Physical Limits to Growth and Technological Progress: the debate *Limits to Growth versus* Sussex

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Abstract

In the 70s, the growing concern about environmental degradation caused by human action in pursuit of material progress has generated both in scientific circles and in society a discussion addressing the physical limitations imposed by the environment to economic growth. In the early 70's, a debate between the Sussex and MIT researches was presented in the works *Limits to Growth* (Meadows et al, 1972) and *Models of Doom: A Critique of Limits to Growth.* (Cole et al, 1973) The centerpiece of the discussion concerned the role of technological change in overcoming the limits to growth. Later on further studies were developed by these researchers, updating the arguments raised in the 70. With the increasing environmental problems, it becomes relevant to reopen this debate and to follow the arguments currently being developed in order to rethink the existing development model.

Keywords: Economic Growth, Limits to Growth, Technological Progress.

Introduction

In the early '70s, the growing concern about environmental degradation caused by human action in pursuit of material progress has generated both in scientific circles and in society, an intense debate that questioned the relentless pursuit of economic growth by countries and discussed the existence of physical limits imposed by the environment to this growth. In this context, on the one hand, appeared optimistic positions, which bet on overcoming the natural limits by technological advances and, on the other had, by some researchers, a certain pessimism about the role of technology in the restraint of the human activity pressures on the environment.

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Regarding the pessimistic side of the 70s environmental issues, highlights the production of the report *Limits to Growth*. The initiative to discuss the limits to growth came from the Italian industrialist Aurelio Peccei, that in 1968 formed the Club of Rome, bringing together researchers, entrepreneurs and government staff from different countries to discuss the future problems of mankind. Later, a group of MIT scientists, led by Dennis Meadows, was asked by the Club to write the report that, based on the use of computational models, indicated problems of world economic growth in the long term. The report, published in 1972, was widely disseminated and is, even today, one of the best known works dealing with the problems of continued economic and population growth. The research findings indicated that the scarcity of natural resources and environmental degradation were the main constraints in absolute terms of economic growth and that the technological advances would not be able to contain the increasing environmental pressures resulting from human activity. (CORAZZA, 2005)

Thus, according to Meadows et al. (1972), the fundamental problems facing society comes from maintaining an unlimited economic growth without considering the existence of a planet with finite natural resources. The exponential growth of consumption and population would lead to exhaustion of the planet's resources and increasing pollution levels in a not too distant future. All scenarios generated by the computer model of the report resulted in a large ecological collapse, followed by elevation of mortality and decline in living standards of the population. Technological change, in any scenario, would not alter the results significantly. On the one hand, the use of nuclear energy, for example, would extend indefinitely the production, but on the other, would generate increasing levels of pollution. That is, the introduction of technological advances would only delay the collapse due to increased human activity and, therefore, according to the Meadows team, the only way to prevent the collapse would be to combat the sources of exponential growth with a zero economic growth policy. However, technological pessimism in the report, as well as the proposal of an absolute limit to growth, were reasons for disagreement in scientific circles.

Researchers at the Science Policy Research Unit (SPRU), of te University of Sussex in England, produced a detailed critique of the Limits to Growth from a neo-Schumpeterian approach. The SPRU, founded by Professor Christopher Freeman in 1966, is a recognized research center for studies on the role of technological change in the process of economic development. The critique was published in 1973, with two titles: *Thinking About the Future: A Critique of Limits to Growth* and *Models of Doom: A Critique of Limits to Growth* in Britain and the United States, respectively. The authors emphasized the importance of technological progress, which would have been underestimated in the report. Subsequently, the Meadows team wrote an answer to Sussex’s criticism, which was also published in

the American version of the book, organized by researchers at SPRU, named “A Response to Sussex”. (MEADOWS et al., 1973)

For Freeman (1984), the solution of zero growth proposed by Meadows team reflects the results of an extremely pessimistic model that underestimates the possibility of technical change and the capacity of social system to respond to problems such as pollution and exponential growth of the population. Freeman said an economy whose production was based on intensive use of natural resources would inevitably find limits to growth. However, considering that the economic growth model would be extended over many decades ahead is to disregard the future possibilities opened to society to make intelligent use of technological change and thus modify the pattern of growth.

