Zeitschrift: Archives des sciences et compte rendu des séances de la Société
Herausgeber: Société de Physique et d'Histoire Naturelle de Genève
Band: 55 (2002)
Heft: 3

Artikel: From viability envelopes to sustainable societies : a place for various and efficient economical and cultural expressions on the planet

Autor: Greppin, Hubert / Degli Agosti, Robert / Priceputu, Ana-Maria

DOI: https://doi.org/10.5169/seals-740298

Archs Sci. Genève	Vol. 55	Fasc. 3	pp. 125-148	Décembre 2002

FROM VIABILITY ENVELOPES TO SUSTAINABLE SOCIETIES: A PLACE FOR VARIOUS AND EFFICIENT ECONOMICAL AND CULTURAL EXPRESSIONS ON THE PLANET

BY

Hubert GREPPIN[1], Robert DEGLI AGOSTI[1,2], Ana-Maria PRICEPUTU[1,3]

Conférence du 5 décembre 2002 au Muséum d'Histoire naturelle

ABSTRACT

From Viability Envelopes to Sustainable Societies: A place for various and efficient economical and cultural expressions on the planet. - The concept of viability envelopes (physical, chemical, biological levels) is developed as well as the general consequences and conditions to put in place a global and local sustainable development as defined by official institutions. The three logics and associated regulation processes that define a viable relation-space are presented. Some sentinel variables are proposed. There are, for example, the population life expectancy (PLE) and net photosynthetic production (NPP) on a soil or a sea of ecological quality, as well as the mean temperature and atmospheric CO_2 variation velocities. These elementary indicators permit us to follow and evaluate the degree of interaction between human oxygen respiration and energetic consumption with the photosynthetic oxygen production by green plants, as well as the correlation with the thermic and greenhouse effect. The increase or decrease of PLE and NPP as well as the phase-space evolution of the thermic and CO_2 pattern can give us a precocious information, for the near future, on the sense of sustainability (positive or negative way) provoked by a socio-economic pattern and energetic choice. A cybernetical model is presented as well as different ways of positive adaptation and management.

Key-words: Sustainability, Viability Envelopes, Sentinel Variables.

INTRODUCTION

The notion of sustainable development is the result of various discussions in numerous international meetings, since the United Nations Conference on the Human Environment, at Stockholm in 1972 (SCEPS, 1970; SACHS, 1980; CLARKE & TIMBERLAKE, 1982; GEO 3, 2002). At that conference, the concept of Ecodevelopment was proposed, and discussed again in the Earth Summit, at Rio de Janeiro in 1992 (U.N. Conference on Environment and Development. HAAS *et al.*, 1992; CORCELLE, 1993; VOINOV, 2002). At this occasion the conclusions of the Brundtland Report of the World Commission on Environment and Development (1987) has been firmly accepted as well

[1] University of Geneva, Department of Plant Biology and Botany, Place de l'Université 3, CH-1204 Genève 4, Switzerland. hubert.greppin@bota.unige.ch, http://www.unige.ch/LABPV.

[2] University of Geneva, University Centre of Human Ecology and Environmental Sciences (CUEH), Uni Mail, Boulevard du Pont-d'Arve 40, CH-1211 Geneva 4, Switzerland.

[3] University of Geneva, HEC-Management Studies, Logilab, Uni Mail, Boulevard du Pont-d'Arve 40, CH-1211 Geneva 4, Switzerland.

as the included concept of Sustainability (WCED, 1989; PEARCE & ATKINSON, 1998). Afterwards, this concept was inserted in some local policies or national laws (Action 21), quite before the Johannesburg Summit (see www.johannesburgsummit.org; www.collectif-joburg2002.org, 2002) whose resulting decisions and recommendations, as well as some former ones, were mitigated or not binding (example: Kyoto Protocol. LEPETIT & VIGUIER, 2002; GUESNERIE *et al.*, 2003). Sustainability is a point of view that has been partially initiated by T.R. MALTHUS (political economy, agriculture, demography; 1798).

Sustainability is a general and heuristic concept (CORCELLE, 1993; MOLDAN *et al.*, 1997; PEARCE & ATKINSON, 1998; VOINOV, 2002), which is partially ambiguous. Its real relevance can only be determined a long time after the application of a new economical and social program whose implied goal would be to develop a sustainable society with security. It results from this intrinsic hysteresis a gap between the identification of a real sustainability and the applied political program engaged for that. This particularly concerns the relation between human societies with nature ecosystems (space-time scale effect). This relation and the delay to detect the reality of sustainability could induce some damages with a high socio-economic cost, if the observed outcomes and real statement would be a diminution of sustainability. But how can this situation be estimated with a limited risk ?

More than one hundred indicators (MOLDAN *et al.*, 1997; BLANCHET & NOVEMBER, 1998) are proposed to describe and analyse the complex socio-economical and environmental network that sustain the human life and society, and determine the quality and evolution of the sustainability. Each indicator (environmental, economic, social, institutional: state, driving forces, responses) and its variation and place in this network has not the same significance and value, hence a hierarchy (dynamical and systemic relation tree) must be constructed to identify the first limiting and more restrictive elementary and absolutely necessary factors, to sustain with security the life viability of human populations and the biosphere too. The other indicators are important to value and appreciate the quality and complexity level of the observed sustainability in progress (economical and socio-cultural aspects; secondary environmental characters; robustness of the sustainable network), in a situation where the necessity of the viability factors has been satisfied (GREPPIN *et al.*, 2000).

1. ECOSYSTEMS

All living beings, from bacteria to animals, are characterized by the existence of spontaneous actions and reactions ("life irritability"), expressed by the permanent ebb and flow of energy and matter oriented in time (chronobiology), as well as a restricted circulation of genetic information and signals. Before the human presence, this internal and environmental coupling was realized by the articulation of two structural and functioning logics: the planetarian physical, chemical, and geological logic with the ecological and biological logic, that permitted the different and numerous world organisms (~1,2 10^7 different species: 4% autotrophic plants, 96% heterotrophic biomass) to dominate, transform and organize the surroundings, according to the proper and specific genetic finality, the adaptive ecological and physiological goals and/or values of these ones (the emergence of culture. GREPPIN & PRICEPUTU, 2002).

The whole biomass corresponds to ~8,3 10^{11} t C (99% living on the continents: turnover, ~18 years; and 1% in seas: turnover, ~18 days), and the dead organic mass: 1,6.10^{12} t C. The autotrophic biomass of green plants weigh 8,0 10^{11} t C and the heterotrophic bacteria, protists, fungi, and animals: 0,3 10^{11} t C (BUDYKO, 1986; ALBERTS *et al.*,1989; RAMADE, 1989; HEINRICH & HERGT, 1990; SCHLESINGER, 1991; GREPPIN *et al.*, 1998; GORSKHOV *et al.*, 2000).

The annual organic production by photosynthesis is about 7,3 10^{10} t C /y, next to totally mineralized (CO_2, H_2O, N_x, etc.) by the catabolism, at the climacic dynamical equilibrium. The biogeochemical recycling under the sun control (temperature, water cycle and erosion, biological activity), as well as by the sedimentation, lithogenesis and orogenesis velocities, presents numerous subcycles of different periods (10^{-1} to 10^8 years) and turnovers (stock effect). About 60 % of the photosynthesis is produced on the continents (~2/3 in forests) and ~40 % in seas (80% by ultraplanktonic algae).

From the sun energy that reach the planet (1,75.10^{17} W; 345 W/m^2; 5,54.10^{24} J/y), only a fraction is effective (1,2.10^{17} W; 234 W/m^2; 3,76.10^{24} J/y) because the albedo reflection (clouds and planet surface structure: temperature regulation by a negative feedback). From this fraction 1,1.10^{24} J/y are absorbed by the atmosphere and 2,6.10^{24} J/y are reaching the earth sphere surface. The emerged surface receive 7,6.10^{23} J/y and the oceans: 1,8.10^{24} J/y (HOUGHTON *et al.*, 1990; BERGER, 1992; MCILVEEN, 1992). From this energy, ~4% is utilized for plant evapotranspiration, ~0,5% for photosynthetic activity (3,8.10^{21} J/y on the emerged surface and 2,5.10^{21} J/y in oceans), and 40% to produce the water precipitations (~1/3 on the continents). The energy balance is to heat the planet at a mean temperature of ~15°C (288 K°). Without the greenhouse effect (7,2.10^{16} W; 141,5 W/m^2; 2,27.10^{24} J/y) depending of the atmospheric composition (H_2O, CO_2, CH_4, N_2O, etc.) and responsible of a temperature positive feedback, in connection with the oceans (H_2O, CO_2), the mean temperature would be: -18°C (255 K°). The organic C produced by photosynthesis corresponds to 1.10^{21} J/y on the emerged surface and 0,6.10^{21} J/y in oceans (SCHLESSINGER, 1991; FALKOWSKY *et al.*, 2000; ROJSTACZER *et al.*, 2002).

Life is an open system, thermodynamically far from equilibrium and under the control of sun energy (organic biosynthesis, water circulation, albedo, temperature, etc.), as well as under the effect of internal dynamics of earth energy (3,9 10^{20} J/y) to loop the mineral-organic recycling (erosion versus orogenesis and volcanism). It results in a dialectic and cybernetic relation (positive, negative interactions and feedbacks; feedforwards; servomechanisms) between living systems and the global and local planetarian environment under the climatic regulation. Mediation and optimization are made through the interaction between the biospace properties (various genetic messages, mutations, recombinations, populations genetics, ecological web, etc.) and the ecospace (dynamics of physical, geological and chemical properties, biogeochemical cycles, the permanent and historical co-transformation-revolution-evolution between the biosphere and the surroundings). By this co-action the living matter is space-time adapted and viable (ecosystems: biocenosis associated with animal societies) despite the short - and long time permanent changing of the environment (climatic and geological evolution), as well as some recurrent catastrophes and shocks (BUDYKO, 1986; RAMADE, 1987; ÖREMLAND, 1993; ROBINSON, 1993; GREPPIN *et al.*, 1998; GEO 3, 2002).

Apart human societies, a dynamical sub-equilibrium, depending on temperature, water, CO_2, and light (climate parameters), was reached in the biosphere: the climax (probably a strange attractor in structurally subequilibrium), characterized by specific and various biocenosis with quantitative and qualitative parameters (biomass, fluxes, productivity, network structure of functionning, biodiversity, etc.), as well as animal societies with a specific impact on the environment (emergence of territoriality). At this stage of equilibrium, all the annual organic production is mineralized in CO_2 and H_2O, and the gas volume ratio $O_2/CO_2=1$ (equilibration between the general anabolism with the catabolism to maintain the same biomass with a little and momentary loss by sedimentation and fossilization). Because the ecological web structure (top down and bottom up control) with the one-way of energy circulation between the different ecological levels, associated to different thermodynamic yields, all the bacteria, protists, fungi, plants and animals are circumscribed and optimized (growth, development, biodiversity) in some physical, chemical and biological envelopes of viability, strictly conditioning the living activities of the biomass and ecosystems organization and morphology.

