakes and tsunamis, flooding, desertification, plagues, asteroid impact...
- Artificial (anthropic): direct (metabolic waste, industrial waste, transport emissions...), or indirect (e.g. nuclear pollution caused by unforeseeable natural events). Sometimes the origin is difficult to ascribe; e.g. the heat wave that caused 35 000 casualties in Europe in the summer of 2003, was of anthropic origin? (the UN-IPCC admits since 2007 that the present climatic change is of anthropic origin).

According to its primary destination:

- Atmospheric pollution.
- Hydrological pollution.

- Soil pollution.

According to its nature (changes in matter):

- Physical pollution: ionising radiation, other electromagnetic pollutant radiations, thermal pollution (too hot, too cold, thermal cracks...), mechanical pollution (noise, vibration, debris...).
- Chemical pollution: noxious gases, noxious solutes (e.g. heavy metal ions, hydrocarbons...), and harmful aerosols.
- Biological pollution: health damaging microorganisms, introduction of stranger organisms that displace autochthonous wanted organisms, genetic pollution. Many times, however, pollution encompasses all these natures (e.g. domestic litter causes physical, chemical, and biological pollution).

Most pressing problems

From the point of view of developed societies, the most pressing problems on the relationship between humans and the environment are due to:

- Population explosion, mainly in the third world. World population was $<1\cdot10^9$ in year 1500, $3\cdot10^9$ in 1950, $6\cdot10^9$ in 2000, $7\cdot10^9$ in 2011...
- Poverty in the third world (and a part of the first world too). In 2000, 20% of the world population consume 80% of the natural material.
- Proliferation of weapons of mass destruction (nuclear, biological, or chemical), and terrorist attacks.
- Energy and water availability. Scarcity of raw materials in general, because of the increasing population and per-capita consumption, and the pollution caused by its utilization.
- Climate changes. Related to the energy use, drastic changes in regional weather (floods, hurricanes, droughts, desertification...), associated to a mild global warming due to the increment in the greenhouse effect (produced by atmospheric accumulation of the massive emission of contaminants from human activities), are already escalating in the severity ranking of environmental problems.

This global and far-reaching environmental problem of anthropogenic origin demands a conscious approach. What can we do? First, let us see what we want to do, in relation with the environment:

- Guarantee, imperatively, that our basic needs are satisfied: respiration, drink, food, shelter…
- Profit from what the environment offers (raw materials, energy, room…) to develop our living standard, i.e. to help our comfort, our travels, our communications…
- Avoid the damage to us from the environment, both from natural causes (e.g. floods, hurricanes) and from our own contribution (the ‘Don’t cut the branch you sit on’ aphorism, or the Spanish version ‘don’t throw stones on your roof’).
- Avoid our damaging the environment because we may suffer a reflected damage, or we might need the resources later on, including in the ‘we’ our next generations.

Population and wealth distribution problem

We are in an unprecedented stage of human development (extrapolating backwards, the ‘big-bang’ of the environmental problem seems to be just two centuries ago, with the onset of Industrial Revolution, where human population and its fossil fuel utilization significantly increased.

Population explosion can be appreciated in Fig. 2, showing estimates from 1800 to 2100, based on UN 2010 projections (red, orange, green) and US Census Bureau historical estimates (black). We are $7\cdot10^9$ persons in Nov-2011. According to the highest estimate, the world population may rise to $16\cdot10^9$ by 2100; according to the lowest estimate, it may decline to only $6\cdot10^9$. The best estimate of the total number of people who have ever lived up to 2002 is $106\cdot10^9$ persons (thence, some 6% of all ever-lived persons are presently alive). Mortality rate is rising in the poor world (what is a shame to all us), and massive migrations bring trouble to developed societies. The only rational solution seems to be family planning based on education and the development it conveys.

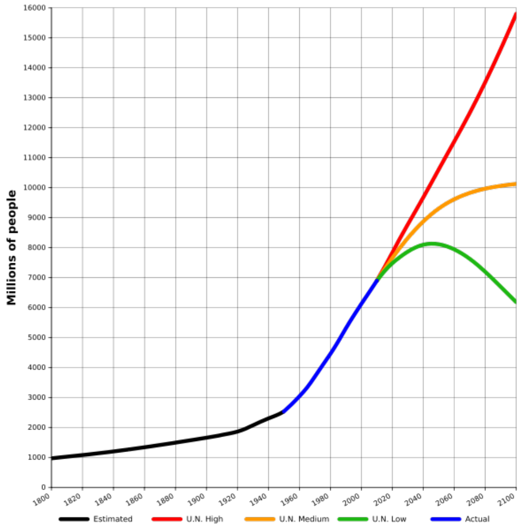

Fig. 2. World population.

