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ECOLOGICAL ECONOMICS

1.- Introduction

Ecological economics is a recently developed field, which sees the economy as a subsystem of a larger finite global ecosystem. Ecological economists question the sustainability of the economy because of its environmental impacts and its material and energy requirements, and also because of the growth of population. Attempts at assigning money values to environmental services and losses, and attempts at correcting macroeconomic accounting, are part of ecological economics, but its main thrust is rather in developing physical indicators and indexes of sustainability. Ecological economists also work on the relations between property rights and resource management, they model the interactions between the economy and the environment, they study ecological distribution conflicts, they use management tools such as integrated environmental assessment and multi-criteria decision aids, and they propose new instruments of environmental policy.

2.- Origins

The book that came out of the first world conference of ecological economists in Washington D.C. in 1990 (Costanza ed, 1991) defined the field as "the science and management of sustainability". In the late 19th c. and early 20th c. the biologist and urban planner Patrick Geddes, the "narodnik" revolutionary and physician Sergei Podolinski, the engineer and social reformer Josef Popper-Lynkeus had unsuccessfully tried to promote a biophysical view of the economy, as a subsystem embedded in a larger system subject to the laws of thermodynamics (Martinez-Alier and Schlupmann, 1987). By 1850 or 1860 the carbon cycle and the cycles of plant nutrients had been discovered, while the first and second laws of thermodynamics (conservation and transformation of energy, but also dissipation of energy and increase in entropy) had been established. The contrived conflict between the "optimistic" theory of evolution which explained the diversity of life, and the "pessimistic" second law of thermodynamics, was a staple of the cultural diet of the early 1900s. Therefore, the main ingredients for an ecological view of the economy were present much before the birth of a self-conscious ecological economics, delayed by the strict boundaries between the natural and the social sciences.

The biologist and systems ecologist Alfred Lotka, born in 1880,introduced in the 1910s and early 1920s the fundamental distinction between the endosomatic use and the exosomatic use of energy by humans. The Nobel prize in chemistry Frederick Soddy, born in 1877, wrote also on energy and the economy. He compared "real wealth" which grows at the rhythms of nature and which, if turned into manufactured capital, is worn down, with "virtual wealth" in the form of debts which apparently could grow exponentially for ever. Later, four well-known economists, who did not yet form a school, are seen in retrospect as ecological economists: Kenneth Boulding, born in 1910, who worked mainly on general systems analysis, K. W. Kapp, born also in 1910, and S. von Ciriacy-Wantrup, born in 1906, who were both institutionalist economists, Nicholas Georgescu-Roegen, born in 1906, who was the author of The Entropy Law and the Economic Process (1971). The systems ecologist H. T. Odum, born in 1924, studied the use of energy in the economy: some of his former students were among the founders of the International Society for Ecological Economics in 1987. Other sources of ecological economics are in Environmental and Resource Economics (i.e. microeconomics applied to environmental pollution and the depletion of natural resources), in Human Ecology, Ecological Anthropology, Agroecology and Urban Ecology, and also in the study of "industrial metabolism" as developed by Robert Ayres, now known as Industrial Ecology.

After an influential meeting in Sweden in 1982 on the integration of economics and ecology organised by the ecologist AnnMari Jansson, the International Society for Ecological Economics (ISEE) was launched at a workshop in Barcelona in 1987, precisely on the same year as the Brundtland Report on "sustainable development" was published. Herman Daly (a former student of Georgescu-Roegen, and today's best known ecological economist) proposed that the word "development" should mean changes in the economic and social structure, while "growth" means an increase in the scale of the economy which probably cannot be ecologically sustained. "Sustainable development" is thus acceptable to most ecological economists, while "sustainable growth" is not (Daly, 1994). The first issue of the successful academic journal Ecological Economics came out in 1989, edited since then by the ecologist Robert Costanza, who was also the first president of ISEE. The ISEE has affiliated societies in Argentina and Uruguay, Australia and New Zealand, Brazil, Canada, the European Union, India, Russia, the United States.