The biosphere is functioning for 3,8 10^9 years, with a viable and sustainable growth (quantitative production equilibrated with the surroundings) and development (qualitative properties: differentiation, adaptation, evolution, innovation, diversity), despite diverse recurrent cosmic and environmental constraints, periodic fluctuations, shocks and catastrophes. The biosphere is not a static system, but evolves in a permanent change in space and time by combinations of various dynamically occurring renewals and maintenance of ecosystems and populations of different species through a dialectic of global vs. local sustainabilities of life and its subsystems; this is realized by the life and death of every population individual, the appearance of new species and the disappearance of other ones. For a global and momentaneous dynamical equilibrium, and to make firm the presence of life on earth, these interrelations of local and global sustainabilities in various hierarchical multiscale are very important. The biosphere is composed of $\sim 10^{30}$ cells with a potential of molecular mutations of 10^{500} from which only a few fraction (10^{50}) has been prospected during the last 3,8 10^9 years of life presence on earth (1,9 10^{15} minutes). The capacity of viability and dynamical sustainability is very high in the usual and natural fluctuations of the environment and climatic evolution (glacial and interglacial recurrence: multisecular variations, ~20, 40, 100 ky; MILANKOVITCH, 1941; BARTLEIN & PRENTICE, 1990). What could be the analogy with sustainability in human societies?

2. HUMAN SOCIETIES

Animal societies did appear very late during the evolution of life (carboniferous era: 3.10^8 years ago). That is the result of innovative genetic combinations that permit new degrees of liberty with regards to ecospace and environmental fluctuations, but this only for few and restricted species (insects, birds, mammals). Usually, when the ecospace is modified, and a threshold is reached for temperature, water supply, etc., all the biocenosis (biomass, biodiversity) is modified (climatic or anthropic effect). It is not exactly so for animal societies: this type of monospecific organization is always (by its genetic nature) attempting to maintain its structure against the perturbations; and at least, this society remains in the food web envelope or, depending on the environmental gap, the sociosystem disappears because unviable.

For the moment, we have not this last type of response concerning human societies (Cro Magnon cultures: ~10^5 years), because the intrinsic capacity to escape the ecological fatum (great freewill property, long and short term memories, territoriality, sustained apprenticeship, capacity of technical innovation and development, permanent scientific and economic evolution, differentiation of values: socio-political, ethical, juridical, theological, artistic and economical levels). This superstructure has progressively civilized (Palaeolithic, Neolithic, Industrial and Informatic Revolution, etc.) and transformed the earth functionning (extra-cultural logics: physical, geological, chemical and biological) that is supporting our activities, by the virtue of our liberty and economical capacity.

It means that our development is circumscribed and even encaged by the extra-cultural envelopes (without direct determination), and socially controlled, and economically determined. In fact, this development is dependent on the articulation of three logics (see Fig. 1), and the resulting free space of liberty, included in these specific interactions. It is these space properties that can ensure viability and sustainability for human society, for a long term. The observation of man necessities in spatial travels is a good situation to identify the real nature and quantity of elementary and viability parameters that are necessary to live in outer terrestrial space. So a comparison could be made with what is given for that by the biosphere and the planet. Then it would be possible to estimate the financial and energetic cost and the substitution possibilities, without climate forcing on earth.

If during 10^5 years, no extensive and important limiting effects were appearing despite the nature of our society (capacity of no-integration in the biosphere diktat) and the relative low degrading impact on the surroundings, it is not the case now (climate risk, pollution, etc.). Since the last part of the 20th century, we are in the vicinity of the physical, chemical and biological limits of the planet to sustain the present type of anthropic activities. The reason is the fact of a same order of magnitude between the flux of energy (amplification of the greenhouse effect) and matter from anthropic sources with the usual activities of the biosphere and the planet. The co-action between the extra-cultural envelopes and the society metabolism and organization must be adjusted for a real economical and cultural sustainability (PILLET & ODUM, 1987; PILLET, 1993; ODUM, 1996; GREPPIN *et al.*, 1998; SCHELLNHUBER & WENZEL, 1998; WACKERNAGEL & REES, 1999).

The cultural motto that we are, as society or person, totally autonomous and free of any natural determination and souvereign in the sphere of Law and Economy must be adjusted, to respect the limit of sustainability, with the physical, chemical, geological, and biological envelopes of viability.

3. SUSTAINABILITY

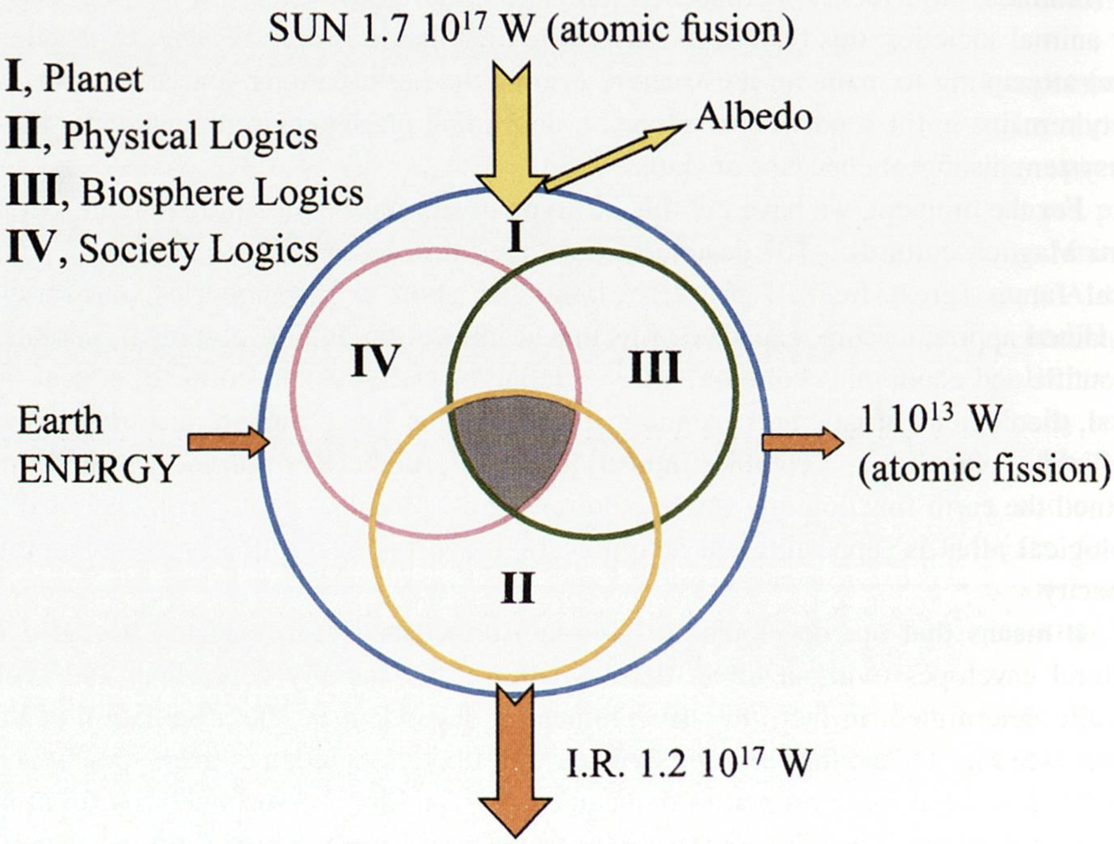


FIG. 1.

Articulation of the planetarian fundamental three logics (structure, functioning, regulation: PLANET, I): Physics - Chemistry - Geology (II); Biosphere (III) ; Human Societies (IV). I.R.: infra-red energy. Grey zone: viability relations space for human activities (viability envelope).

Since the socio-economic and environmental debate at the Rio Conference, and next, the term Sustainable Development is progressively becoming a general leitmotiv associated with a lot of publications. However it has never found a really agreed definition and, in other part, actually, not any country in the world is in such configuration (sustainable ecological and economical structure and functioning for a long term). This concept is more a political vision than a scientific one, but a necessity for making firm the future.

Sustainability could be characterized as *"paths of social, economic and political progress that meet the needs of the present (with a guarantee of equity for all the present countries and nations, and groups of population), without compromising or endangering the ability of future generations to meet their own needs"*. This definition, self-adjusted to human activities, corresponds to an ethical and political management (responsibility, equity, solidarity between generations, social groups and territories, respect of ecological equilibria: Nature is not an object we can manipulate as we want; prevention, precaution). Technical and scientific management and so forth economical organization, are subordinated to this cultural approach. This means that the effects of cultural values and socio-economic actions must be compatible with the presence of viable and sustainable human life (quality of life) in a heterogeneous cultural perception by different societies. Profound knowledge of the structure and dynamics of such systems, at the interface between biosphere - society - environment, is a prerequisite for a global management in the way of a real sustainability from where viability is upstream (CLARK & MUNN, 1986; WCED, 1989; WBGU, 1995; ERCKMAN, 1998; SCHELLNHUBER & WENZEL, 1998; WACKERNAGEL & REES, 1999; TOLBA, 2001; GEO 3, 2002). Concerning the natural externalities (unpaid Nature "economy") to be internalized, different approaches have been proposed to determine some virtual (shadow money) or analogous economical pricing, or the determination of the biosphere quantity and surface that are necessary to compensate the consequences of our economic activity: about two planets for the moment (PILLET & ODUM, 1987; ODUM, 1996; BROWN & ULGIATI, 1998; WACKERNAGEL & REES, 1999; FARBER *et al.*, 2002).Others are tempting to clear up this problem by the usual economic approach founded on the market property (SCHMIDHEINY, 1991; BÜRGENMEIER, 1994; HAURIE, 2002a,b; HAURIE & VIGUIER, 2002; HOLLIDAY *et al.*, 2002). Alternate solutions could be prospected too (SACHS, 1980; RIST *et al.*, 1986; GIARINI & STAHEL, 1990; PERROT *et al.*, 1992; ERCKMAN, 1998).

If the introduction of moral considerations is not something new in economy, as observed at the historical and cultural level, the present and laic aspect of these proposals is innovate in comparison with the usual spirit of the Market and the free Enterprise.

4. VIABILITY

Viability is a clear all/nothing concept (flip-flop system): alive or dead, and corresponds to the minimal platform for a sustainable development. It could be useful to characterize the space-time evolution of all-living populations, societies and ecosystems. Biospheric and anthropospheric ecosystems are in permanent co-action; they are constituted by different biocenosis associated with animal, as well as human societies, which are in a multiscale networking and tensorial relation with different biotopes and specific human societies environment. The viability of both interacting systems is a prerequisite for engaging and supporting a sustainable development (GREPPIN, 1978; AUBIN, 1991).