Industrialised societies are consuming valuable resources and contaminating at a quick pace, and the foreseeable development of non-industrialised countries appears unsustainable, at least to the first world, since, to them, i.e. to developing societies, there are more urgent needs that local or global pollution, namely: procuring daily food (clean water above all), sanitation and medical care, protection against natural and man-made disasters (floods and droughts, war), education... Notice the commonalities and differences that different societies have on their problems:

- Developed-societies major problems are health (heart stroke, hypertension, obesity...), security (terrorism, arms control, strikes...), environment (global warming, urban pollution...), infrastructure damage (electricity blackout, bad weather...), etc.
- Developing-societies major problems are health (AIDS, malaria, hunger, unsafe water...), security (war, sacking, slavery...), environment (lack of water and sanitation, floods and draughts), and lack of infrastructures.

Sharing benefits and costs? The human species, with about half of 1% of the total biomass on the planet, appropriates about half of the total products of photosynthesis. It is regrettable that, after the holistic view we gained from the first whole Earth's pictures from Moon journeys in the late 1960s, human wealth differences and environmental problems are not levelling off but going deeper. Poverty of the third world (and a part of the first world too) is increasing. In 2000, 20% of the world population consume 80% of the natural materials (Fig. 3), although they claim they have 'produced' much of the resources. Without equity of humans to basic needs (food, water, shelter, health and education), peace cannot be sustained.

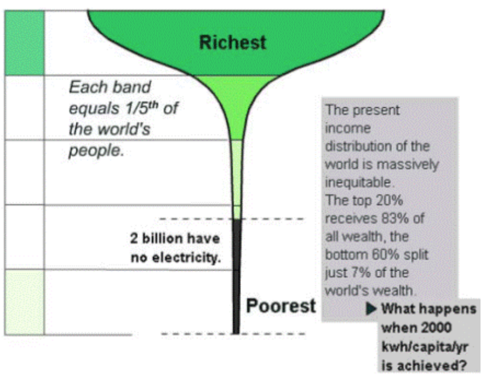

Fig. 3. World wealth distribution.

A related issue to environmental concern is the process of integration of local economies and cultures known as globalization, which developed at the same time as ecology (in the 1960s), jointly pushed by the easy of telecommunication and transport technologies. Globalization, as any other human undertaking, has pros and cons, depending more on people attitudes than on intrinsic characteristics (humankind is unfortunately reckoned foolish enough to make a new weapon from every new discovery):

- Some positive effects: mutual acceptance of universal human rights, and cooperation for better education, health, and security services; e.g. pandemic control, financial and technical assistance for development and in case of misfortune by natural disasters; and a broader knowledge of other people ways of living, with cultural links favouring a more peaceful relationship than before.
- Some negative effects: in some cases, the more developed societies, instead of helping the less developed ones, abuse of them (e.g. exploiting poor workers and recruiting the clever, exhausting natural resources and placing polluting industries abroad, imposing foreign cultural habits without regard of local cultural heritage ...); evolution theory shows how important diversity is, not only for biological survival and progress, but for cultural richness, and even for financial stability. It is not fair for developed societies to demand cheap goods and services from poor countries, not care for the negative local impact, and blame them for the associated degradation of the global environment.

War proliferation

Another related issue to wealth distribution is the proliferation of terrorist attacks and weapons of mass destruction (nuclear, biological, or chemical). Injustice, objective and subjective, is a powerful driver of violence and revenge.

Crime and extortion have always been with humankind, but developed societies must try to minimise its impact by early detection of risks, prevention of causes and effects (taking precautionary action), and effective remediation of damage. Mental disorders, at both individual and society levels, should be treated (not just by punishment), by enhancing physical and mental health care.

The traditional principle of non-interference in national conflicts has changed to humanitarian intervention, where military force is used against another nation to stop human-rights violations, in view of the collective responsibility.

