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REINIER DE MAN

ARE THERE LIMITS TO ECONOMIC GROWTH? – THE FORBIDDEN QUESTION

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A PERSONAL INTRODUCTION

This note is meant to become part of a first chapter in a longer essay (or even book) on the history of sustainability, including ideas on limits to growth. As the other parts, it has a strong autobiographical component. My work on energy policies, environment and sustainability started in the early seventies. As a chemistry student, I became (as many others of my generation) increasingly interested in questions of ecology, natural resources and energy. After reading the 'Limits to Growth' report, I decided to work on these issues rather than in the field of chemistry.

I joined a new group at the Groningen Chemistry department that worked on alternative energy strategies. Depletion of North Sea oil was one of the concrete themes I was working on and I became involved in intensive an emotional discussions on the future of 'spaceship earth', on the exhaustion of resources, the necessity to build wind turbines and fight nuclear energy.

As natural scientists we were negatively surprised about what economic science had to say about the physical and ecological conditions for a working economic system: virtually nothing. We were extremely dissatisfied with economic models that did not even account for the direction of change when defining 'elasticities', for example. Not only did we see an almost complete neglect of the physical world in which the economy is embedded, we also were shocked about the absence of elementary systems thinking.

Gradually the main questions I tried to answer in my work – when working at different universities and preparing my dissertation – focussed on the use of technical and economic knowledge, especially model calculations, in decision making on energy and ecology. These questions were both on the technical quality of the models and scenario used and on the quality of the decision processes. It became clear to me – as to everyone else who spent some time on it – that models underlying the Club of Rome's 'Limits to Growth' did have serious shortcomings with regard to methodology and data used. But I also saw that these shortcomings did not discredit the validity of the issue at stake, the physical limits to economic growth.

Some years after my Groningen years, I was again reminded how physical reality remains largely outside the view field of standard economic discipline. With Dr J.H.C. Lisman, a retired scientist at the Dutch Central Statistics Bureau, I wrote an article on the use and misuse of the entropy concept in the economic science. The article showed how the concept was loosely used by some economists, thereby not recognising their proper natural science background. We did not succeed to have it published in one of the Dutch economic journals. Apparently, we were not welcome to criticise well respected economy professors at high positions. Eventually we published it in a natural science journal, Chemisch Weekblad. Reactions were not very enthusiastic either: "what you write is correct, but should be known by any pre-graduate natural science student."

What was common sense in natural science was not acceptable in the realm of the economic discipline. In this note, I will quote even more remarkable examples of the iron wall between the two worlds. Denying the realities of the physical world has appalling consequences for how economists tend to look at natural resources and energy. Whereas economists can easily define endless cycles of value creation, they forget that endless loops of materials or energy in the real word are logically impossible on the basis of second law of thermodynamics. The first law states that in a closed system (or the entire universe) energy is constant and cannot be lost. The second law states that available energy in a closed system is constantly decreasing or, in another formulation, that entropy is constantly increasing. To keep cycles running, there is a constant need of adding energy from the outside, in the case of our world, energy from the sun. It is only logical that, apart from additional practical limits, the theoretical limit to 'sustainable' growth is given by amount of solar energy we can crop.

Endless, zero-energy using, cycles are an illusion and who preaches their possibility either lacks intelligence or is cheating. Practical limits to growth can of course be overcome by better technology, better market organisation and related improvements. However, the second law of thermodynamics poses theoretical limits to what is logically possible and any claim that such limits can be overcome cannot and should not be taken seriously.

In this note, I will try to show how vested interest, with economists as their usual allies, have tried to discredit ideas of ‘Limits to Growth’ in many different ways, most often by pointing at the weakness of the methodologies and the low quality of the data used. Indeed, many of the methodologies show serious faults and many data are debatable, as I will show. However, none of these criticisms are strong enough to convince us that ‘Limits to Growth’ are non-existent. Even the basic message of the original ‘Limits to Growth’ report remains valid. The methodologies and the assumptions behind the so-called World-3 model were and are debatable, as is the almost ridiculously high level of aggregation. However, the basic idea of tricky feed-back loops and the resulting ‘overshoot and collapse’ scenarios remains valid. Contrary to what many believe, real developments between 1970 and 2000 are very much consistent with the outcome of the baseline calculations made in 1972. What could not be foreseen in 1972 in any detail is that the world in the beginning of the 21st century is faced with a very concrete threat that may lead to serious destabilisation of the entire system: climate change by uncontrolled increase in CO2 emissions. An overshoot of more than 2 °C is almost certain with potentially disastrous consequences. The ´doomsday prophesies´, ridiculed in the 1970s, may become reality earlier than foreseen.

There is a need to keep get the ´Limits to Growth´ issue (actually: “Limiting unacceptable consequences of uncontrolled growth”) on the agenda. Softening the agenda to “sustainable growth”, “green growth” or “circular economy” will make the problems worse rather than solving them, as I will show in other parts of this essay/book.