Outside the United States and Europe, the Japanese "entropy school" of economic analysis (Tamanoi, Tsuchida, Murota, 1984) studied the environmental services provided by the water cycle, and also the ancient urban ecosystems of Japan. In India, there was much work since the 1970s by economists but also by biologists (Madhav Gadgil) on the links between forest or water management and common property rights, nowadays one main focus of interest in ecological economics (Berkes and Folke, eds., 1998). Other early ecological economists (whose major works were not in English) are, in France, Rene Passet (1979, 1996), and Ignacy Sachs who proposed in the early 1970s the notion of "eco-development"; Roefie Hueting (1980) in the Netherlands and Christian Leipert (1989) in Germany; Jose-Manuel Naredo in Spain. (For general introductions to the field: Costanza et al eds, 1997; Costanza et al 1997; Common, 1995).

3. Scope

Ecological economists see the economy as an open system. In thermodynamics, systems are classified as "open" to the entry and exit of energy and materials, "closed" to the entry and exit of materials though open to the entry and exit of energy, such as the Earth, and "isolated" systems (without entry or exit of energy and materials). The availability of free energy and the cycling of materials allows life forms to become ever more organised and complex, the same applies to the economy. Dissipated energy and waste are produced in the process. At least part of the waste can be recycled or, when not, the economy takes in new resources. However, if the scale of the economy is too large and its speed is too rapid, then the natural cycles cannot produce the resources or absorb or assimilate the residues such as, for instance, heavy metals or carbon dioxide. In ecological economics the economy is see as embedded in the ecosystem (or, more accurately, in the historically changing social perception of the ecosystem). The economy is also embedded in a structure of property rights on environmental resources and services, in a social distribution of power and income, in social structures of gender, social class or caste.

Instead, in conventional economics the economy is seen as a self-sufficient system where prices for consumer goods and services, and prices for the services of production factors, are formed. This pre-analytic stand is reflected in the category of "externalities". Ecological economists (Norgaard, 1990) have disputed the view expressed in the 1960s by Barnett, Krutilla and many other resource economists, that since natural resources are cheap, they must be abundant. Markets are myopic, they discount the future, they cannot see future uncertain scarcities of sources or sinks. Ecological economists understand and even sympathize with attempts at "internalizing" externalities into the price system, they readily concur with proposals to correct prices by taxes (such as "natural capital depletion taxes" or taxes on pollution) but they deny that there exists a set of "ecologically correct prices".

In summary, ecological economics is a new transdisciplinary field which develops or introduces topics and methods such as:

-new indicators and indices of (un)sustainability of the economy;

-the application of ecological notions of carrying capacity and resilience to human ecosystems;

-the valuation of environmental services in money terms, but also the discussion on incommensurability of values, and the application of multi-criteria evaluation methods;

-risk assessment, uncertainty, complexity and "post-normal" science;

-integrated environmental assessment, including building of scenarios, dynamic modelling, participatory methods of decision making;

-ecological macroeconomics, the measurement of "natural capital", the debate between "weak" and "strong" notions of sustainability;

-relations between ecological and feminist economics;

-ecological distribution conflicts;

-relations between the allocation of property rights and resource management, old and new communal institutions for environmental management;

-international trade and the environment, the "ecological debt";

-environmental causes and consequences of technological change, relations between ecological economics and evolutionary economics;

-theories of consumption (needs, satisfactors), as they relate to environmental impacts;

-the "dematerialization" debate; relations with industrial ecology;

-applications in business administration;

-instruments of environmental policy, often centred on the "precautionary principle" (or on "safe minimum standards", as developed by Ciriacy-Wantrup).

Only some of these points can be developed in the remaining space, doing some injustice by this choice to other work by ecological economists.