Energy and water availability. Climate change

A great environmental problem is the scarcity of raw materials in general, and of water and energy in particular, because of the increasing population and per-capita consumption, and the pollution caused by its utilization, i.e. the contamination of the atmosphere (particulate, smog, acid rain), of epicontinental waters, marine shores, landfills, flora & fauna biodiversity loss, mechanical noise and vibrations, electromagnetic radiations and radioactive particles, visual contamination...

Fortunately, industrialised countries now have 60% of their economy based on services instead of extraction of raw materials and manufacturing of goods.

Global primary energy consumption has grown from 380 EJ in 1990, to 496 EJ in 2005 ($496\cdot10^{18}$ J⇔2400 W/cap) in 2005 (but unevenly distributed; e.g. 10 400 W/cap in USA). Prospects are 700 EJ in 2050, and 800 EJ in 2100.

Related to the energy use is climate change, with drastic fluctuations in regional weather (floods, hurricanes, droughts, desertification...), associated to a mild global warming due to the increment in the greenhouse effect (produced by atmospheric accumulation of the massive emission of contaminants from human activities). Climate change is escalating in the severity ranking of environmental problems.

Global CO_2 emission have grown from $7.5\cdot10^{12}$ kg of carbon⇔$27.5\cdot10^{12}$ kg of CO_2 ($5.5\cdot10^{12}$ kg of carbon due to fossil fuels) in 1990, to $8.8\cdot10^{12}$ kg of carbon in 2005. A few countries, with 20 per cent of world population, produce 57 per cent of gross world product (based on purchasing-power parity), and account for 46 per cent of greenhouse gas emissions (UNEP-2007). Why we know that atmospheric CO_2 increase is anthropogenic? Because of several good correlations: increase versus production; the ratios $^{14}C/^{12}C$ and $^{13}C/^{12}C$ in the air are declining, and fossil fuels have no ^{14}C and little ^{13}C; etc. The atmospheric molar fraction of CO_2 has increased from 285 ppm in year 1800 and centuries before, to 385 ppm in 2010; the present target for 2050 is to keep it below 490 ppm, to avoid the global air temperature to raise more than 2 ºC, what requires to decrease CO_2 global emissions some 85% relative to year 2000 level. Notice that this goal is not to prevent a climatic change but to minimise its effect and try to get adapted, although one should never forget that, to a large part of developing societies, there is a more urgent need for clean water and food (and protection against current illness and floods), than the threat of climate change.

Another environmental problem associated to energy use (particularly to refrigerant fluids and foaming agents) is ozone depletion in the stratosphere, a potential health problem by decreasing the ionising radiation shield protection the ozone layer provides.

Legacy problems

Humankind lives today in an environment that is a common heritage from our ancestors and must be passed to our heirs: we are not owners of the world but temporary users (old African adagio, also stated in the Koran). We should take into account steady and transient states in a long-term analysis of our utilization of the environment, trying to define not only our present-day interactions, but with a multi-generation perspective:

- What legacy have we inherited from our ancestors: a dominant position in the ecosphere (we defend pretty well from beasts, colds, fires, floods, hunger...), libraries (not only accumulating scientific and technical knowledge, but plenty of artistic creations), infrastructures (cities, transport, electricity, telecommunications)...
- What legacy are we building for our heirs: new knowledge, better infrastructures (e.g. internet), genetically modified crops and animals, industrial and nuclear waste, climate change? Let the new generations have a better heritage than ours.

In order to get a sustainable development, we (developed societies) try to act on our societies (rich and poor) and our environment (ours and theirs) to procure a sustainable life (for us and them, and from our offspring). To do that, we must learn how things work (and how humans behave), establish quality standards and procedures, and take responsibilities; e.g.:

- How to agree on reasonable human needs? Are they changing with time?
- How to agree on sharing resources (sources and sinks)? Should they be proportional to needs or to productivity? Are natural resources expensive or too cheap? How to agree on resources pricing?
- How to agree on reasonable clean environment? Is it changing with time? How to clean the environment? Are we contaminating so much with our waste? Unfortunately we answer yes and no, depending on who is the subject, as one may easily verify when asking smokers, drivers, campers, householders, vendors, clients...
- How to agree on reasonable risks? Should they be proportional to actual or to expected benefit? On individual or community bases? How to minimise risk exposure? Not everything is predictable, but some factors may be anticipated (e.g., flood damage has recently increased not only because of climate changes, but because more lowlands are being inhabited, there is more people living there, and upstream lands have been deforested).