Indicators could be constructed as sentinel variables (see Fig. 2) to appreciate the viability and sustainability evolution, simultaneously at the world global level and at the regional one, a change in one part of the system often could cause unexpected changes in other parts. The monitoring in space and time aims to detect the increase or decrease of the viability and by that way to validate or not the socio-economical choice tempting to go in a sustainable way (GREPPIN, 1978; GREPPIN *et al.*, 2000, 2002). So, it could be possible to escape the risk of unsustainability by the observation of a few physical, chemical and biological parameters (viability envelope), as for example: the yearly population mean life expectancy (PLE), the yearly oxygen and photosynthetic net production (O_2-NPP) by the phytomass, the yearly water precipitations and circulation, the variation velocities and patterns of the mean temperature and atmospheric gases (CO_2, CH_4, N_2O, etc), the biodiversity, etc.

5. DEMOGRAPHIC ENVELOPE

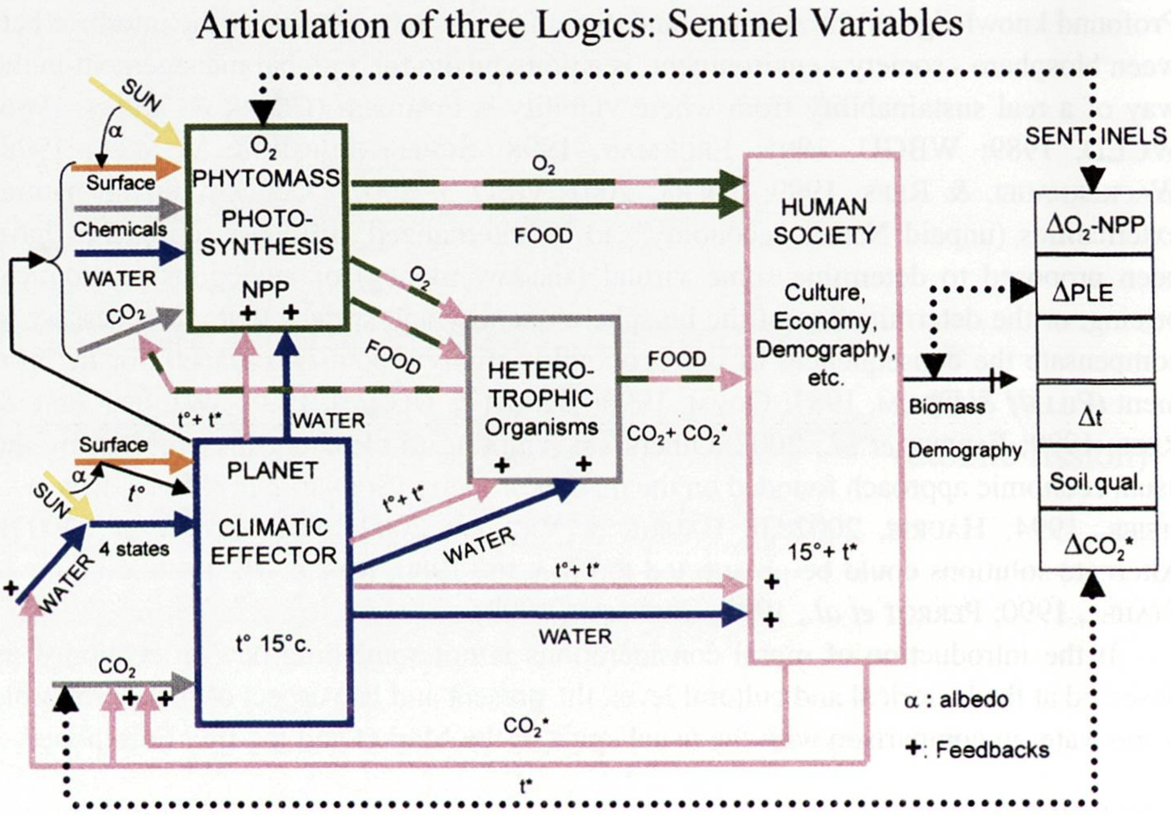


FIG. 2.

Schema of the elementary relations between the three logics (II, III, IV).

II. Physical Planet (surface, albedo, temperature t°, water, chemical composition : atmosphere, oceans, etc.). Natural climatic control.

III. Biosphere (autotrophic green plants, heterotrophic bacteria, fungi and animals): biomass and food production; chimio and photosynthesis, respiration, fermentation; biogeochemical recycling).

IV. Human activities (t*, CO_2* (and GHG): excess of anthropic actions out of the natural climatic equilibrium).

Sentinel variables: yearly monitoring of the photosynthetic oxygen and net production variation (Δ Ox-NPP); yearly variation of the population mean life expectancy (Δ PLE); temperature (Δt) and atmospheric carbonic gas (ΔCO_2): variation velocities against long term mean values. Other indicators: CH_4, N_2O, dust, O_3, U.V., Water, etc. Measurement of the elementary viabilty - sustainability conditioning evolution (minimal platform).

Human viability is strictly dependant on the lifespan of *Homo sapiens sapiens* (10^5 years ago) from which the existence is intrinsically controlled and limited by the genetic information and biological conditioning. This duration could be evaluated by different approaches: physiological maintenance capacity, population life expectancy. Some genetic heterogeneity (male, female, etc.) and geographical variations are observed. The following equations (see Fig. 3) give us the relation between both legal age (La; official and civil age) and physiological one (Pa):

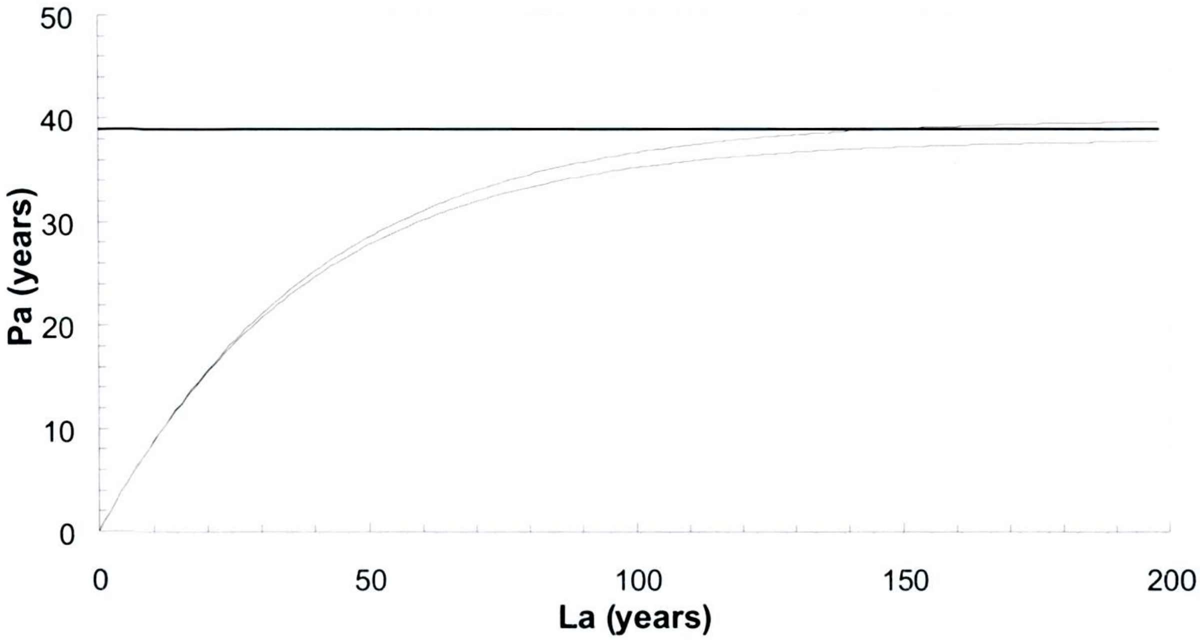


FIG. 3.
Relation between the legal age (La) and the physiological one (Pa).

$$La_t = Pa\max\left(\ln\left(\frac{Pa\max}{Pa\max - Pa_t}\right)\right)$$

$$Pa_t = Pa\max\left(1 - \exp\left(-\frac{La_t}{Pa\max}\right)\right)$$

For Pa max between 38 to 40 years (valuation ensued from cicatrisation velocity of wounds) the maximum potential of legal age corresponds to: 138 – 148 years. Another evaluation could be founded on the sexual maturation and reproduction capacity of women (13 – 50 years old) in relation with the doubling rate of the population growth (multiplication). Owing to this biological threshold and limit, the virtual rate of population growth is 5,4%/year (outset at 13 years old). The long-term mortality rate could tend to a minimum value: 0,5%/year. At this limit of the dynamical equilibrium between life and death of a population, the maximum potential of legal age is ~130 years (PACCAULT &-VIDAL, 1975; AUSTAD, 1997). Given the multiparameter action of natural and socio-economical environment, these theoretical values could never be realized in a population (phenotypic adaptation), but constitute a boundary mark to appreciate the degree of demographic viability between 0 (death) to 1 (maximum theoretical value) (SAUVY, 1976; CHESNAY, 1998; PARK *et al.*, 2001; WEINSTEIN *et al.*, 2001).

The Fig. 4 presents the correlation between the life expectancy of world human population and the GNI (Growth National Income) evolution. We observe, after ~10^4\$ per

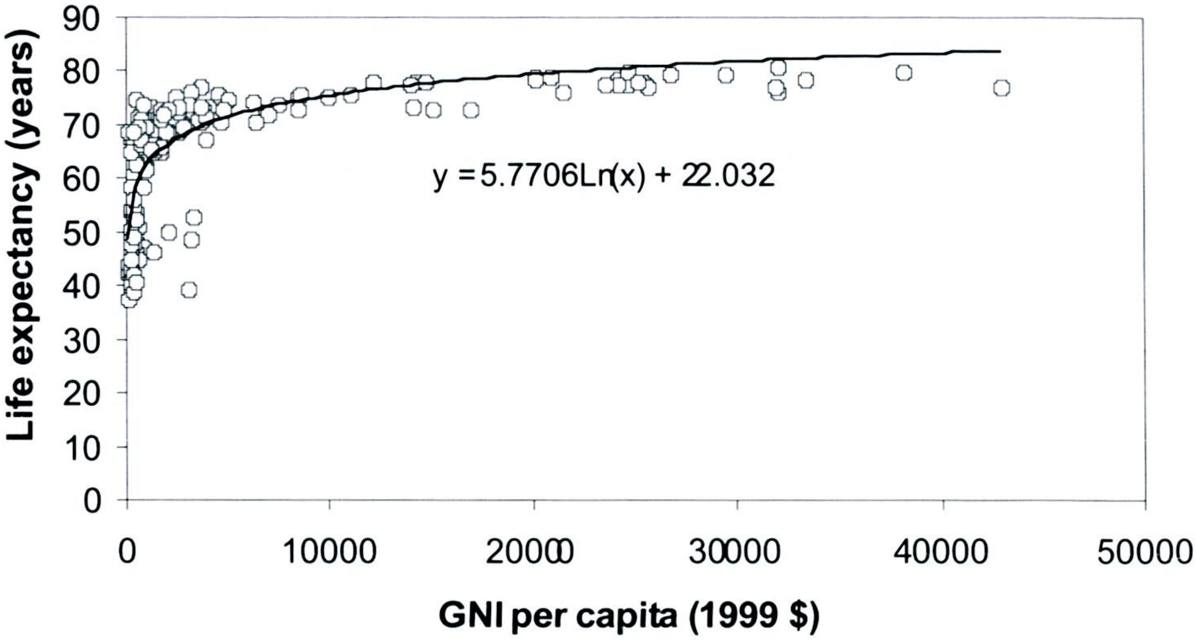


FIG. 4.
Life Expectancy and Gross National Income per Capita (1999 data: world population)

capita, a tendency to an asymptotic evolution of the life expectancy, even though the continuous increase of GNI, and the quality of life and society differentiation (a part of sustainable development: secondary characters). For 1999, the equation is: y = 5.7706 ln(x) + 22.032 (83,2 years at the asymptote). Before a 10^4\$ per capita level, a quasi strict parallelism (linearity) is observed between both variables in progress (90% of the nations, 80% of the world population) (BLOOM, 1999).