Therefore, the researchers of Sussex produced the criticism to technological pessimism of the MIT team, but did not consider the technological progress as a solution to all problems. For the authors, society would have a key role in responding adaptively to the problems that arise from the pressures of human activity on the environment. Thus, the analysis of the debate represented by the report *Limits to Growth* and critics of Sussex make significant contributions not only to understand the environmental debate of the 70s, but to deepen the understanding of the limitations of human intervention and the arguments about environmental issues, which is far from the end today. Thus, the study aims to analyze the main arguments of the discussion on technological progress and the limits to growth in the last forty years, more specifically identify the evolution of the main points of debate between Sussex and *Limits to Growth*.

The critique of Limits to Growth to the blind progress and the critique of Sussex to the technological pessimism

Growth and physical limits: the debate of 70s

The debate on growth and physical limits in 70s is partly polarized between technological optimists and pessimists. Rachel Carson (1962), in his bestselling book *Silent Spring*, criticized the advances in technology directing the attention of the American community to the impacts and dangers of using chemical pesticides in agriculture, particularly DDT. Carson showed that the use of synthetic chemicals to control a few unwanted insects in agriculture was not only responsible for the contamination of plants, animals, water and soil, but also represented a danger to human health due to the management of these pesticides in agricultural production and the possibility of ingestion of contaminated food.

Schumacher (1973) also believed that the possibility of unlimited economic growth was constrained by the availability of natural resources and the pressures imposed on the environment. As for Carson and Meadows, for Schumacher, technological change, instead of saving natural resources, accelerate its exhaustion, since they sought to overcome the limits of nature, which was seen as an obstacle to meeting the economic needs. For the author, the economy should be guided by ethical values that were important to the entire society, including protecting the natural environment and not only strictly economic objectives. Overcoming environmental problems go through changing patterns of consumption and production:

> To talk about the future is useful only if it leads to action now. And what can we do now, while we are still in the position of never having had it so good? To say the least - which is already very much – we must thoroughly understand the problem and begin to see the possibility of evolving a new life-style, with new methods of production and new patterns of consumption: a life-style designed for permanence. (SCHUMACHER, 1973: 8)

On the other hand, many authors emphasized that the view of environmentalists from the 70's was extremely pessimistic for disregarding the advances in technology. Among the technological optimists were many economists, among which we can quote Solow (1974). For the author, the depletion could be prevented indefinitely by technological change, especially for technologies aimed at saving resources, and the ability to replace natural resources for capital and labor in the production process. The resource-saving inventions would probably be created, and would present unlimited capacity to save natural resources.

The Club of Bariloche, in turn, also produced an important critique to the environmentalism of 70 years, especially to the *Limits to Growth*, emphasizing the social factors rather than technological. At a meeting sponsored by the Club of Rome in 1970 in Rio de Janeiro, several researchers, mostly Latin Americans, gathered to discuss the computer model developed by Denis Meadows. From this meeting was created the Club of Bariloche, led by Amilcar Herrera, aimed to develop a model of economic growth from issues raised during the debate.

In the report entitled *Catastrophe or New Society*, Herrera et al. (1976) claimed that the greatest problems facing humanity would not be the physical limits to growth, but socio-political disturbances that generate unequal distribution of power between and within nations. Environmental degradation would not be an inevitable consequence of progress, but a consequence of destructive social values. Any policy to reduce environmental impacts would face difficulties to be deployed homogeneously in a socioeconomically unequal world: to the authors, the share of poor population, living in precarious

conditions, could not abandon the increase in material consumption at the expense of consumption of future generations.

For the authors of the report of the Club of Bariloche, the idea expressed in *Limits to Growth* on the existence of insurmountable physical limits to growth would deny the possibility that all members of human society have an acceptable standard of living. The problem of depletion of natural resources could be solved by the discovery of new reserves in response to technological and economic changes, the first being responsible for access to new reserves and the second for the economic viability to do so. Herrera et al. argue that the fact that the Earth is finite does not automatically correspond to the finitude of natural resources:

> With very few exceptions, the huge volume of mineral resources in the crust are not lost once they have been mined and used, but continue to form an integral part of the planet's resources. They may be temporarily incorporated into capital or consumption goods; they may be chemically combined with other elements; but despite this, they remain indestructible. Technology has shown its ability to find ways of extracting resources from the most diverse geological formations. It can also recover materials that have already been used once or several times. (HERRERA, et al, 1976)

Considering the possible energy constraints that humanity would suffer, the authors suggest that in a scenario of declining fossil fuel reserves, nuclear power could be used as a substitute, backed by large reserves of uranium, to ensure the production of energy for thousands of years. On the other hand, with regard to pollution, their generation would be caused by different factors in developed and underdeveloped countries. While in developed countries, the pollution would result from an intense industrial activity, it would have in underdeveloped countries, poverty as the main cause. Thus, this type of pollution tends to disappear as the population's basic needs such as housing and sanitation were met.