Sharing resources, keeping cleanliness, renouncing to violence, all are subscribed phrases, but people get mad when resources are scarce, and individuals have different acceptance levels for damage to oneself and damage to others: we all accept that rubbish is inevitable, but 'nimby' (not in my back yard). Most of us appreciate a good chicken thigh, but do not want to think on the killing mess.

We must feed and pollute for our living, and thus cleaning is also a must, but being tidy helps a lot. And it is urgent nowadays because sources and sinks are 'shrinking', and population growing. We have to find a peaceful solution, knowing that force brute has shown to behave like a boomerang (or the third law of motion: when we push a body, it reacts by opposing a force equal in magnitude). People behave like spring-mass system: they accept gentle pushing offering little resistance, but feel stiff to shaking (and may go out of control near resonances).

Solutions? Education (at individual and social levels), cooperation (social synergy), and regulation (ecotaxes and natural reserves).

In summary, there are many environmental problems at hand, not a minor one being how to go from descriptive talks about the environmental and human impact, to a predictive approach of how to make models that relate cause and effect, and how to take advantage of it.

Solving environmental problems

The environmental problem of finding resources and recycling waste has been solved by nature through evolution. Basically, the fluid media (air, water, and molten rock) has helped disperse contaminants by mass convection and diffusion, often with associated chemical changes (reactions), whereas the population moved to the neighbourhood of resources and fought to defend them. But human progress cannot rely only in natural processes (particularly when we have found they are not convenient to us); we have to solve the problems by our own.

There are many steps in solving a problem:

1. Identify the problem and take consciousness of it.
2. Quantify it and make a mathematical model of natural constraints.
3. Plan several approaches, from the most conservative (if everything works right...), to the more realistic (attenuation of expected disturbances), and include a recovery procedure in case of failure of foreseen measures.

Managing the problem

Environmental management requires first to know human needs, search for raw materials and energy sources, built installations to render these raw sources into usable forms, and to turn contaminant waste into inert substances, possibly able to be reprocessed. And these activities must be permanently optimised by proper monitoring (measuring), auditing (diagnosing), rewarding (economy), and social control (legislation).

To better approach the environmental problem, we first sum up what we want the environment for, then what we are presently doing, and then try to find out the actions required and means available to improve the situation. What we want is:

- To keep us alive; the environment is our life support system, and we know how difficult it is to build artificial environments like in a space station.
- To defend ourselves from environmental risks: beasts, colds, fires, floods, famine…
- To get natural resources for our living and progress: air, water, food, energy, and materials.
- To put away our waste: domestic (solid, liquid, gas), and industrial.
- To enjoy the beauties of the environment: outdoor activities, landscapes, ecotourism…

But in our struggle to take advantage of the environment what we do not want is:

- War. Our fight for resources should not be at the expense of someone else's life: peace must be maintained for our own sake; cooperation is more fruitful than fight.

- Poverty. Our benefit should not be at the expense of someone else's poverty; it is not just a case of justice (ethics) but of peace (indigents have but to revolt, and the 21st century menace is coming mainly from social unrest and fanaticism pushed by deep discontent).
- Inflexibility. Biodiversity must be maintained for redundancy of scarce genetic resources. Cultural diversity (linguistic, religious, ethnical) should also be maintained to have a wider seeding and stimulate blossoming.
- Unsustainability. Our present benefit should not compromise tomorrow's way of living; economic development must account not only manufacturing costs but environmental costs.

Sustainable development

In short, our objective function in our humans↔environment exchange should be to take maximum advantage of our environment at present (to meet the needs and aspirations of the present population), without compromising the ability to meet those of the future, what may be called sustainable development (Brundtland Report, UN World Commission on Environment and Development, 1983). With this goal, we sit in between the older oriental way of living in harmony with nature (adapting ourselves to it, respecting the powerful natural force, and admiring its beauty), and the newer occidental way of living, trying to control nature (adapting nature to us).