Fig. 5 and 6 show the life expectancy of population over a period of 90 years (1900-1990), as well as the successive new asymptotes for the maximum life expectancy. Some progressive increases are observed for both variables, with a successive higher asymptotic level, but over time, a regression of the incremental variation of the demographic viability capacity appears (see Fig.6). Therefore, all things being equal in other respect, it is possible to evaluate the virtual potential of demographic viability, concerning the world economical present pattern. The value of this boundary mark is ~105 years for the virtual maximum of life expectancy for human people (viability coefficient 1). So it is possible to calibrate the position at time t of the demographic viability in comparison with the boundary mark (% t,max.age) and to follow the positive or negative evolutive trend. A diminution of the value means we are not going in the sense of an increase of viability and sustainability despite the value of the GNI variation in the case, for example, where it momentarily increases. The same approach at the world level could be completed by the space-time analysis of the situation in different countries. The time monitoring of this indicator could be utilized to construct a viability risk variable that could be introduced

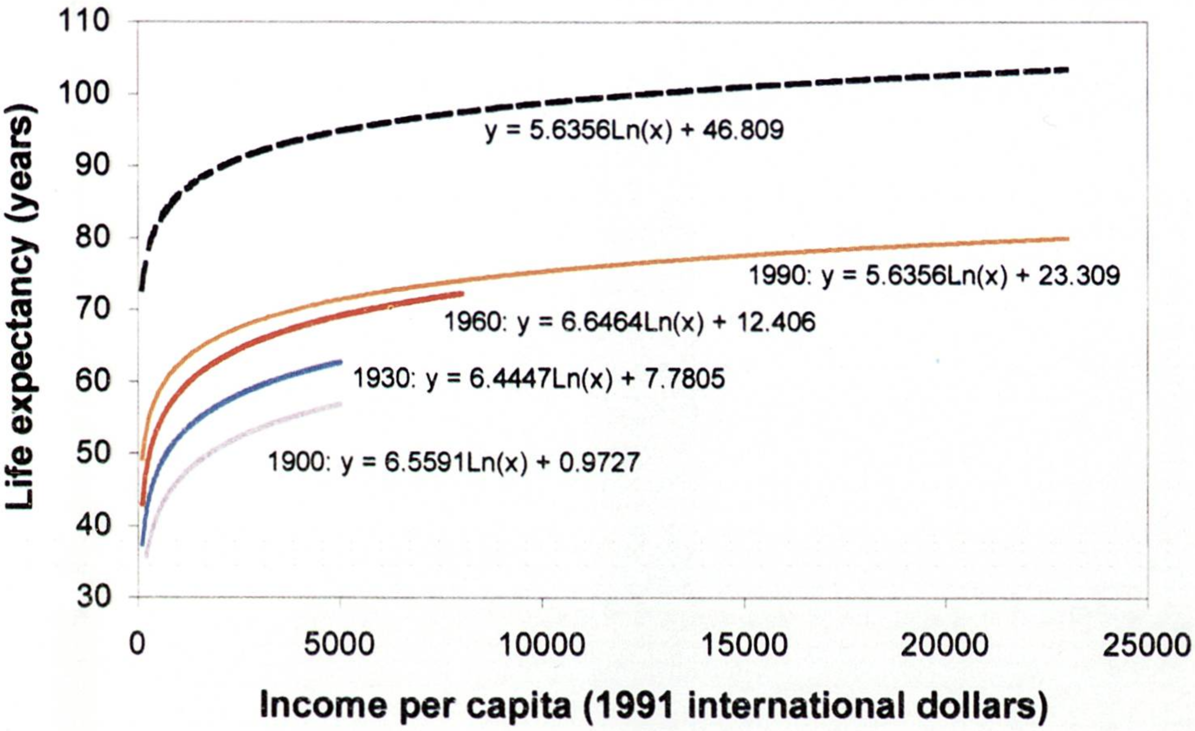


FIG. 5.

Life Expectancy (LE) and GNI per Capita during 90 years (Bloom modified) for the world population (1991 international $). Broken line: estimation of the maximum population life expectancy (boundary mark: 104,9 y).

in a general model of sustainability. Moreover the elementary indicator of human development (HDI) is shortly correlated with PLE (PNUD, 1999).

Note here that the relation between GNI (or GDI) per capita versus consumption of energy per capita presents an analogous pattern of evolution (not presented here), but as a consequence of a better yield and economical utilization as well as a policy against pollution and the amplification of the third economical sector. The margin between the GNI per capita with the momentary asymptote of population expectancy, for all that this viability indicator is not decreasing, could be a measurement we are in connection with this life expectancy criterion in a sustainable situation, from which the progress in economical differentiation could be expressed by the ratios between the both indicators.

We can see (table 1), for respectively 50 and 75% of the world population the different values of the population life expectancy, as well as the position (%) with respect of the boundary mark (viability envelope). A discrimination in analysis could be made between the PLE at birth or 5 years old or at 60 years old (Europe: 21 % pop. > 60 y; 2050: 40 %). That to appreciate the relative loss or gain in economical terms (positive vs. negative damages: see Fig.7). A standardization and calibration could be determined per capita in relation with GNI or GDI virtual loss or gain concerning the PLE evolution. Another way could be the actuarial calculation (life insurance practice).The GNI to LE ratio (table 1) points out that, after the threshold of 10 000 $ per capita, the GNI increase

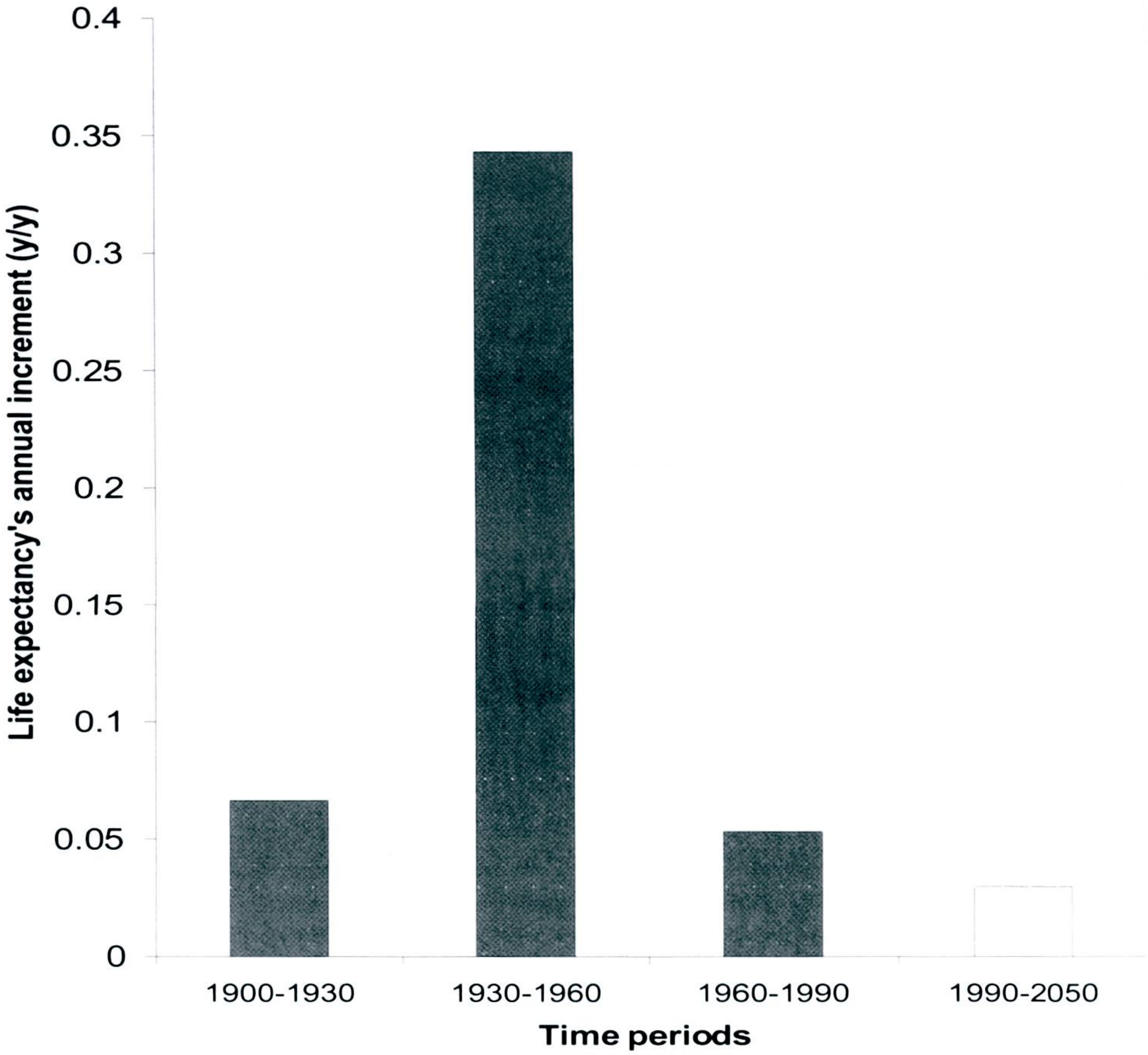


FIG. 6.

Increment variation of the world population life expectancy (1900: 61,34 y; 1930: 63,34 y; 1960: 73,64 y; 1990: 75,24 y; prevision for 2050: 93,3 y).

is progessively uncoupled to PLE, so that LE is in progress to the boundary mark, showing the variety of sustainability at the maximum of life duration with a great variety of GNI per capitra (secondary sustainable characters). A backward evolution of this viability indice (LE) means we are not going in the way of sustainability, at the world and/or country level. The GDI evolution in relation with LE gives the same pattern, but with a low value of the potential LE (~101 y).During last decades, the PLE, in numerous countries (Africa and other regions) has significantly declined (loss of sustainability) for different reasons: epidemic diseases, war, scarcity, environmental and climate changes, socio-economic and political transitions, etc.