The Limits to Growth

The authors of *Limits to Growth* aimed to answer two questions. The first, whose affirmative answer is almost the starting point of work, questioned whether the rates of population and capital growth could be physically maintained in the world. For the second, on the other hand, there would not be accurate or definitive solution, since it wondered how many people could survive on earth, with what level of wealth and for how long. To analyze it, the authors used a model based on System Dynamics, which was created by Professor Jay W. Forrester at the Massachusetts Institute of Technology (MIT) during the mid-50s. The advantage of the Forrester model, later adapted for the

report of the Club of Rome by Dennis Meadows, was to facilitate the understanding of the dynamic behavior of complex systems, whose variables are interrelated in many ways over time.

In the report *Limits to Growth*, the five basic factors of the study, contained in World3[3], were the population, food production, industrialization, pollution and consumption of nonrenewable natural resources, since these elements were taken as determinants of economic growth of the planet. In the authors' analysis, the model World3 was *"imperfect, oversimplified, and unfinished"*, but, despite the limitations, it was a most useful model for dealing with global problems of long-term: *"is the only model that exists, whose reach is truly global in scope, with a longer time horizon than thirty years and includes important variables such as population, food production and pollution, not as independent entities but as dynamic elements in interaction, just as they are in the real world."*(MEADOWS et al. 1972: 18)

In addition, the authors highlighted two advantages of formal and mathematical models on the 'mental models': the assumptions were clear and precise and thus likely to be examined and criticized by everyone, besides, the chances for them to be more complicated, could be investigated, without error, by computer. Finally, despite the preliminary nature of the model, its publication was important, since it could be useful for decision-makers around the world. It would be impractical to wait for perfect models, because policies are made daily, from formal or mental models that will affect the economy and society in the future.

From different scenarios, the *Limits to Growth* model shows that, unless humanity seeks a condition of ecological and economic stability, with deliberate restriction of population growth and capital, the limits of physical growth of the planet must be reached the end of 21s century. In the most optimistic scenario of continuing growth, there is adoption of technology in all sectors of the world model to circumvent existing limits: it is considered that there are 'unlimited' reserves of energy from the use of nuclear technology, natural resources are fully exploited and 75% of them are recycled, that is reducing the generation of pollution at a quarter of its value by 70, doubling the income of the land and that effective methods of birth control become available to the world population. However, despite the application of these technologies at the end of 21s century, the increasing industrial activity is interrupted and the mortality rate increases due to the exhaustion of natural resources, accumulation of pollution and reduced food production.

[3] The World1 was prepared by Forrester for a visit by members of the MIT Club of Rome, then a more refined model, World2, was published in a book entitled *World Dynamics*. The final study that generated the World3 was conducted by one of his students, Dennis Meadows, and was published in *Limits to Growth*.

According to the authors, the behavior of the system consisted of the exponential growth of population and capital and, consequently, collapse - this would occur with or without the introduction of a set of technological changes. Thus, despite a mostly upbeat view on society, the adoption of new technologies would be unable to rule out indefinitely the limits to growth:

> Over the past 300 years, humanity has an impressive record pushing back the apparent limits of economic and population growth for a number of spectacular advances. Since the recent history of a large part of human society has been so continuously marked by great successes, it is quite natural that many people expect that technological advances continue indefinitely away from the physical limits. They speak of the future with a resounding technological optimism. (MEADOWS et al., 1972: 128)

In addition, the side effects of technology in various areas of the world system - physical, economic and social - could not be disregarded. One example is the result of the Green Revolution in many regions, despite the increase of agricultural production; it worsened the conditions of economic inequality, unemployment in the agricultural area and the rural exodus. Thus, the social and political institutions were unable to anticipate technological changes and the delay would tend to aggravate social instability of the global system. However, the model built did not allow detection of changes in social patterns, just watched as the relationship between physical variables. It was assumed stable social conditions, such as peace, stability and education and, consequently, to underestimate the negative effects of social backwardness and the side effects of new technologies.