An idea of the actions planned to fight against the environmental problem may be grasped from the EU targets for year 2020:

- 20% reduction of greenhouse emissions (1990 base), by increasing renewable energies, capturing massive CO_2 exhausts, introducing second-generation biomass fuels, vehicle fleet renovation, electrical vehicles, maintain nuclear power stations and funding nuclear fusion research, taxing large CO_2 emissions...
- 20% saving of primary energy use (1990 base), by increasing energy efficiency in all kinds of transformation, by changing to high-efficiency lighting (ban on incandescent lamp production beyond 2012), better building insulation, promoting solar-assisted domestic hot-water systems, vehicle fleet renovation...
- 20% contribution of renewable energy to primary energy pool (40% in electricity production), by wind power (including large off-shore farms of 5..10 MW per windmill), solar thermal and photovoltaic power plants, and by mixing at least 10% of biofuels to fossil fuels in transportation.

Some steps in managing waste (particularly solid waste) may be:

1. Avoid producing waste: avoid unnecessary inputs, and try to reuse outputs (e.g. reuse packaging).
2. If not possible, minimise waste delivery by recycling it to a less demanding task (e.g. reuse journal paper for packaging).
3. If not possible, stabilise then and dispose it inertly (e.g. since pre-historic times, disposal of collective human excrements has been dropped on dug ditches, later to be land filled, i.e. the latrines).
4. If not possible, label accordingly and dispose it in a safe place (e.g. chemical waste).
5. If not possible, dispose temporarily in a secure (monitored) place, and devote some R&D effort to stabilise the waste in the future (e.g. nuclear waste).

A THERMODYNAMIC VIEW OF ENVIRONMENTAL SCIENCE AND TECHNOLOGY

All physical and chemical subjects are important, but thermodynamics is crucial, in the sense that it embraces all kind of energies (physical, chemical, and biological), it governs all kind of equilibriums, and it sets restrictions on all kind of processes.

- The thermal state of the environment is the main conditioning for life support. Although artificial means to palliate inconvenient ambient temperatures have been developed (heating and cooling), the cost quickly becomes unbearable.
- The global thermal state on Earth is controlled by its radiation budget, which heavily depend on cloud cover and, to a lesser extent, on ice cover. Variations in cloud formation and precipitation, and on ice melting, have a major impact on climate effects.
- The main driver for all atmospheric and oceanic circulations is the differential heating from the Sun over the Earth's surface.
- All major environmental concerns are directly related to thermodynamic processes: the increase in the greenhouse effect that causes climate changes, the decrease in the protective ozone layer thickness due to release of old refrigerant gases, the acid rain and other chemical pollution due to combustion, etc.

For instance, one should be aware that:

- We do not consume matter or energy; both, matter and energy are conservative magnitudes which we only transform. Thermodynamics shows how to set balances for this conservative magnitudes (mass, momentum, and energy).
- We consume 'organization' of matter and of energy; i.e., we only 'make use' of matter and energy (not consumption), but in so doing we degrade their quality or usefulness. Thermodynamics shows that any possible distributions of conservative magnitudes in an isolated system, evolves towards a unique state of the system: the equilibrium state, and teaches which are the characteristics of this principal state.
- We have learnt that all kind of degraded matter or energy can be restored to their initial conditions, but at the expense of some external energy source. Thermodynamics shows how to predict this limit work 'exergy' for maximum benefit and minimum cost.
- We know that all mass and energy flows are proportional to some driving forces. It is for more detailed subjects like Heat transfer, Fluid dynamics, and Chemical kinetics, to show how these flow rates can be computed, but Thermodynamics already sets some constrains on these kinetic processes.
- We are accustomed to our natural environment: temperature around 300 K, pressure around 100 kPa, 21% oxygen molecules in air, fresh water down the rivers, a gravity vector of constant intensity and direction (which provides spatial orientation even with closed eyes), a nearly constant period of day-and-night duration (which provides time synchronism to biological clocks)… we have even adapted to certain micro-organisms in the environment. If we are exposed to a different environment (e.g. after a long trip) we suffer an accommodation period which may end in adaptation or not (stable or unstable behaviour).
- Recent changes in the environment due to human activity (which can be traced back some 10 000 years ago to the development of the first cities in the Neolithic Revolution, or some 200 years ago to the development of machine-based manufacturing and transportation in the Industrial Revolution, or just a few decades ago to the development of megalopolis with many-million inhabitants), have shown to be a source of present damage and future risk to human kind, from respiratory illness for city dwellers, to global climate change and its associated catastrophes (hurricanes, floods, droughts, desertification…). Vital resources like fresh water, fossil fuels, and fishing grounds, are in shortage due to massive exploitation. Pandemic diseases are more frequent than before, helped by massive transportation traffics. Anthropic impact is becoming more and more evident (and population is growing exponentially).
- Humans in the past have adapted to big natural changes in Earth's environment (the last glacial period ended just 15 000 years ago); we have managed to force big changes in our local environment (e.g. space heating and cooling); we have even built totally artificial environments for us to live in outer space (although only for a short while and few people). Many environmental