TABLE 1. Life Expectancy (LE) for 75 % of the world population (50* %). LE Index: %tage to boundary mark (104,9 y). GNI: Gross National Income.

Nr.	*Nation*	*Pop. 10^6 H (2000)*	*Life Exp. (years)*	*LE Indice %*	*Rank*	*GNI/LE $/H/y*	*Rank*
1*	China	1264,5	71	67,7	10	10,9	17
2*	India	1002,1	61	58,1	19	7,3	20
3*	U.S.A.	275,6	77	73,4	5	397,4	3
4*	Indonesia	212,2	64	61,0	18	9,0	18
5*	Brazil	170,1	68	64,8	13	65,0	8
6	Pakistan	150,6	58	55,3	21	8,1	19
7	Fed. Russia	145,2	67	63,8	14	33,8	11
8	Bangladesh	128,1	59	56,2	20	6,2	21
9	Japan	126,9	81	77,2	1	397,9	2
10	Nigeria	123,3	52	49,5	22	5,9	22
11	Mexico	99,6	72	68,6	8	61,1	9
12	Germany	82,1	77	73,4	6	329,2	4
13	Philippine	80,3	67	63,8	15	15,2	16
14	Vietnam	78,7	66	62,9	16	29,6	12
15	Egypt	68,3	65	61,9	17	21,5	15
16	Iran	67,4	69	65,7	12	25,5	14
17	Turkey	65,3	69	65,7	11	42,0	10
18	Ethiopia	64,1	46	43,8	23	2,1	23
19	Thailand	62,0	72	68,6	9	27,2	13
20	United Kingdom	59,8	77	73,4	7	294,0	6
21	France	59,4	78	74,3	3	301,0	5
22	Italy	57,8	78	74,3	4	252,6	7
23	Switzerland	7,1	80	76,2	2	479,3	1
n	World	6066,0	66	62,9	-	103,7	-

6. BIOSPHERE ENVELOPE

The viability of the anthropic activity is de facto coupled with the life expectancy of population as well as with the viability of the biosphere production, transformed or not by the human work, source of income, wealth, economic and cultural development, security vs. environmental and social risks. At the biological level the human gender must breathe oxygen and eat organic food, as well as to profit of the ecosystemic capacity to recycle the matter (environmental viable charge, detoxification). The flux of wastes must be included, as the other exchanges of human society, with the capacity and nature of the dynamic natural and global equilibrium.

Green plants are playing a fundamental role for agriculture and food production, and for emitting the photosynthetic free oxygen, which is needed by all heterotrophic beings, apart anaerobic species. The phytomass production ($6CO_2 + 12\ H_2O \leftrightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O - 2880$ kJ) is strictly dependent on the access to light surface, water disponibility (~700 kg of water is circulating throughout terrestrial plants to produce, by photosynthesis, 1 kg of organic matter; use of $5{,}1.10^{13}$ t./y water for the world phytomass), temperature, CO_2 and mineralia.

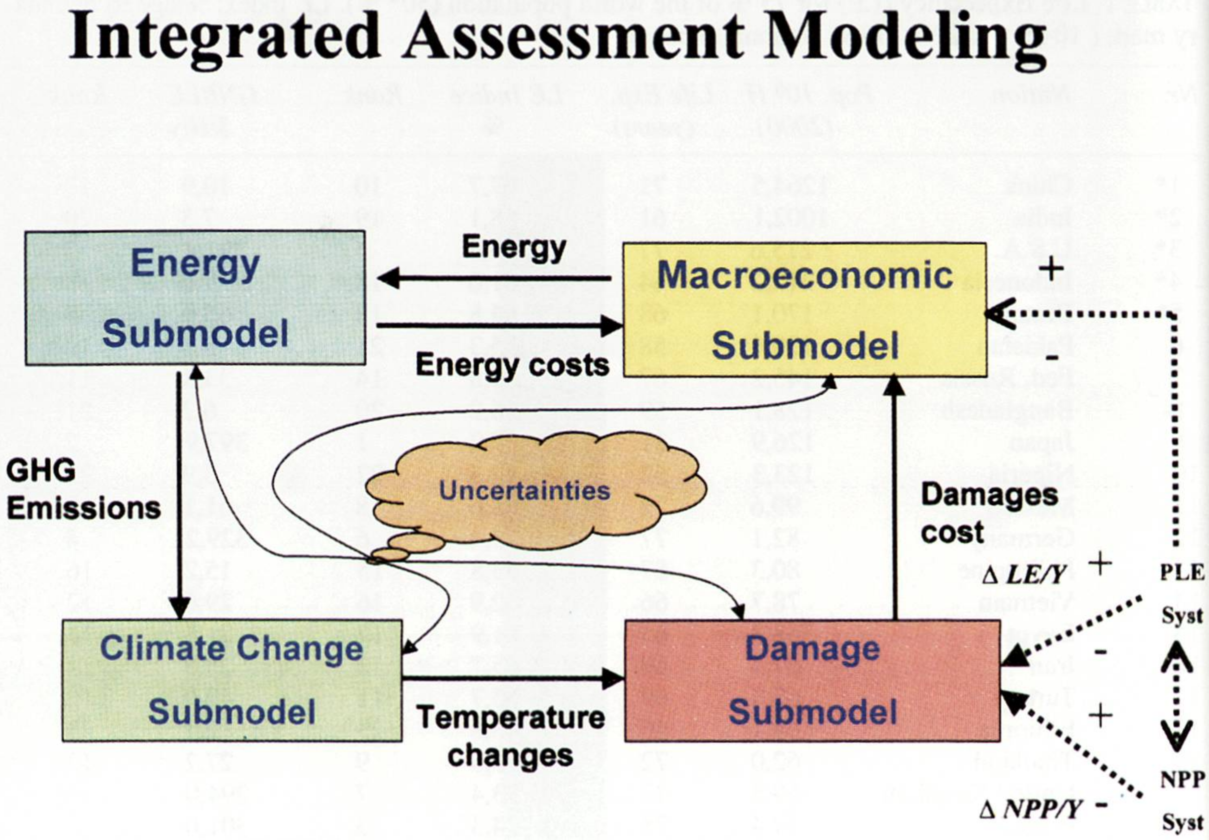


FIG. 7:
Integration of the sentinel variables in an economical model (NCCR - PSI, modified).

The following equations, for example, present the relation at the planet level (emerged surface) between the net primary productivity (NPP: g. organic matter/m^2/year) with respectively the mean temperature (x ºC) and the annual precipitation (x mm/year) (LIETH, 1975):

$$a)\ y(NPP) = \frac{3000}{1+e^{1,315-0,119x}}$$

$$b)\ y(NPP) = 3000\left(1-e^{-0,000664x}\right)$$

Water is the most limiting factor. It means that the phytomass production gives us an indirect indication about the water disponibility for human activities (continental precipitations: $1,1.10^{14}$ t/y ;runoff: $4,7.10^{13}$ t/y (GREPPIN *et al.*, 2000; GEO 3, 2002).The 7,3 10^{10} t C/y of organic matter produced by photosynthesis correspond to the emission of 1,9 10^{11} t free O_2/y, respired in majority by heterotrophic species. The human respiration (~1,5 t O_2/H/y: variation between 0,3 to 5,0 (short time). ANONYMOUS, 1972) is totally compensated by the photosynthetic production of food by agriculture. So the actual deficit is only the consequence of the organic energy consumption (fossil fuel, ~1,6 10^{10} t.O_2/y; 2.3.10^{10} tCO_2 /y); oxygen is taken away for the heterotrophic respiration utilized by the other organisms for maintenance, growth, development and recycling of the biosphere; but the atmospheric O_2 stock is very high (1,2 10^{15} t) compared to CO_2 (2,6.10^{12}t). This consumption of oxygen is coupled with the production of carbonic gas and an associated thermic amplification of the climate (IPCC, 2001).

The measurement of O_2 production could be indirectly made via the registration of day/night and seasonal CO_2 fixation (see photosynthesis equation above), or by the light absorption, reflection and fluorescence measurement and monitoring (satellites, aeroplane or helicopter) at different wavelengths (FIELD *et al.*, 1992, 1995; DAO, 1999; GAERTNER, 2001; LOBELL *et al.*, 2002), to determine the terrestrial annual production of phytomass (dry weight). We present here some equations to approximate the global mean value of the NPP and O_2 production, according to the nature of the different biocenosis surfaces: S (VITOUSEK *et al.*, 1986; SCHLESINGER, 1991; ROJSTACZER *et al.*, 2002).

1. S. agriculture (1,4 10^7 km^2) x NPPm (2,9 10^2 t/km^2/y) x 2,666 = 1,1 10^{10} t O_2/y
2. S. agri. grazing (3,3 10^7 km^2) x NPP_m (1,8 10^2 t/km^2/y) x 2,666 = 1,6 10^{10} t O_2/y
3. S. forests (3,3 10^7 km^2) x NPP_m (7,6 10^2 t/km^2/y) x 2,666 = 6,7 10^{10} t O_2/y
4. S. vegetation (3,0 10^7 km^2) x NPP_m (3,1 10^2 t/km^2/y) x 2,666 = 2,4 10^{10} t O_2/y
5. S. swamps, lakes (0,45 10^7 km^2) x NPP_m (7,1 10^2 t/km^2/y) x 2,666 = 0,85 10^{10} t O_2/y
6. S. deserts (3,9 10^7 km^2) x NPP_m (0,5 10^2 t/km^2/y) x 2,666 = 0,2 10^{10} t O_2/y

Total: 1,285 10^{11} t O_2/y (continents)
0,661 10^{11} t O_2/y (oceans)
1,946 10^{11} t O_2/y (planet) (absorption of 2,675.10^{11} t CO_2 /y)

The global yearly NPP of O_2 (1,946 10^{11} t/y) could be considered as another boundary mark of the biosphere viability, because the short-term probability of an increase is very low. So, the decrease of this indicator, for example, means that we are not going in a sustainable economical way because an unadapted and integrated interaction with the ecosystems and the environment; especially if more than 30 % of the global photosynthetic oxygen is monopolized for economical activities (world consumption now : ~9 % ; local consumption: USA: 40 %; Switzerland 65 %; Quatar: >100 %; India, 15 %, China, 26 %. Because the atmospheric pool of oxygen is very high: 6300 times more than the yearly photosynthesis, no disadvantages, at this level, are appearing for the moment).