Models of Doom: a critique of the Limits to Growth

The critique developed by the team at Science Policy Research Unit (SPRU), from University of Sussex, had as its central point on the role attributed to technological change in models of the MIT. The SPRU team, also multidisciplinary, was composed of researchers in economics, engineering, mathematics, biology and statistics, among who were economists Freeman and Pavitt. The criticisms of the group were gathered in the book *Models of Doom: A Critique of The Limits to Growth*[4], published in 1973, with an article-reply written by the authors of Limits to Growth entitled "Response to Sussex." The book is divided into two parts: first, the authors question the methodological validity of each

[4] Na Inglaterra, o livro foi publicado com o título *Thinking about the future: a critique of the Limits to Growth* (Sussex University Press, May 17, 1973)

subsystem and the world system World3 used by MIT, in the latter questions the ideological basis of the group, hidden by the apparent neutrality of the ‘computing models’.

In methodological terms, the Sussex team outlines a series of possible errors arising from distortions of the trends of the variables, whose database is inadequate, and the absence of adaptive processes in the model. On the one hand, the absence of a reliable database for the years 1900 to 1970 would involve a construction of an unsatisfactory model for trends, which can cause large distortions. On the other hand, the absence of adaptive economy, in which there is no return of social and technological processes, excludes the most important element in the system dynamics: a shift in values. This change could lead to strong changes in assumptions of the model: likely change the pattern of population growth, emergence of new technologies more efficient and productive and industry feedback mechanisms that could prevent catastrophe. According to Cole and Curnow, the introduction of technological progress in the MIT model, omitted in some sectors, would have the effect of prolonging indefinitely the collapse of the system. Therefore, in *Limits to Growth*, the assumptions that inevitably provoke the collapse arise of a particular vision of the world, associated with a poor model, not a necessary result of World3:

> Forrester and Meadows assumptions are very much a reflection of their generally pessimistic view of the world. Early chapters have shown that in many cases the data from which the numerical values used in the models are estimated are poor. It is all to easy for a systematic bias reflecting a particularly pessimistic (or for that matter optimistic) view to influence the actual estimates used. (COLE & CURNOW, 1973: 133)

Thus, the use of ‘computational models’, although not completely rejected, is a subject of great criticism by the staff of SPRU. According to them, there would be certain fetishism related to computer use, which apparently provide a precise knowledge of variables and unknown relationships. The simplicity of the techniques implies an oversimplification of reality and the factors that are difficult to calculate tend to be overlooked - such as political and values changes. Moreover, according to Freeman, the use of the models could not replace the theoretical discussion and definition of political assumptions, that the use of the computer becomes inaccessible to people who do not have the technical knowledge of mathematics. Thus, it is established the ideological discussion, held in the second part of the book, which had been omitted by the team of *Limits to Growth.* (FREEMAN, 1973)

According to Freeman, the assumptions about the relationships between variables in the model would be much influenced by contemporary social theories, with an important role to Malthus. The results, therefore, would not be simple mathematical results, but the consequences of "mental models" of researchers - these, hidden in *Limits to Growth* from the emphasis on the superiority of

"computational models". For the author, the expression *"'Malthus in, Malthus out' does bring out the essential point that what is on the computer print-out depends on the assumptions which are made about real-world relationships, and these assumptions in turn are heavily influenced by those contemporary social theories and values to which the computer modelers are exposed."* (FREEMAN, 1973: 8)

Thus, by assuming exponential growth of population and capital, Forrester and Meadows are based on the Malthusian idea that economic growth, by inducing the increase in population, would fall back because of the difficulty of producing enough food. Therefore, the authors revive the interest in the concerns of classical economists, among them, that growth is precluded by physical limits. However, according to Pavitt, it is known that the classical predictions about the physical limits, possibly linked to the interests of the landed aristocracy, were incorrect. During the period, could be experiencing a similar process in which the most important debate about the social equality was being relegated to promote the debate on the physical limits. According to Pavitt:

> (...) some contemporary economists have argued that the movement hostile to economic growth can be seen as supporting the interests of the materially well-off, who find that life is less pleasant for them when an ever larger number of people begin to approach the same living standards as their own and, in particularly, when they start using the same, scarce infrastructure. (PAVITT, 1973: 154)