attitudes are possible for us to adopt. One may believe that life is a changing process that we have but to adapt to, and live with (a kind of progressive adaptive view). Others may believe that Nature should be preserved as it was before human impact (a kind of conservative view, shared by some ecologists). Still others may be more conscious about risks and opportunities, and want to know better in advance, to try avoiding foreseeable risks while taking advantage of the environment (the scientific or reflexive view here advocated). As for any other policy, it is for us to choose, but better making an informed choice than leaving it to others.

A thermodynamic view of environmental problems in human progress

We may consider a thermodynamic universe (an evolving non-equilibrium isolated system) comprising the sun (S), our Earth ecosystem (E), and background space (B), as in Fig. 4a. The end-user may directly exploit the environment (extractive or primary sector, in economy) by recollection, fishing, hunting, quarrying, agriculture, cattle rising, mining... (the major development took place with the Neolithic Revolution in the 8th millennia BC). Later, human ingenuity help to develop machines that greatly increased efficiency in exploiting natural resources and providing manufactured goods (the major development took place at the Industrial Revolution in the 19th century). Nowadays the end user appears to be an information consumer, since matter and energy are conservative; we consume processing services for water and food, electrical commodity, education, health advice, financial transactions, entertainment... And, in analogy to the forced cooling on the heat-removal side of thermodynamic machines, wastes can no longer be left to natural recycling, but public and private effort is needed.