The global impact and relation with Nature could be illustrated by the fact that the world-anthropomass (~0,01‰, whole biomass) is utilizing ~4% of O_2-NPP for respiration and ~9 % for fuel consumption (not compensated: deficit, 1,7.10^{10} t/y), and in other part 87% of O_2-NPP is respired by the world heterotrophic biomass (4 % whole biomass). It means , in proportion of the physical presence, our part is 600 times more important than the mean value of the majority of living beings; this is a measure of our environmental pressure (VITOUSEK *et. al.*, 1986; SCHLESINGER, 1991; KOTLYAKOV *et al.*, 1999; GORSHKOV *et al.*, 2000; ROJSTACZER *et al.*, 2002).

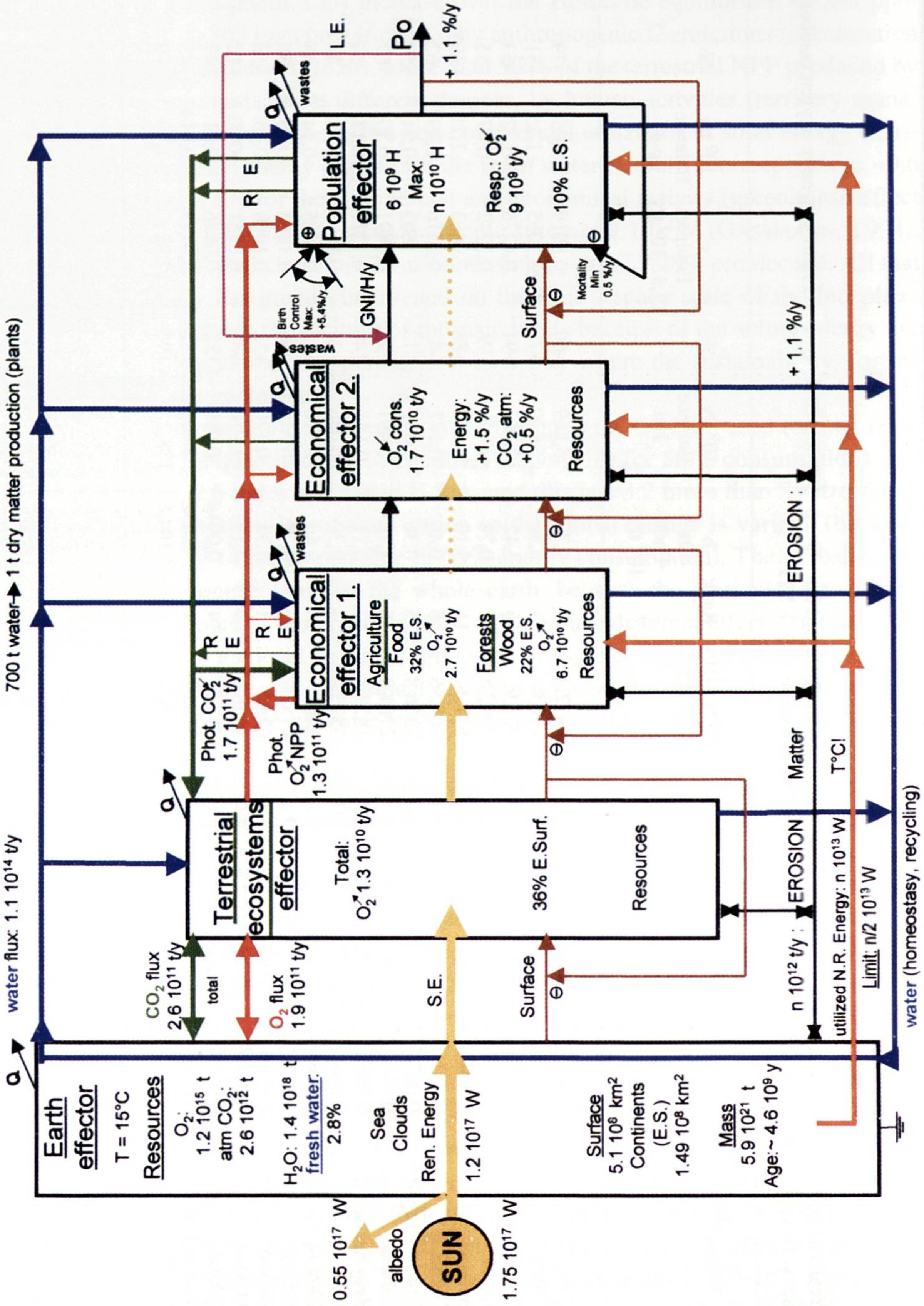
The ~30 % atmospheric CO_2 increase over the Holocene equilibrium of 280 ppm (ice core analysis) to 365 ppm now is caused by anthropogenic C emissions (acceleration since the industrial revolution, 1850). More than 50 % of the terrestrial NPP produced by green plants are manipulated, at different degrees, by human activities (territory management, agriculture, forestry, etc.). The non-commercial utilization of solar energy (agricultural photosynthesis, energy to produce the fresh water rainfalls) corresponds to ~9,6 10^{22} J/y vs. 3,5 10^{20} J /y for the commercial and economical activity (greenhouse effect amplification: CO_2, CH_4 etc.; Climate anthropic forcing: 7.10^{14}W (GASSMANN, 1994). The worldwide fossil fuel consumption is increasing by around 20% pro decade. All that means the humanity has greatly intervened on the time - space scale of the biosphere system and that we are in the vicinity of intrinsic limits because of the actual energy use (see Fig. 8: viability elementary parameters) in a way where the sustainability, for the nearing future is not guaranteed.

Each nation of the world is diversely contributing to the O_2-NPP used for fuel combustion (see table 2): quantitatively (4 countries responsible for 50 % consumption), and per capita (Quatar, 2,6 times more than U.S.A, and this last 3.2 times than Switzerland). It results that the contribution of each nation to the global change is various (between ~200 countries, only 14 are responsible of 75% energy consumption). The globalization of these different contributions on the whole earth, because the particular geographic localization and climate of each nation (200), will produce different effects, not necessarily corresponding to the local emission (importation vs. exportation of pollution. Global climatic change). Finally the economical capacity to solve this problem and to go to a better sustainability will be different too (necessity of an international cooperation and specific agreements).

The O_2-NPP indicator (yearly photosynthetic flux) permits to detect the sense of evolution of the sustainable relation with the biosphere (gain or loss of O_2 -NPP),and so, to be sure that the economical pattern really is in the way of viability both for biosphere and human life.As for LE indicator a relative pricing could be made by the way of oxygen relation with human respiration (~0,3 tons /year per capita) The fact that different GNI/ O_2-NPP are sustaining the human activities induces the idea that different cultural and socio-economic paths could be prospected for a sustainable relation with Nature. To be integrated in the biosphere constraints, and with the hypothesis that a physico-chemical procedure permits the CO_2 sequestration, restricted utilization of oxygen at 9 % world photosynthesis is given in table 2. If this stock is distributed between all the nations with equity (pro rata inhabitants), important reduction must be made, especially for advanced countries where the scientific capacity for energy substitution is existing. The dynamical enclosure of economical activity with H_2O, O_2, CO_2, the surface and energy is presented in Fig. 8, as the LE and O_2-NPP indicators. The consequences, at long term, of the existence of viability envelopes (100-150 years) are the dynamical stabilization of the world demography (limit :n 10^{10} H. Now, the human population is 10^4-10^5 higher than if it was the case for an animal species, 6.10^9. A measure of our liberty and specificity. GREPPIN, 1993) as well as the flux of energy for economic purpose (reduction to ~50 % of the actual climate forcing energy. Potential renewable energy: $2,5.10^{23}$ J/y; potential

TABLE 2: Yearly Oxygen Respiration and Fuel Combustion (tons) for 75 % of the World Population (50* %). GNI per capita ratio vs. yearly oxygen combustion per capita. Oxygen photosynthetic production (estimation) and equipartition of 9 % NPP.

Nr.	Nation[1996]	Ox. resp. 10^9 t/y	a Ox. fuels 10^9 t/y	Ox. fuels/H/y t/H/y	Rank	GNI/Ox.f./H/y \$/t/H/y	Rank	b Ox. Phot 10^9 t/y	10^9 t/y Balance b-a	%	c Equipart. 17,82 10^9 t/y.	10^9 t/y Balance c-a	%
1*	U.S.A.	0,4077	3,8612	14,3	2	2422,3	7	9,73	5,869	+60	0,8019	-3,05	-79
2*	China	1,8663	2,4499	2,0	15	420,0	13	8,36	5,910	+71	3,7065	+1,25	+51
3*	Fed. Russia	0,2215	1,1505	7,7	4	325,9	15	13,42	12,269	+91	0,4276	-0,72	-63
4*	Japan	0,1890	0,8505	6,7	7	5092,5	2	0,78	-0,070	-9	0,3742	-0,47	-55
5	India	1,4493	0,7264	0,7	16	671,4	11	5,10	4,373	+86	2,9403	+2,21	+304
6	Germany	0,1231	0,6272	7,6	5	3002,6	6	0,44	-0,187	-43	0,2316	-0,39	-62
7	United Kingdom	0,0877	0,4057	6,9	6	3376,8	5	0,36	-0,045	-13	0,1603	-0,24	-59
8	Canada	0,0766	0,2981	10,0	3	2161,0	8	3,70	3,401	+92	0,0891	-0,20	-67
9	Rep. Korea	0,0685	0,2972	6,5	9	1522,4	10	0,12	-0,177	-148	0,1277	-0,17	-54
10	Italy	0,0861	0,2937	5,1	10	3525,4	4	0,39	0,096	+25	0,1603	-0,13	-44
11	Ukraine	0,0766	0,2893	5,5	11	140,0	16	0,60	0,310	+52	0,1425	-0,14	-48
12	France	0,0877	0,2635	4,5	12	4757,7	3	0,78	0,516	+66	0,1063	-0,10	-38
13	Poland	0,0580	0,2599	6,7	8	628,3	12	0,38	0,120	+32	0,1069	-0,15	-58
14	Mexico	0,1414	0,2535	2,6	14	1946,1	9	2,17	1,916	+88	0,2851	+0,03	+12
15	Quatar	0,0009	0,0212	38,0	1	417,6	14	0,0014	-0,019	-1357	0,0016	-0,01	-47
16	Switzerland	0,0109	0,0322	4,4	13	8018,1	1	0,052	0,0198	+38	0,0178	-0,014	-43
n	World	8,6155	16,3202	2,9	-	2360,6	-	194,6	178,2	+92	17,82	+1,49	+9