4.- Disputes on value standards

The Greek distinction (as in Aristotle's *Politica*) between "oikonomia" (the art of material provisioning of the household) and "chrematistics" (the study of the formation of market prices, in order to make money) seems irrelevant because material provisioning appears to be mostly achieved through market exchanges, and there is a fusion of chrematistics with oikonomia. However, many caring activities in families and in society, and many services of Nature (Waring, 1988), remain outside the market. In ecological economics the word "economics" is used in a sense closer to "oikonomia" than to "chrematistics". Ecological economics is not committed to a unique type of value expressed in a single numeraire. "The issue is not whether it is only the market place that can determine value, for economists have long debated other means of valuation; our concern is with the assumption that in any dialogue, all valuations or "numeraires" should be reducible to a single one-dimension standard" (Funtowicz and Ravetz, 1994: 198). Ecological economics encompasses money-valuation, and also physical appraisals of the environmental impacts of the human economy measured in their own physical "numeraires".

Nature provides resources for the production of commodities and it also provides environmental amenities. As shown by Gretchen Daily, R. de Groot and other authors, Nature, more importantly, gives gratis essential life-support services such as the cycling of nutrients, the water cycle, soil formation, climate regulation, conservation and evolution of biodiversity, concentration of minerals, dispersal or assimilation of pollutants, diverse forms of useful energy, etc. Attempts have been made to assign money values to the annual flows of some environmental services, to compare them to GNP in monetary units of account.

For instance, the cycling of nutrients (nitrogen, phosphorous) in some natural systems may be given a plausible money value by comparison with the costs of alternative human-made technologies. Could this same methodology (i.e. the cost of alternative technology) be applied consistently to the valuation of biodiversity in a kind of science fiction Jurassic Park framework? For biodiversity, money valuation has taken a completely different tack, namely the small sums exchanged in some "bioprospecting" contracts, or fictitious subjective money values in terms of "willingness to pay" for conservation projects, i.e. the so-called Contingent Valuation method favoured by environmental economists (though not by most ecological economists). How to count the service that Nature provides us by concentrating minerals which we disperse? ("Exergy" costs have been calculated by industrial ecologists, but the technology for creating mineral deposits does not exist). Therefore, the figures obtained for the money values of environmental services provided free by Nature are incongruous. They are useful, however, in stimulating the debate on how "to take Nature into account".

Ecological economics rests on a foundation of "weak comparability of values" (O'Neill, 1993). One example: let us assume that a new large garbage dump must be built near a city, and that there are three possible locations, A, B, C, one of which will be sacrificed. In our example, the three different locations are compared under three different types of value: value as habitat, value as landscape, and economic value. Location A is a most valuable publicly owned wetland (valuable as habitat or ecosystem because of its richness of species) but a monotonous landscape, much visited by bird-watchers and schools (and, as such, of some economic value according to the "travel cost method"). Location C produces much rent as industrial and urban land, and therefore ranks first in economic value, but ranks only third as an ecosystem or habitat, and comes second as landscape (because of its historical qualities). Location B is an old agricultural area of beautiful derelict orchards and ancient manor houses, which ranks first as landscape, but ranks only third as rent-producing, and second as ecosystem or habitat. Which location should be sacrificed? How to decide? Should and could all values be reduced to a super-value, so as to achieve strong comparability, and even strong commensurability (cardinal measurement)? In the example, the economic values (in actual or fictitious markets) of all three locations have been taken into account, but there is no super-value (economic, or otherwise such as for instance net energy production by which the wetland would presumably come out on top). Certainly, the present rankings could be reconsidered. Thus, the landscape value of A could be upgraded, and its economic value (as also that of B) could be increased by Contingent Valuation. Also, giving more weight to some criteria than to others, or "veto thresholds" for some criteria such as the "endangered species" provision in American legislation, or the introduction of more locations or more criteria, would help us to escape from the present deadlock. The point of the exercise is merely to show the meaning of "weak comparability of values". The decision-making process need not be irrational (by lottery, for instance).

In contrast to such a multi-criteria approach (Munda, 1995), in cost-benefit analysis the projects to be evaluated are all valued in the same numeraire (present value in money terms of costs and benefits, including of course monetarized externalities and environmental amenities).