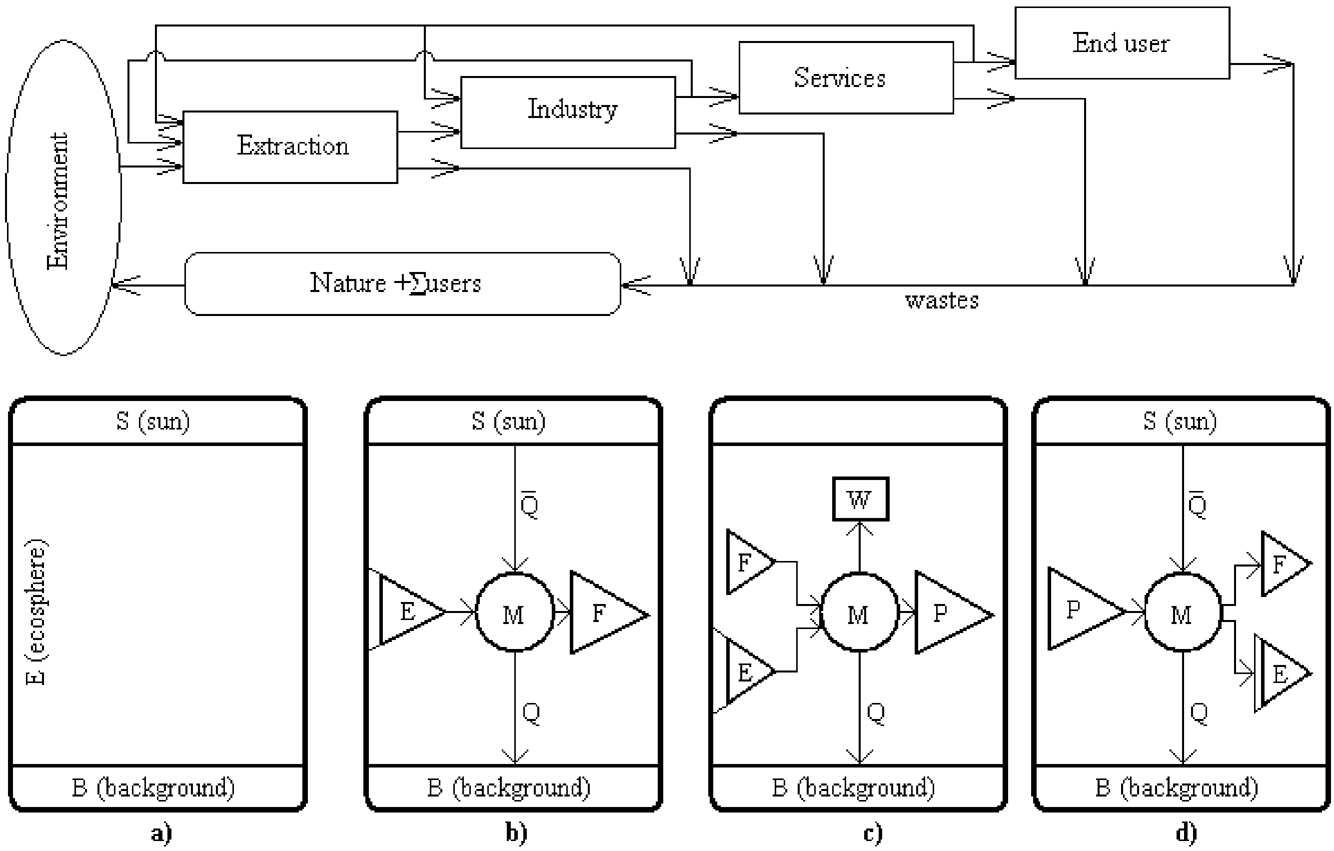

Fig. 4. Human activities in relation to the environment, and different thermodynamic approaches. a) Thermodynamic universe, b) Photosynthesis, c) Industrial development, d) Ecological progress. A circle represents a cyclical or perpetual machine (does not change during the process); a triangle represents matter storage: substances in the environment E, valuable fuels F, or polluting products P; a rectangle represents an storage of energy. Three systems are considered: reference useless background energy B, medium useful solar energy S, and full usage work energy W (an ideal reversible mechanical or electrical energy storage, since work is not a storable but a transient magnitude).

Figure 4b represents the natural evolution from remote times to pre-industrial humankind: the S/B non-equilibrium allowed E to synthesise some valuable substances that we name fuels (F), part of which (the fossil fuels) were accumulated. We may think of a perpetual machine (M) that performs such a photosynthetic task (perpetual here means that it does not changes, or recovers cyclically, as ideal engines).

The Industrial Revolution has brought great human progress (at least in material aspects), by the ability to generate great amount of work (W), Fig. 4c, with heat engines (coal-powered steam engines, crude-oil and natural gas 'gas engines', and nuclear-powered steam engines). The drawback of this Industrial development has been the pollution of the environment associated to the products (P) of the combustion (or nuclear decomposition) of fuels. With the model of an infinite environment capable of natural recovery (by the already-known process from a) to b) in Fig. 4), little care must be paid to pollution (P), it is just a matter of avoiding local effects by moving to another place. But we have learnt that the infinite-environment-model is no longer tenable, since human activities are nowadays at a global scale, and we have to face two possible paths: either we continue 'as usual business' and try to better accommodate to foreseeable-changing circumstances, or better we start to mimic what we have learnt of 'natural evolution' process (from a) to b) in Fig. 4) and try to contribute to a sustainable ecosphere as we understand it today (it might be that the extinction of homo species is, as for the extinction of dinosaurs, holistically for the best, but who dears to rely on that). The negligible use of solar energy during the Industrial Revolution (mainly hydraulic energy, some 3% of world primary energy consumption) has been pinpointed by removing system S in Fig. 4c.

The best move then is to implement regeneration activities on top of traditional industrial activities, i.e., to base progress on ecological development, as sketched in Fig. 1d, synthesising new fuels (F) and a clean environment (E) from the products (P) of traditional industrial operations. This environmental-control approach is not new, but it was required before only in small artificial habitats, as submarines and spacecrafts, and now must be applied to the whole planet ecosphere.

Environmental management technologies

Physico-chemical environmental processes may be grouped as:

- Mass processes (diffusion and convection), often with chemical change (reactions).
- Energy processes (diffusion, convection, and radiation), most of the times associated to matter flows (e.g. water cycle), but also to electromagnetic radiation.