Earth effector
T = 15°C
Resources
O2: 1.2 10^15 t
atm CO2: 2.6 10^12 t
H2O: 1.4 10^18 t
fresh water: 2.8%
Sea
Clouds
Ren. Energy
1.2 10^17 W
Surface
5.1 10^8 km2
Continents (E.S.)
1.49 10^8 km2
Mass
5.9 10^21 t
Age: ~ 4.6 10^9 y
SUN
albedo
0.55 10^17 W
1.75 10^17 W
water flux: 1.1 10^14 t/y
700 t water → 1 t dry matter production (plants)
CO2 flux 2.6 10^11 t/y
total
O2 flux 1.9 10^11 t/y
S.E.
Surface
Terrestrial ecosystems effector
Total: O2 1.3 10^10 t/y
36% E.Surf.
Resources
Phot. CO2 1.7 10^11 t/y
Phot. O2 NPP 1.3 10^11 t/y
Economical effector 1.
Agriculture
Food
32% E.S.
O2 2.7 10^10 t/y
Forests
Wood
22% E.S.
O2 6.7 10^10 t/y
Resources
Economical effector 2.
O2 cons. 1.7 10^10 t/y
Energy: +1.5 %/y
CO2 atm: +0.5 %/y
Resources
Population effector
6 10^9 H
Max: n 10^10 H
Resp.: O2 9 10^9 t/y
10% E.S.
Birth Control Max: +5.4%/y
Mortality Min 0.5 %/y
GNI/H/y
Surface
wastes
R
E
L.E.
Po
+ 1.1 %/y
Matter
T°C!
EROSION
n 10^12 t/y
utilized N.R. Energy: n 10^13 W
Limit: n/2 10^13 W
water (homeostasy, recycling)

atomic fusion energy: $1{,}7.10^{31}$ J, but limitation because the thermic effect: $1{,}2.10^{21}$ J/y), and quantitative growth (differentiated and evolutive maintenance growth only, the economic doing and undoing integrated in viability envelopes) in various cultural and economical type of development (expansion and new growth could be continuously made in outer earth space and on other planets) (GOLDIN & WINTERS, 1995; GREPPIN *et al.*, 1998; PNUD, 1999; PNUE, 1999; LENOUX, 2000).

7. THERMIC ENVELOPE

Living cells and ecosystems are very sensitive to temperature and its variation. For example, between 0 °C and 60 °C (then proteins are progressively denaturated) the molecular motion is increasing of ~20 %, but at the same time the speed of cell metabolic reactions is 60 times more rapid (Vant'Hoff rule).A prolonged environmental variation of a few degree of the yearly mean temperature, in particular at the limit of a biocenosis structure and climax, could produce an important transition (biomass, productivity, O_2, CO_2 and water fluxes, biodiversity) to another ecosystemic equilibrium, in ascending or descending ways of complexity: desert ⇔ tundra ⇔ taiga etc. (RAMADE, 1998). This ecospace-biospace adaptation is depending of the genic dotation and population genetics as well as the specific threshold and temperature adaptation velocity vs. the thermic acceleration or deceleration and the effect of this one on water disponibility.

Given the importance and possible consequences of a climatic global change, more than thousand international experts, consultants and researchers have studied this probability since 1988 (IPCC, WMO, UNEP etc.). In Switzerland, and apart other research projects on the climate by different institutions (Climate science-shuttle: www.proclim.ch; SEPP, 1992 - 2001: HÄBERLI *et al.*, 2002, etc.,), the NCCR Climate program (variability, predictability, climate risk, technical and economical modelisation and integration) has been active since 2000. The objective of the NCCR International Dimension of Sustainable Resource Use (11 modules) is to establish a framework for research on resource use and to create a platform for scientific exchange in order to contribute to the goal of moving towards sustainability in its environmental, economic (efficient and viable coupling of climate and economic dynamics, http://ecolu-info.unige.ch/~nccrwp4/) and social dimensions (www.nccr-climate.unibe.ch and http://ecolu-info.unige.ch/recherche/nccrwp4/).

FIG. 8.

Biogeophysicochemical Model and Anthropogenic Activity Insertion.

E: economic production of CO_2 or O_2 consumption. E.S., E.Surf.: emerged surface. LE: population life expectancy. NR: non renewable energy. R: respiration. SE: sun energy. Q: degradation of energy, heat: entropy. Economical effector 1: primary sector. Economical effector 2: I, II, III sectors. Blue: water circulation and cycling. Orange: anthropic energy utilization. Red: oxygen production by photosynthesis and utilization (respiration and combustion). Yellow: sun energy (thermic action, water evaporation and circulation, wind control and atmospheric pressure in co-action with oceans, clouds production, evapotranspiration, CO_2 concentration in atmosphere and hydrosphere, photosynthesis and diverse photochemical reactions, etc.). Cybernetic control.

The contribution of the anthropic activities (fossil energy utilization: $2{,}2.10^{10}$ t.CO^2 /y), to the greenhouse effect has been clearly shown, despite other minor contributions (BARKER & ROSS, 1999; IPCC, 2002; REBETEZ, 2002). A simple and theoretical demonstration that we are engaged in a dead alley is easy to do by the extension to all the world (6.10^9 H.) of the actual and local situation: it gives $3{,}1.10^{11}$ t/y on the Quatar basis of consumption (~5000 ppm, atmospheric CO_2; +25 °C), $1{,}1.10^{11}$ t/y for an USA generalized level (~1900 ppm; + 8 °C), and $3{,}6.10^{10}$ t/y for a Switzerland level (600 ppm; + 3 °C). The condition for a global mean temperature stabilization corresponds to ~3 t CO^2/H (for 6.10^9 H). It means: - 95% for the Quatar CO_2 production; - 85% for USA; - 50% for Switzerland (0,2 % of the actual world production of CO_2 on 0,02 % of emerged surface for 0,12 % of the world population: 6,1 t CO_2/H/y); + 20% for China; + 200% for India (equity application).

A way to appreciate the thermic perturbation evolution could be the use of an adapted sentinel variable of viability: for example a thermic phase-space diagram associating the temperature variation velocity vs. the yearly temperature anomaly against the multiannual mean temperature. Initially, owing to the complexity and insufficient knowledge about the details of the multi-compartmentalized cybernetic control of the climate, we propose to consider this phase-space path as an expression of the evolutive equilibrium capacity of the planet to regulate the temperature (GREPPIN *et al.*, 2003). A standardization and calibration could be made with the analysis of paleoclimatic data (the actual mean temperature evolves 15 to 20 times more rapidly than in the past). A phase path indicator (pile index) could give us an image of this evolutive capacity (pile structure more stacked: predominance of homeostasy) or could illustrate some positive feedback effect (phase structure more slaky): since ~1985, a new change is appearing (positive feedback) with some acceleration of the temperature (piloting of the negative feedback by a positive one). The same type of approach could be made with the atmospheric CO_2 variation velocity (an evolutive correlation with the temperature pattern is observed).

CONCLUSION

Sustainability evolution could be appreciated with security by physical, chemical, geological and biological envelopes of viability (sentinel variables), that permit the construction, by political and economical choices in the society, a real sustainable development, because circumscribed in these extracultural and necessary parameters for life viability (human societies and biosphere). We have now all in hands, at the scientific level, for such an estimating. But some difficulties exist: a) at the international institutions level where the information can't be nothing other as a mixture between scientific facts and probabilities with diplomatic expression and omissions that are a real necessity to reassemble the maximum of culturally and economically different nations in this way (progression step by step, little by little in a partially irreversible process of environmental changes), with the risk of the existence of point of no-return and high socio-economic costs. b) at the high school level where the interdisciplinary approach is very difficult to establish for different intrinsic reasons. For example the extreme individualism and originality of the researchers (society pressure for that), as well as the reciprocal judgement of values, and some lack of understanding between exact and natural sciences vs. human sciences s.l. The research capacity of these last must be more stimulated, but with some cooperation and financial joint management with exact and natural sciences, a prerequisite for the study of the biosphere-society-environment interaction.

But at least, what is sure is that the restricted scientific axiology will be limited for the adaptation in a terrestrial sustainability. If sciences are a necessity, a thinking on the existential finality of individual and society (world of values and culture) is probably an important and efficient key to boost the way to sustainability: the support of the adaptation to viability and sustainability (new efficient socio-economic and cultural models). The fragility of human societies essentially is of social nature.

ACKNOWLEDGMENTS

The authors are very grateful to professor Alain Haurie (Logilab), NCCR WP4 coordinator, for his help and advices, as well as to professors Beat Bürgenmeier (CUEH director), Charles Hussy (Geographic department director) and William Broughton (Plant Biology department director).

RÉSUMÉ

Le concept d'enveloppes de viabilité (physique, chimique, biologique) est développé, ainsi que les conditions générales et conséquences à mettre en place pour un développement soutenable local et global, tel que défini par les institutions officielles. Sont présentées les trois logiques et les processus de régulation associés, lesquels définissent un espace de relations viables. Quelques variables sentinelles sont proposées. Ce sont, par exemple, l'espérance de vie de la population (PLE) et la production photosynthétique nette (NPP) sur un sol ou une mer de qualité écologique, la vitesse de variation de la température moyenne et du CO2 atmosphérique. Ces indicateurs élémentaires permettent de suivre et d'évaluer le degré d'interaction entre la respiration humaine d'oxygène et la consommation énergétique avec la production photosynthétique d'oxygène par les plantes vertes, ainsi que la corrélation avec l'effet de serre thermique. L'augmentation ou la diminution de PLE et NPP, ainsi que l'évolution de l'espace de phase du pattern thermique et de CO2 peut nous donner une information précoce sur le sens de la soutenabilité (positif ou négatif) provoqué par un pattern socio-politique et un choix énergétique. Un modèle cybernétique est présenté ainsi que différentes voies pour une adaptation et un management positifs.

REFERENCES

ALBERTS, B., D. BRAY, J. LEWIS, M. RAFF, K. ROBERTS & J.D. WATSON. 1989. Molecular biology. Garland Pub. N.Y.

ANONYME. 1972. Tables scientifiques. Ciba-Geigy, Bâle.

AUBIN, J.P. 1991. Viability Theory. Birkäuser Verlag, Boston.

AUSTAD, S.N. 1997. Why We Age. John Wiley & Sons, N.Y.

BARKER, J.R. & M.H. ROSS, 1999. An introduction to global warming. Am. J. Phys. 67: 1216-1226.

BARTLEIN, P.J. & I.C. Prentice. 1990. Orbital variations, climate and paleoecology. Tree, 4: 195-199.

BERGER, A. 1992. Le climat de la terre. De Boeck Université, Bruxelles.

BLANCHET, C. & A. November 1998. Indicateurs de développement durable appliqués à l'aménagement du territoire. CES, CUEH, IUED, Genève.

BLOOM, B.R. 1999. The Future of Public Health. Nature 402: 63-64.

BROWN, M.T. & S. ULGIATI. 1998. From Biosphere to Society: Emergy perspective on environmental services and natural capital. *In*: The Co-Action between Living Systems and the Planet. (Greppin H. *et al.* eds), pp 179-199. Université de Genève, Genève.

BUDYKO, M.I.. 1986. The Evolution of Biosphere. D. Reidel Publ., Dordrecht.

BÜRGENMEIER, B. 1994. Economy, Environment and Technology. M.E. Sharpe., N.Y.