In microeconomics, there is strong comparability of values, and indeed strong commensurability, when externalities are internalized into the price system, as in the definition of a Pigovian tax as the economic value of the externality at optimum pollution level. In macroeconomics, El Serafy's practical proposals to "green" the GNP (in Costanza, 1991) -the results of which will depend on the chosen rate of interest- do not go beyond strong commensurability in money terms. According to El Serafy, not all receipts from the sale of exhaustible resources ("natural capital") should be included in GNP, only one part should be included, "true" income, and the rest should be counted as "decapitalization" or the "user cost" of such "natural capital" which should be invested at compound interest over the period until the resource is exhausted, so as to allow the country to live at the same standard of living even when running out of the resources. This proposal, based on the definition of "income" by Hicks, and related to Hotelling's rule in resource microeconomics, is based on a notion of "weak" sustainability only. "Weak" sustainability allows the substitution of manufactured capital for so-called "natural capital" -implying therefore a common unit of measurement, i.e. money value- while "strong" sustainability refers to the maintenance of physical natural resources and services (David Pearce and Kerry Turner introduced this distinction c. 1990).

The so-called "Environmental Kuznets Curve", an inverted U-curve, relates income and some environmental impacts (de Bruyn and Opschoor, 1997). In urban situations, as incomes grow sulphur dioxide emissions first increase and then decrease, while carbon dioxide emissions increase with incomes. If something improves and something deteriorates, one reaction from the conventional economist might be to put weights or to put prices on such effects, in the pursuit of commensurability of values. However, the uncertainty and complexity of such situations (sulphur dioxide may counteract the greenhouse effect, for instance), and the fact that the price of externalities would depend on the outcome of social conflicts, implies that the economist's accounts would be convincing only for the believers of the same school.

When the pattern of use of environmental resources and services and the burdens of pollution are shown to depend on changing social structures and on power and income distribution, then we enter the field of political ecology which originates in geography and anthropology, and which we define as the study of "ecological distribution conflicts". Economic growth leads to increased environmental impacts, and to increased conflicts (often outside the market sphere). Hence, for instance, the growth of the Environmental Justice movement in the United States. Examples abound of the failure of the price system to indicate such environmental impacts, or (to use K. W. Kapp's idea), examples abound of cost-shifting successes. Thus, attempts at using cost-benefit analysis of the increased greenhouse effect (as in reports of the Intergovernmental Panel on Climate Change) are not convincing because of the arbitrariness of the discount rate (Azar and Sterner, 1996, see below), and also because many items are not easily measured in physical terms, much less easily valued in money terms. Moreover, the very pattern of prices in the economy would be different to start with, without the free access to carbon sinks - or should restrictions be imposed on the "ecological footprint" of rich economies or on the "human appropriation of net primary production" (see below). Should equal property rights on carbon sinks be bestowed on everybody, there might still be a tendency for the price of carbon emissions to be low, according to the principle "the poor sell cheap". Everybody is owner, except slaves, of her or his own body and health, however poor people sell their health cheaply when working for a wage in mines or plantations. Free use of sinks has been modelled in a neo-Ricardian framework by Ch. Perrings, Martin O'Connor and other authors, showing how the pattern of prices in the economy would be different assuming different outcomes for ecological distribution conflicts.

Some remarks are still needed on the discount rate. Economists explain discounting of the future by subjective "time-preference", or because economic growth per capita caused by today's investments, will make the marginal utility of consumption lower for our descendants than it is for us today. Accepting this second argument, namely, discounting arises from the productivity of capital, and taking into account that such "productivity" is a mixture of true increases in production and a lot of environmental destruction, then the discount factor should be the per capita rate of sustainable economic growth, subtracting therefore the destruction of environmental resources and services. Now, in order to determine the present-economic-value of such destruction caused by economic growth (loss of biodiversity, filling up of carbon sinks, production of radioactive waste...), we need not only to put money-figures on it (as discussed above), we need also a discount rate. Which?