The tools we have at hand (or need to be developed) to manage environmental problems can be grouped as:

- Air management: temperature, pressure, and gas composition control. It is essential to understand our atmosphere, and the physical, chemical and biological processes within.
    - Air conditioning (climatisation) may include ventilation (air renewal), space heating/cooling, and humidity control. Temperature control aims at maintaining people, equipment, and structures, within acceptable temperature margins, for the different thermal loads imposed by its own workings (dissipation), and by a hostile environment. The need arises because most active equipment can only work at room temperatures, i.e. 20±20 ºC (not only for humans, but for batteries and most electronic equipment), and thermal expansion may affect delicate structures.
    - Air treatment to control its composition (i.e. besides pressure and temperature conditioning), can be to add/subtract water vapour (humidifying/dehumidifying), to get rid of solid particles (dry and wet scrubbers), or to get rid of unwanted gases (e.g. CO_2) and vapours (e.g. odours, in active carbon filters).

- Water management: supply and disposal, composition (e.g. total dissolved solids, biological demand of oxygen, turbidity, acidity, dissolved gases), water treatment. It is essential to understand the whole water cycle, particularly the continental part, and develop technologies for water saving, reutilisation, desalination....
  - First record of water conditioning, in 2000 BC, is in Sanskrit writings, mentioning boiling in copper vessels, filtering through charcoal, and keeping it in earthen vessels.
- Land management, including advanced food technologies for farming, fishing, handling (e.g. see Cold effects on living matter), mining management (other than for fuels), and solid waste management: domestic, urban, industrial, and agriculture waste. Dangerous waste treatment (chemical, biological, nuclear). Landfills.
- Energy management. The flow of materials associated to present energy use is the cause for the major environmental problem: climate change, pollution... Energy technologies should have the Sun as ultimate guide, from photosynthesis to renewable energies and fusion.
- Manufacturing management. The choice of raw materials and processes involved in the manufacturing of goods should be clearly stated for the end user to make a sound choice. Eco-labels (issued by sector associations, administrations, or international standards) are currently used for consumer products (houses, cars, electrical appliances, computers, phones...), indicating environmental impact from cradle (raw materials used) to grave (how to dispose off).
- Transportation management, etc.

Environmental measurements

The major breakthrough in environmental measurements has come from Earth observation satellite missions since 1960s. The Global Monitoring for Environment and Security initiative (GMES), jointly carried out with the European Union, and ESA's Climate Change Initiative of ESA's Living Planet Programme, includes the following research fields:

• Atmosphere
  - Variability and causes of changes in the Earth global climate system.
  - Life cycles of clouds and aerosols.
  - Dynamics of atmospheric circulation and associated chemistry.
  - Modelling and forecast of atmospheric composition and air quality.
  - Troposphere/Stratosphere/Mesosphere/Thermosphere coupling processes.

• Oceans
  - Physical, biological and chemical processes of air/sea interactions.
  - Understanding land/ocean interactions and anthropogenic influences.
  - Marine ecosystem variability.
  - Interaction between variations in ocean dynamics, thermohaline circulation, sea level and climate.

• Land surface
  - Interaction of terrestrial ecosystems with other components of the Earth system, particularly associated with climate variability.
  - Influence of anthropogenic factors on land surfaces (use of natural resources and land-use change) and impact on ecosystems.
  - Effect of land surface status on terrestrial carbon cycle.
  - Remote sensing of biodiversity.

• Cryosphere
  - Role of snow and glaciers on global water cycle and role in climate change.

• Solid Earth
  - Gravity field (geodesy).
  - Identification of physical and chemical impact of volcanic activity.
  - Role of magnetic-field variability on the distribution of ionised particles in the atmosphere and their possible climate impact.

A list of subjects and instruments related to environmental science may be:

- Greenhouse: radiometers on satellites and ground.
- Meteorology: surface maps, height maps, and height profiles (sounding).
- Oceanography: at surface and depth.
- Biology (sampling and remote sensing).
- Geology (land sampling, and geodesy).
- Basic instruments
  - Thermometry (probes and radiometers)
  - Piezometry
  - Hygrometry (in air and soils)
  - Flowmetry (winds, ocean currents, streams)
  - Precipitation (particle size, distribution and amount)
  - Salinity (by electrical conductivity), acidity (pH), dissolved oxygen, dissolved carbon dioxide, and other chemical probe analysis
  - Spectro-radiometry (for chemical analysis and remote sensing)
  - Active scanners like sonar, radar, lidar...

Back to Index