The team of researchers from Sussex, therefore, considers that the political and social obstacles to growth are more challenging than the purely physical limits and that the main problem is to stimulate growth that preserves the environment and is more socially equitable. The zero growth in such a context would be unacceptable, since poverty was still the biggest problem for most people in the world. There would have, however, also emphasized by the MIT team, the need to develop technologies that do not harm the environment and contribute to the conservation of finite resources. In this sense, says Freeman *"We should not fall into the error of some of the more pessimistic ecologists: failure to consider the tremendous potential of changing technology in relation to human social systems."* (FREEMAN, 1973:11)

In general, we can say that the SPRU researchers agree on the importance of environmental issues addressed by the Club of Rome and highlight the role of the report to stimulate discussion about the future of society. However, they criticize the emphasis on physical limits on the models and the lack of adaptive response of humans to these problems, mainly from the development of new technologies. In this sense, the main interest of researchers from Sussex focuses on discussion of policies for science and technology, whose progress would depend on a number of conflicting factors

in the period, such as the increasing amount of resources devoted to R&D and the unequal distribution of resources, mainly focused on military innovation in developed countries.

The response to Sussex: Malthusian assumptions and a new vision of the economy.

After the criticisms made by the staff of SPRU, the authors Donella Meadows, Dennis Meadows, Jorgen Randers and William Behrens III, writers of *Limits to Growth*, wrote the article "A Response to Sussex", which clarified some points about the model used and group's own judgments about the ideological basis implicit in the work. In addition, the authors criticized the researchers of Sussex for not suggest alternatives and do not describe in precise terms the process of social change and technological advancement that would enable continued growth.

First, with respect to the model used, the MIT team did not effectively sought perfection: the models of dynamical systems are general and holistic; they do not seek short-term prediction and accuracy, but the exploration of trends and dynamics in the long term. In addition, the society could not wait for perfect models and long-term goals, but should quickly implement the best possible model, even if under the influence of subjective impressions of a group, to promote policies for the future.

In turn, on the questioning of the ideological basis of the group, the authors of *Limits to Growth* reaffirmed the existence of physical limits to population and capital growth. They said Freeman is correct in saying "Malthus in, Malthus out": the computational model World3 is a logical consequence of the vision of a finite Earth. This view is determined by four assumptions: i) there is a finite stock of nonrenewable resources, ii) the ability of the environment to absorb pollutants is finite; iii) the amount of arable land is limited; iv) there is a finite amount of food obtainable from each hectare of land. However, according to them:

> From our Malthusian point of view, western man is entirely too prone to rejoice in his newly-irrigated land, underwater oil-drilling rigs, Green Revolution, and catalytic converters and to ignore the eroded, salinized, or strip-mined land, dumps of wasted resources, depleted ore bodies, simplified ecosystems, and deprivation of other cultures he leaves in the wake of his 'progress'. (MEADOWS et al., 1973: 227)

This blind belief in progress, in modern society, would cause the pressures caused by the limitation of any resource to be withdrawn to allow further growth. In other words, the choice would always be to remove the symptoms of the limits, rather than diminish the forces of growth. Contrary to the suggestion of Sussex's researchers the present trend of technological progress would promote an expansion of the pressures on the physical limits of the world system.

Therefore, the authors of *Limits to Growth* are skeptical about the ability of technology to overcome future challenges of society. It would be preferable and less risky, have a stable society without economic growth than count on the miraculous power of technological progress: *"We are uncomfortable with the idea of basing the future of our society on technologies that have not yet been invented and whose side effects we cannot assess."* (MEADOWS et al., 1973: 237) In addition, to the authors:

> It seems to us not only more realistic, but more socially responsible and more useful to investigate the ways in which society might adjust itself to earthly limitations, rather than to assume away all such limitation. We are indeed Malthusians, at least in a broad, total-system sense. (MEADOWS et al, 1973: 142)

In criticizing the conclusions of the *Limits to Growth* and did not suggest alternatives or other methodologies, the SPRU team is contributing to maintaining the status quo because it does not stimulate any change of view on the present economic and political processes of society. In "A Response to Sussex", the authors note that few researchers were actually thinking about how society would be in the future when there is strong pressure on the physical limits. Among them stood out Georgescu-Roegen, Herman Daly, Kenneth Boulding and Ezra Mishan, who cited the need to think the economy in a stabilized physical state. (MEADOWS et al. 1973: 230)

The current debate: the economy beyond the physical limits versus a new technological paradigm

Limits to Growth: The 30-years update

In 2004, thirty-two years after the publication of *Limits to Growth*, was released *Limits to Growth: The 30-Year Update* by the same authors of the initial work. Despite recognizing the increasing of environmental awareness and technological advances that occurred after the publication of *Limits to Growth*, the authors stated that no change occurred in the period invalidated the considerations made initially. Even when are considered technical changes over the last thirty years as the policies of birth control, the green revolution in agriculture and the replacement of resources, the World III model still generates scenarios of economic collapse.