5.- Environmental indexes of (un)sustainability

Because of the shortcomings of money valuation, ecological economists favour physical indicators and indexes in order to judge the overall impact of the human economy on the environment. Therefore, we leave here aside monetary corrections to GNP, such as El Serafy's (see above), or Hueting's, which calculates the economic costs of adjusting the economy to socially negotiated norms or standards of pollution and resource extraction, in a "cost-effectiveness" approach (by "cost-effectiveness" is meant the analysis of the cheapest instrument in money terms in order to adjust the economy to such physical norms or standards). We also leave aside Cobb's and Daly's ambitious Index of Sustainable Economic Welfare (ISEW) (Daly and Cobb, 1989, 1994), first calculated for the United States, which has inspired work in many countries, and whose end-result is a figure in money terms strongly commensurable with GNP though often showing quite a different trend.

The main physical indexes of (un)sustainability discussed at present are as follows:

-HANPP (human appropriation of net primary production) as proposed by Vitousek et al. (1986). The NPP is the amount of energy that the primary producers, the plants, make available to the rest of living species, the heterotrophs. Of this NPP, humankind "coopts" around 40 per cent in terrestrial ecosystems. It is assumed that, the higher the HANPP, the less biomass is available for "wild" biodiversity. The proportion of NPP appropriated by humans is increasing because of population growth, and also because of increasing demands on land per person for urbanization, for growing feedstuffs, for growing timber ("plantations are not forests" is a slogan of environmental activists in the Tropics).

-Ecospace and Ecological Footprint. Which is the environmental load of the economy, in terms of space? H.T. Odum had posed the question, and later authors (Opschoor, Rees) developed some answers. Rather than asking what maximum population a particular region or country can support sustainably, the question becomes: how large an area of productive land is needed (as source and sink) in order to sustain a given population indefinitely, at its current standard of living and with current technologies? Computations, not only for cities or metropolitan regions (whose "ecological footprint" is hundreds of times larger than their own territories) but for whole countries, show that some densely populated European countries (assuming per capita eco-footprints of 3 ha) or Japan or Korea (with per capita eco-footprints of 2 ha) occupy eco-spaces ten times larger than their own territories. This is "appropriated carrying capacity", from which an "ecological debt" arises. (For details, Wackernagel and Rees, 1995).

-EROI, which stands for "energy return on (energy) input", also originates in H.T. Odum's work. Is there a trend towards an increasing energy-cost of obtaining energy? (Hall, Cleveland, Kaufman, 1986). The idea of looking at the basic economics of human society as a flow of energy is well known to ecological anthropologists (through Roy Rappaport's *Pigs for the Ancestors* and similar work). It goes back to Podolinski in 1880. Engels in 1882 exchanged correspondence with Marx on this topic, he denied the relevance of energy accounting for Marxian economics. Clearly, for an economy to be sustainable, the energy productivity of human work (i.e. how much energy is made available per day, by one day of human work) must be higher (or equal, is everybody is working) than the efficiency of the transformation of the energy intake into human work. The energy productivity of a coal miner (wrote Podolinski) was much larger than that a primitive agriculturalist could obtain, but this energy surplus from fossil fuels was transitory. Max Weber in 1909 had criticised Wilhelm Ostwald's interpretation of economic history in terms of a) an increased use of energy, b) an increased efficiency in the use of energy, because economic decisions on new industrial processes or new products were based on prices, entrepreneurs did not pay attention to energy accounts per se. (No environmental auditing of firms was still required). Max Weber (whose book review against Ostwald was much praised by Hayek in later years), did not yet question energy prices from the environmental point of view as we would today. In the early 1970s there were a number of studies on energy flow in agriculture, of which the best known were those of David Pimentel showing a decrease in energy efficiency in maize cultivation in the United Sate, because of the large energy input from outside agriculture itself. A new field was opened up by such studies (historic and cross-section) on the efficiency in the use of energy in different sectors of the economy, including the energy sector itself (fuelwood, oil, gas, etc.) (Peet, 1992), taking also into account that increased energy efficiency might paradoxically lead to increased energy use, by reducing its cost (the Jevons effect). Such energy analysis has nothing to do, in principle, with the adoption of an "energy theory of value", or with the view that sources of energy are more problematic for sustainability than sinks for residues.