CHESNAIS, J.C. 1998. La démographie. PUF, Paris.

CLARCK, W.C. & R.E. MUNN. 1986. Sustainable Development of the Biosphere. Cambridge Univ. Press, Cambridge.

CLARKE, R. & L. TIMBERLAKE. 1982. Stockholm Plus Ten --Promises, Promises ? The Decade Since the 1972 U.N. Environment Conference. Earthscan, London.

CORCELLE, G. 1993. 20 ans après Stockholm: la Conférence des Nations Unies de Rio de Janeiro sur l'environnement et le développement: point de départ ou aboutissement? Rev. Marché Commun et Union Européenne 365: 107-135.

DAO, H. 1999. SIG, Télédétection et Connaissance de l'Environnement. Thèse Fac. SES, no 484. Université de Genève, Genève.

ERCKMAN, S. 1998. Vers une écologie industrielle. C.L. Mayer, eds., Paris.

FALKOWSKI, P., R.J. SCHOLES, E. BOYLE, J. CANADELL, D. CANFIELD, J. ELSER, N. GRUBER, K. HIBBARD, P. HÖGBERG, S. LINDER, F.T. MACKENZIE, B. MOORE, T. PEDERSEN, Y. ROSENTHAL, S. SEITZINGER, V. SMETACEK & W. STEFFEN. 2000. The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System. Science 290: 291-296.

FARBER, S.C., R. COSTANZA & M.A. WILSON. 2002. Economic and ecological concepts for valuing ecosystem services. Ecological Economics 41: 375-392.

FIELD, C.B., F.S. CHAPIN, P.A. MATSON & H.A. MOONEY. 1992. Responses of terrestrial ecosystems to the changing atmosphere. Ann. Rev. Ecology and Systematics 23: 201-235.

FIELD, C.B., J.T. RANDERSON & C.M. MALMSTRÖM. 1995. Global net primary production: Combining ecology and remote sensing. Remote Sensing of Environment 51: 74-88.

GAERTNER, P.S. 2001. Optimization analysis and integrated models of the enhanced greenhouse effect. Environmental Modeling and Assessment 6: 7-34.

GASSMANN, F. 1996. Effet de serre: modèles et réalités. Georg, Genève.

GEO 3. 2002. L'avenir de l'environnement mondial. De Boeck Université, Bruxelles.

GIARINI, O. & W.R. STAHEL. 1990. Les limites du certain. PPUR, Lausanne.

GOLDIN, I., & L.A. WINTERS. 1995. The Economics of Sustainable Development.Cambridge Univ. Press, Cambrigde.

GORSHKOV, V.G., V.V. GORSHKOV & A.M. MAKARIEVA. 2000. Biotic Regulation of the Environment: Key Issue of Global Change. Springer Verlag, Berlin.

GREPPIN, H.. 1978. Ecologie humaine et enveloppes de viabilité. Médecine & Hygiène (Genève) 36: 3589-3594.

GREPPIN, H. 1993. Régulation et limite démographique. *In*: SEBES (I.Rens, ed.), pp 33-38. Médecine et Hygiène, Genève.

GREPPIN, H., R. DEGLI AGOSTI & C. Penel (eds.) 1998. The Co-Action between Living

Systems and the Planet. University of Geneva, Geneva.

GREPPIN, H., R. DEGLI AGOSTI, & C. HUSSY, 2000. Fondement naturel pour un développement durable: les enveloppes physiques, chimiques et biologiques de viabilité. Archs. Sci.(Genève) 53: 7-42.

GREPPIN, H., R. DEGLI AGOSTI & A.M. PRICEPUTU. 2002. The Concept of Viability Envelope. NCCR-WP4, working paper no 13 , http://ecolu-info.unige.ch/recherche/nccrwp4/

GREPPIN, H. & A.M. PRICEPUTU. 2002. Dialectique du bioespace et de l'écoespace : émergence de la territorialité, de la biocénose aux sociétés. Cahiers géographiques (Genève) 4: 27-38.

GREPPIN, H., R. DEGLI AGOSTI, & A.M. PRICEPUTU. 2003. The variation velocity analysis of yearly temperature anomalies as an expression of the thermic regulatory network on the planet, submitted.

Guesnerie, R., P. Champsaur & A. Lipietz. 2003. Kyoto et l'économie de l'effet de serre. La documentation fançaise, Paris.

HAAS, P., M. LEVY & T. PARSON. 1992. Apraising the Earth Summit : how should we judge UNCD's success? Environment 34: 6-11, 26-33.

Häberli, R., R. Gessler, W. Grossenbacher-Mansuy & D. Lehmann-Pollheimer. 2002. Objectif, Qualité de la Vie. Georg, Genève.

HAURIE, A. 2002a. Integrated Assessment Modeling for Global Climate Change : an infinite Horizon Optimization Viewpoint. Working paper no 2. http://ecolu-info.unige.ch/recherche/nccrwp4/workingpapers/

HAURIE, A. 2002b. Turnpikes in multidiscount rate environments and GCC policy evaluation.Working paper no 10. Idem.

HAURIE, A. & L. Viguier. 2002. A Stochastic Dynamic Game of Carbon Emissions Trading. Working paper no 15. Idem.

HEINRICH, D. & M. HERGT. 1990. DTV-Atlas zur Oekologie. Deutscher Taschenbuch Verlag, München.

HOLLIDAY, C.O., S. SCHMIDHEINY & P. WATTS. 2002. Walking the Talk. Greenleaf Pub., Sheffield.

HOUGHTON, J.T., G.J. JENKINS & J.J. EPHRAUMS. 1990. Climate Change. The IPCC Scientific Assessment. Cambridge University Press, N.Y.

IPCC. 2001. Climate Change 2001. 3 vol. (Geneva: WMO and UNEP). Cambridge University Press, Cambridge and NY.

KOTLYAKOV, V.M., A.A. LIOUTY, E.A. FINKO, A.N. KRENJE, Y.G. LEONOV, A.A. VELICHKO & P. JORDAN. 1999. Ressources and Environment. World Atlas. Hölzel, Vienna.

LEEMANS, R. & G. ZUIDEMA 1995. Evaluating changes in land cover and their importance for global change. Tree 10: 76-81.

LENOUX, M.. 2000. La dynamique du temps et du climat. Dunod, Paris.

LEPETIT, P. & L. VIGUIER. 2002. The United States and climate change. La Documentation Française, IFRI,CFE, Paris.

LIETH, H.. 1975. Modeling the Primary Productivity of the World. *In*: Primary Productivity of the Biosphere, H. Lieth, Whittaker, R.H., eds. Springer Verlag, N.Y., pp :237-263.

LOBELL, D.B., J.A. HICKE, G.P. ASNER, C.B. FIELD, C.J. TUCKER & S.O. LOS 2002. Satellite estimates of productivity and light efficiency in United States agriculture. Global Change Biology 8:722-735, 928-998.

MALTHUS, T.R. 1798. Essai sur le principe de population. INED (1980), Paris.

MCILVEEN, R. 1992. Fundamentals of Weather and Climate. Chapman & Hall, London.

MILANKOVITCH, M.M. 1941. Canon of Insolation and the Ice-Age Problem. Beograd Acad.Roy. Serbe. English translation by Israel Program for Scientific Translation and published for the U.S. Dep. of Commerce and National Science Foundation.

MOLDAN, B., S. BILHARZ & R. MATRAVERS. 1997. Sustainability Indicators. Wiley, N.Y.

ODUM, H.T. 1996. Environment Accounting. Wiley, N.Y.

ÖREMLAND, R.S. 1993. Biogeochemistry of Global Change. Chapman & Hall, N.Y

PACCAULT, A. & C. VIDAL 1975. A chacun son temps. Flammarion, Paris.

PARK, S.C., E.S. HWANG, H.S. KIM & W.Y. PARK (eds.) 2001. Healthy Aging for functional Longevity. Annals NY Acad. Sc. vol. 954, 321 p.

PEARCE, D. & G. ATKINSON, 1998. The Concept of Sustainable Development: An Evaluation of its Usefulness Ten Years after Brundtland. Swiss Journal of Economics and Statistics, 134: 251-269.

PERROT, M.D., G. RIST & F. SABELLI, 1992. La Mythologie programmée. PUF, Paris.

PILLET, G. & H.T. Odum. 1987. E^3, énergie, écologie, économie. Georg, Genève.

PILLET, G. 1993. La capacité écologique des nations. Ecodécision 8: 18-22.

PNUD. 1999. Rapport mondial sur le développement humain. De Boeck Université, Bruxelles.

PNUE. 1999. L'avenir de l'environnement mondial. De Boeck Université, Bruxelles.

RAMADE, F. 1987. Les catastrophes écologiques. McGraw-Hill, Paris.

RAMADE, F. 1989. Eléments d'écologie. McGraw-Hill, Paris.

REBETEZ, M. 2002. La Suisse se réchauffe. PPUR, Lausanne.

RIST, G., & F. SABELLI (eds.) 1986. Il était une fois le développement. Ed. d'En bas, Lausanne.

ROBINSON, A. 1993. Earth Shock. Thames and Hudson, London.

ROJSTACZER, S., S.M. STERLING & N.J. MOORE. 2002. Human Appropriation of Photosynthesis Products. Science 294: 2549-2552.

SACHS, I. 1980. Stratégies de l'écodéveloppement. Les Editions ouvrières, Paris

SAUVY, A. 1976. Eléments de démographie. PUF, Paris.

SCEPS. 1970. Man's Impact on the Global Environment. Study of Critical Environmental Problems. MIT Press, Cambridge.

SCHELLNHUBER, H.J. & V. Wenzel. 1998. Earth System Analysis: Integrating Science for Sustainability. Springer Verlag, Berlin.

SCHLESINGER, W.H. 1991. Biogeochemistry: an analysis of global change. Academic Press, N.Y.

SCHMIDHEINY, S. 1992. Changer de cap. Dunod, Paris.

VITOUSEK, P.M., P.R. EHRLICH, A.H. EHRLICH & P.A. MATSON. 1986. Human Appropriation of the Products of Photosynthesis. Bioscience 34: 368-373.

TOLBA, M.K. (ed.) 2001.Our Fragile World Challenges and Opportunities for Sustainable Development. Eolss Pub., Oxford.

VOINOV, A.A. 2002. Paradoxes of Sustainability; http://kabir.cbl.umces.edu/AV/PUBS/PARADOX/Sust_Par.html.

WACKERNAGEL, M. & W. Rees. 1999. Notre empreinte écologique. Ecosociété, Montréal.

WBGU. 1995. World in Transition: Ways toward Global Environmental Solutions. Springer Verlag, Berlin.

WCED. 1989. Our Common Future (The Brundtland Commission). Oxford Univ. Press, Oxford.

WEINSTEIN, M., A.I. Hermalin & M. Stoto (eds.) 2001. Population Health and Aging. Annals NY Acad. Sc. Vol. 954, 321 p.