The forces that drive the economic system to collapse remain the exponential growth of the economy and population. The limiting factors of growth also remain the same as the first report: energy, natural resources and the planet's capacity to absorb pollutants. About ten scenarios were

generated in *Limits to Growth: The 30-Year Update*. Only two of them do not lead to a collapse in the economic system. Both of these scenarios assumed stable population and industrial output per capita, plus the addition of the production process technologies that combat pollution and preserve natural resources, from the year 2002.

According to the authors, the ability of technological change to prevent the collapse depends on the explicit or implicit goals of society as a whole. If the society wants to explicitly or implicitly explore nature, new technologies that lead to destruction of the environment and the maximization of short-term results will be developed. Thus, the intrinsic goals of society can accelerate the collapse rather than prevent it.

When dealing with natural resources used in agricultural production, the authors stress that the limits to food production have been achieved. The soils have been degraded by processes such as erosion and salinization, while the cultivated areas remain constant. Agricultural productivity has offset the loss of soil productivity but it cannot increase indefinitely. The boundaries of the aquifers were also achieved due to the unsustainable use at the same time that many countries are facing reduction of per capita water due to environmental problems, rising extraction costs or scarcity.

The maintenance of oil dependence in the composition of world energy matrix is also criticized. Over 80% of world energy came from fossil fuels when the report was prepared. While recognizing that oil reserves have increased due to reassessment and discovery of new reserves, the authors emphasize the finiteness of resources and limited capacity of the planet to deal with its waste and pollutants.

Finally, unlike the zero economic growth proposal, present in *Limits to Growth*, the proposal of the recent report does not suggest a policy of zero economic growth, but a shift to a goal of quality development and not merely quantitative:

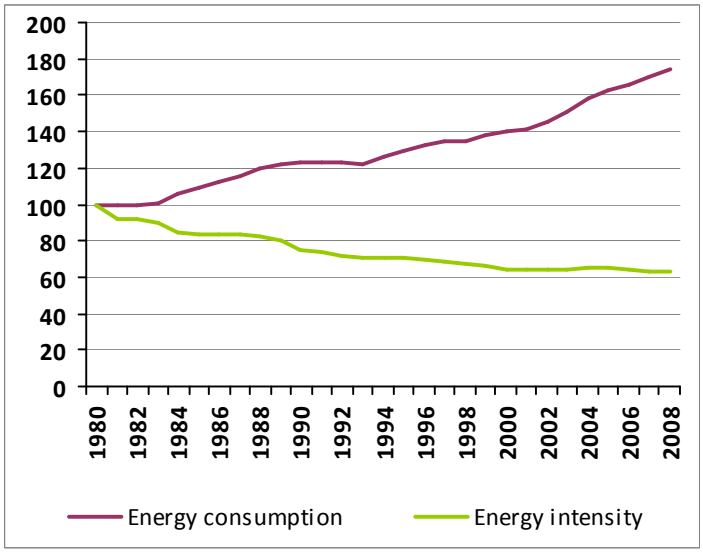
> A sustainable society would be interested in qualitative development, not physical expansion. It would use material growth as a considered tool, not a perpetual mandate. Neither for nor against growth, it would begin to discriminate among kinds of growth and purposes for growth. It would ask what the growth is for, and who would benefit, and what it would cost, and how long it would last, and whether the growth could be accommodated by the sources and sinks of the earth. (MEADOWS et al, 2004)

Relative decoupling: Energy Consumption and Carbon Dioxide Emissions

Over the past thirty years, world economic growth was accompanied by an increase in energy efficiency especially in developed countries. Although there was a reduction in energy intensity, there

was an increase in total energy consumption, in other words, the decoupling was relative and not absolute, as shown in Chart 1. In 2008, the United States, Europe and China were responsible for more than half the world's energy consumption. Global energy intensity was stable in 2000 due to the increase of energy consumption in China that doubled between 2002 and 2008.