-MIPS and DMR/TMR. The indicator called MIPS (material input per unit service) was developed at the Wuppertal Institute (by Schmidt-Bleek). It adds up the materials used for production directly and indirectly (the "ecological rucksack"), such as mineral ores, the energy carriers (coal, oil), all biomass (though not water, which is used in much larger amounts), including the whole "life-cycle" down to the disposal or recycling phases. This material input is measured in tons, and it is compared with the services provided, sector by sector and, in principle, for the whole economy. For instance, in order to provide the service of one passenger-one km, or in order to provide the service of living space of so many square metres, which is the amount of materials involved, comparing different regions of the world, or historically? MIPS is useful as a measure of the material intensity of production but not as a measure of toxicity of materials. The MIPS notion has been developed further in the statistics published by the World Resources Institute in 1997, on the Direct Material Requirement and the Total Material Requirement (i.e. the aggregate tonnage, including in the TMR the "ecological rucksacks") coming into the economies of some countries (United States, Germany, Netherlands, Japan) both from domestic sources and from imports, therefore testing the hypothesis of "dematerialization" of production (Bunker, 1996, Cleveland and Ruth, 1998).

All the indexes mentioned here are measured in different units. How should a situation be judged in which, for instance, a synthetic indicator or index such as TMR improves while HANPP deteriorates, EROI decreases, and GNP grows? Commensurability would imply reducing such values to an encompassing super-value but this is not necessary in order to reach reasonable judgements by a sort of macroeconomic multicriteria evaluation or integrated assessment (Faucheux and O'Connor, 1998).

6.- The "dematerialization" of consumption?

In economic theories of production and consumption, compensation and substitution reign supreme. Not so in ecological economics, where diverse standards of value are deployed "to take Nature into account" (O'Connor and Spash, eds., 1999). In the ecological economics theory of consumption, some goods are more important and cannot be substituted by other goods (economists call this a "lexicographic" order of preferences). Thus, no other good can substitute or compensate for the minimum amount of endosomatic energy necessary for human life. This does not imply a biological view of human needs, on the contrary, the human species exhibits enormous intra-specific socially-caused differences in the use of exosomatic energy. To call either the endosomatic consumption of 1500 or 2000 kcal or the exosomatic use of 100,000 or 200,000 kcal per person/day a "socially constructed need, or want" would leave aside the ecological explanations and/or implications of such use of energy, while to call the daily endosomatic consumption of 1500 or 2000 kcal a "revealed preference" would betray the conventional economist's metaphysical viewpoint.

There is another approach which, as pointed out by John Gowdy, builds upon the "principle of irreducibility" of needs (proclaimed by Georgescu-Roegen in the previous edition of the Encyclopedia of the Social Sciences, article on "Utility"). According to Max-Neef (Ekins and Max-Neef, 1992) all humans have the same needs, described as "subsistence", "affection", "protection", "understanding", "participation", "leisure", "creation", "identity". "freedom"... and there is no generalised principle of substitution among them. Such needs can be satisfied by a variety of "satisfactors". Instead of taking the economic services as given, as in MIPS (passenger-km, square metres of living space), we may ask why is there so much travel, why so much building of houses with new materials instead of restoration of old ones... There is now research on the following question: Is there a trend to use "satisfactors" increasingly intensive in energy and materials in order to satisfy predominantly non-material needs? (Jackson and Marks, 1999). Expectations that an economy which has less industry will be less resource intensive, are perhaps premature. Input-output analysis of household lifestyles (by Faye Duchin and other authors) shows the high material and energy requirements of the consumption patterns of many of those employed in the "post-industrial" sector.