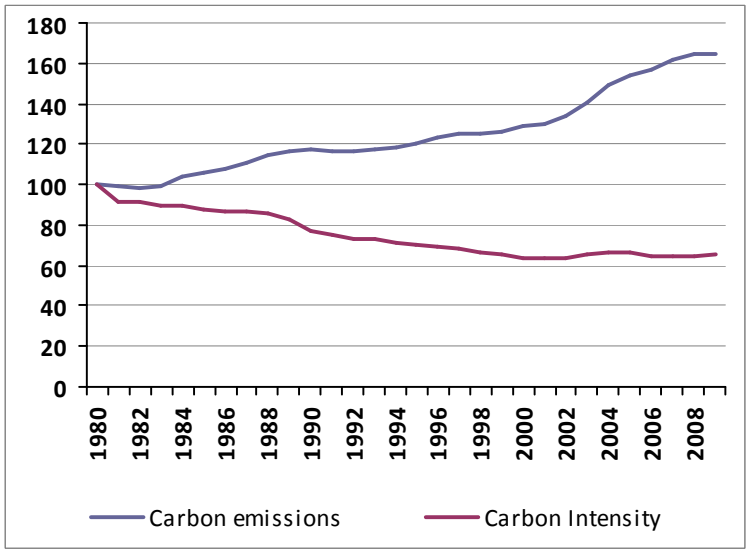
Chart 1: Variation in worldwide total energy consumption and the world energy intensity



Fonte: US Energy Information Administration, 2011.

The global emissions of carbon dioxide have increased since 1980. China, U.S. and EU, respectively the three largest emitter of CO2, accounted for 56% of total emissions in 2008. Between 2002 and 2008 China doubled its CO2 emissions, while its energy intensity remained stable. The relative world decoupling that had been going on since the 80's were discontinued in the 2000s by the increase in Chinese emissions. Thus, the total global emissions of CO2 that was increasing since 1980 further increased even more in the 2000s, as shown in Chart 2.

Chart 2: Variation of total emissions of carbon dioxide from energy use and carbon intensity variation



Fonte: US Energy Information Administration, 2011.

Technological paradigm shift and sustainable growth

Unlike *Limits to Growth* team, researchers at SPRU do not come back, in a clear and united way, to the debate about the physical limits occurred in 70 years. There are only, as discussed below, a growing concern with environmental issues and policies for the development of technologies that solve the social and environmental challenges of today. Freeman, in his article "The Greening of Technology and Models of Innovation" (1996), in particular, discusses some issues raised by the Sussex group's critique of *Limits to Growth*. However, his view does not differ fundamentally from other analyzed studies.

Freeman (1996) emphasizes the change in material and energy intensity of economic growth. According to the author the relative energy consumption, as we have seen declines in advanced industrialized countries during the decades of 70 and 80. This reduction was mainly due to structural changes in production and especially the development of materials and technologies that save energy. The Information and Communication Technologies (ICTs) have been important in reducing the number and size of components in many products, as well as to facilitate the design and construction of process control systems of waste and dejects.

However, according to Freeman, these elements were not sufficient to ensure the transition to sustainable growth in the global economy, as we have seen a large increase in carbon dioxide emissions and energy consumption (Chart 1 and 2). ICT could in fact help save material, energy and reduce transportation costs, but its effectiveness would depend, above all, social and economic policies, as well as science and technology. Therefore, the transition to sustainable growth depends on the priorities of public and private research and policy to form an institutional arrangement in favor of the transition. This should give priority, among others, the "clean" energy, conservation of materials and regulatory mechanisms to ensure the dissemination of knowledge and innovations. The latter, for example, have a critical role in ensuring the sustainability of newly industrializing countries, such as China, India and Brazil. Thus, besides the emphasis on technological progress, the most important element in the debate of 70 years, Freeman assigns a larger role for institutional changes:

> Looking back on this 1970s debate with the benefit of hindsight, it is easy to see that a great deal depends on the systemic model of innovation. Only if the science and technology system is highly responsive to social and economic demands and only if the economy is highly responsive to institutional change and social policies would it be possible to avert the type of catastrophes predicted by the MIT models at some time during the 21st century. (…) Only a continuing high rate of technical change *and* a set of institutional changes, such as those affecting demographic trends and pollution hazards, would prevent catastrophe indefinitely. (FREEMAN, 1996: 34)

The prevention of the catastrophe predicted by the model of MIT, according to the author, still would not be guaranteed by ICT mainly by institutional problems and delays. In addition to the slow diffusion of new technology, there are several obstacles to the successful establishment of a new technological paradigm based on information-intensive computing and information technology. In an economy driven primarily by the forces of short-term market, changes in the technological trajectory mainly occur incrementally. In addition, the lock-in mechanisms would also help to inhibit radical change of paradigm. Therefore, there would be inertia of established systems and persistence of old technologies and infrastructure for a long period, even after the establishment of the new paradigm. Clearly, the incremental changes that had already occurred intensively have an important role, but major changes would be needed to ensure a sustainable long-term:

> What is required for the world wide transition to a "green technoeconomic paradigm" is something more fundamental than incremental change to an information technology regime. The transition to renewable energy systems in the 21st century will not be possible without some major institutional changes in public transport systems, tax systems, and automobile and airplane culture. Despite the important advances in wind power and solar power, it will not be possible either without some far greater R&D commitment in the public and private sector as well as procurrent policies. (FREEMAN, 1996:38)

In other studies conducted by researchers, we note that there is also a concern centered on technologies, policies and institutions needed to overcome the social and environmental challenges present today. (SMITH, 2008; FREEMAN, 2003; SMITH, 2006) Noteworthy is the publication of *A New Manifesto* (STEPS Centre, 2010), which represents the collective effort of reflection about the problems of today in the latest performed under the SPRU. The report's title refers to the Sussex Manifesto of 1969, when the concerns of researchers at SPRU were mainly centered on social issues and pointed to the need for spending on science and technology to solve the problems of developing countries.

The update of the work in 2010, aims to add environmental issues to the problems pointed out in 1969. According to 2010 report, poverty reduction, social justice and environmental sustainability can only be achieved with the development of science, technology and innovation. The innovation is thought by the authors as a set of ideas, institutions, practices, behaviors and social relations that shape scientific and technological standards. It must be transformed so as to reshape social relations and power, should seek sustainability and not be guided solely by profit, and should pay attention to ecological integrity and social and environmental values different. This means that the benefits of innovation are distributed equally and that science and technology should be shaped by democratic interests.

Furthermore, the report also states that science and technology have been for many decades, the main solution to the challenges of development. These elements, according to the authors, are the ways of inducing national economic growth in a highly competitive global economy and this growth leads indirectly to poverty reduction and the ability to protect the environment. Therefore, as in Freeman (1996), *A New Manifesto* highlights the importance of technological progress to tackle the growing pressure of human activity on the environment. Therefore, as in Freeman (1996), *A New Manifesto* highlights the importance of technological progress to tackle the growing pressure of human activity on the environment. Such studies, performed by researchers at SPRU, differ from the *Models of Doom* from 70s, straddling a more emphatic the environmental issue, but do not affirm the need to think economic activity restricted by the physical limits of the planet. Technological progress is seen as the element capable of solving the problems created for himself over the last century and, therefore, the only problem may be effecting the paradigm shift that generalize technological "miracles" that are able to fend off indefinitely physical limits to the growth of economic transformation.

Conclusion

The analysis of the work of researchers from Sussex and the *Limits of Growth* Group sheds light on issues relevant to think the economic development. The discussion about the material bases of growth is largely neglected in the economy, and although it stimulated important controversies in the 70s, had no great impact and subsequently produced just a few detailed studies in the area. Only recently, with the aggravation of environmental problems, researchers that accept the existence of the physical limits to growth, as Georgescu-Roegen and Herman Daly, have received increased attention by some groups in academia.

The focus of our analysis, the role of technological progress to overcome the physical limits, is at the center of important debates on environmental issues. Of course, technology can contribute significantly to the economy of resources and energy in the production process, but there are two limits to this contribution. The first, highlighted by Freeman, relates to political obstacles, social and institutional, which difficult the transition to a "green" technological paradigm. The second, absolute, defended by the *Limits to Growth*, determines that there is a physical limit to the efficiency of technological advances. Therefore, by neglecting the natural limits of economic growth, most economists are betting that the technological miracle can ensure the continuity of present social and economic structures. This thought, in turn, ignores the impossibility of spreading the material consumption pattern of rich countries to the global population and thus contributes to the maintenance of inequality. On the other hand, it can be argued that social and environmental obstacles can only be overcome from a development model not guided by economic growth but a development that seeks to expand activities that are not heavily based on resources and energy - such as artistic, intellectual, communal - and effectively engaged in the distribution of wealth between and inside countries.

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