7.- Carrying capacity and "neo-Malthusianism"

Many ecological economists have emphasized the pressure of population on resources. Has humankind exceeded "carrying capacity"? This is defined in ecology as the maximum population of a given species, such as frogs in a lake, which can be supported sustainably in a given territory without spoiling its resource base. However, the large differences internal to the human species in the exosomatic use of energy and materials, mean that the first question is, maximum population at which level of consumption? Second, human technologies change at a quick pace. Already Boserup's thesis (1965) of endogenous technical change according to which pre-industrial agricultural systems had changed in response to increases in population density, turned the tables on the Malthusian argument. Third, the territories occupied by humans are not "given", other species are pushed into corners or into oblivion (as the index HANPP implies), and, internal to the human species, territoriality is politically constructed through state migration policies. Fourth, international trade (similar to horizontal transport in ecology, but which humans can regulate consciously) may imply "ecologically unequal exchange", though if one territory lacks a very necessary item which is abundantly present in another territory, then Liebig's law of the minimum would recommend exchange. Then, the joint carrying capacity of all territories would be larger than the sum of the carrying capacities of all autarchic territories. This links up with NGO proposals for Fair and Ecological Trade.

Because of the shortcomings of "carrying capacity" as an index of (un)sustainability for humans, the formula I=P.A.T has been proposed by Paul Ehrlich, where I is environmental impact, P is population, A is affluence per capita, and T stands for the environmental effects of technology. Efforts are being made to operationalize I=PAT. Population becomes then only one variable in order to explain environmental load. Charges of "neo-Malthusianism" are unfounded. True, population remains one important variable. True also, "neo-Malthusian" population policies have caused in recent years many forced sterilizations and large-scale female infanticide in some countries, and they threaten small surviving ethnic groups. However, one hundred year ago, another neo-Malthusian movement in Europe and America (as shown by Francis Ronsin and other authors) opposed Malthus' view that poverty was due to overpopulation rather than social inequality, and fought successfully for limiting births by exercising women's "reproductive rights" (to use today's language), appealing sometimes also to ecological arguments of pressure of population on resources. Human demography is self-conscious or reflective. Though it also follows Verhulst's curve, it is different from the ecology of a population of frogs in a lake.

8.- Final remarks: on transdisciplinarity

Ecological economics, based on methodological pluralism (Norgaard, 1989) must not follow the reductionist road, rather it should adopt Otto Neurath's image of the "orchestration of the sciences", acknowledging and trying to reconcile the contradictions arising between the different disciplines which deal with issues of ecological sustainability. Thus, how could a history of the industrialized agricultural economy be written taking into account the opposite viewpoints of conventional agricultural economics (technical progress, growth of productivity), and of agroecology (loss of biodiversity, decreased energy efficiency)? The image of the "orchestration of the sciences" fits well with the ideas of "co-evolution" and of "emergent complexity" implying the study of the human dimensions of ecological change and therefore the study of human environmental perceptions. This means to introduce self-conscious human agency and reflective human interpretation in ecology. While "emergent complexity" looks more to the unexpected future, "co-evolution" looks toward history.

Ecological economics as an "orchestration of the sciences" takes into account the contradictions between the disciplines, it also takes into account changing historical perceptions of the relations between humans and the environment, and it highlights the limits of the authoritative judgements of any particular expert in a particular discipline. This is not a technocratic or scientistic project. On the contrary. As explained by Funtowicz, Ravetz and other students of environmental risks, in many current problems of importance and urgency, where values are in dispute and uncertainties (not reducible to probabilistic risk) are high, we observe that "certified" experts are often challenged by citizens from environmental groups - for instance, "popular epidemiology" activists inside the Environmental Justice movement in the United States, or debates on nuclear energy or on the labeling of new biotechnological foods, or proud arguments based on the practical knowledge of indigenous and peasant populations. This is "post-normal science", leading toward participatory methods of conflict resolution and even toward "discursive democracy", notions which are dear to ecological economists.

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