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1. THE DISCOVERY OF THE PHYSICAL WORLD

1.1 THE CONTEXT OF THE 1970S

It was certainly not for the first time in history that 'Limits to Growth' became an issue of discussion. But the scientific and political discussions in the 1960s and the 1970 may be regarded as the starting point of discussions that have been taking place until today and that will keep us busy for some time to come: discussions on how finite resources may limit economic growth on the related question of sustainability and sustainable growth.

It was the time of rapidly increasing environmental awareness, triggered by real problems of environmental pollution and the risks of expanding nuclear energy production. As early as 1967, the British economist Ezra J. Mishan published his *The Costs of Economic Growth*, which would become highly popular at the time. In the 1970s, environmental policies and associated institutions were set up, whereas an expanding non-governmental environmental movement was gaining influence. Friends of the Earth was founded in 1969, Greenpeace in 1971. 1972 was an important year in the development of global environmental awareness. Just two highlights in that year: The Club of Rome published its *Limits to Growth Report* and the first *United Nations Conference on the Human Environment* took place in Stockholm.

For a detailed account of the many activities, publications and discussions on global ecological issues at the time, I refer to excellent publications such as Radkau's Global History of the Environment (Radkau 2011 and 2008). The capacity of the natural world both to deal with the increasing environmental pressures and to provide sufficient resources for the growing economy became a central focus. A number of the principles in the Stockholm Declaration agreed at the 1972 UN were referring to this carrying capacity, for example:

2. Natural Resources must be safeguarded
3. The Earth's capacity to produce renewable resources must be maintained
4. Non-renewable resources must be shared an not exhausted
6. Pollution must not exceed the environment's capacity to clean itself

7. Damaging oceanic pollution must be prevented.

Despite their rather general character, these principles showed the contours of an emerging agenda for combined efforts to prevent exhaustion of non-renewable resources, to limit pollution and to gradually switch to renewables. The agenda contained many more questions than answers. To what extent would it be possible to move towards these goals and at the same time provide the growing world economy with the natural resources it requires? Would it be possible at all or is there a need to question economic growth itself? Are there options to partially or completely decouple economic growth from growth in pollution and growth in use of natural resources? Whereas mainstream economists framed the question and consequently their optimistic answers in classical terms of market and price mechanisms, others, mainly scientists with a mathematical or natural science background, pointed at the fundamental and inescapable limitations the physical world poses to the economic system. Taking these limitations into account, they were less optimistic than the mainstream economists about the possibilities of continued economic growth without being restricted by the ecological and physical limits posed by the natural world. The arguments put that natural scientists put forward in the early 1970s are still important today as they show inescapable realities that any design of an economic system should take into account.

The following sections will discuss, from the many publications and topics addressed in the 1970s, two main approaches: the criticism of economic theory on the basis of thermodynamics and the outcomes of model studies as presented in the 1972 Limits to Growth report. These two approaches have been selected as they represent fundamental criticism coming from outside the establishment of economic science and policy and focused on the physical and ecological aspects of the economy. The following text is not meant to be a full historical account of all relevant literature. It is only meant to highlight trends and debates that are still relevant today.

1.2 ENERGY, ENTROPY AND THE ECONOMIC PROCESS

1.2.1 The Entropy Law

Georgescu-Roegen's book *The Entropy Law and the Economic Process*, published in 1971 and based on ideas developed in the second half of the 1960s (Georgescu-Roegen 1971, 1986) marks the beginning of an intense debate on the physical conditions under which the economic process can work. From a natural science point of view, the arguments presented in this book and related publications are nothing new. Since the establishment of thermodynamics as a discipline in the late 19th century, especially by the work of Josiah Willard Gibbs, it had become completely clear to any natural scientist that, in closed systems, entropy increases irreversibly and that to lower entropy, energy has to be added. For the discipline of economics, however, Georgescu-Roegen's book meant a direct attempt to undermine the very basis of its underlying assumptions. Traditional economics had managed to completely disregard the links between the natural world and the economic world of value creation and value exchange. In the economic world of 'value', matter and energy did not exist or were not regarded to play a role that could not be described in traditional economic terms. Georgescu-Roegen convincingly showed that for a proper understanding of the physical basis of the economic world, and the limitations created by this physical basis, insight in the implications of the laws of thermodynamics is indispensable.

The basic argument, based on the First and Second Law of Thermodynamics is extremely simple: In an isolated system, the amount of energy remains constant (the first law), while the available energy continuously and irrevocably degrades into unavailable states (the second law). Similarly, highly available materials irreversibly degrade into less available materials. The concept of availability is important here. Highly concentrated ores, for example, represent a form of high availability or, formulated in thermodynamic terms, low entropy. Waste streams represent high entropy: the materials contained in them are much less available than in the original ore, for example. The same for energy sources: natural gas deposits represent low entropy/high availability. Heat that is generated as a by-product of industrial processes when burning natural gas represents high entropy and low availability in terms of the useful work it can perform in any secondary process. And the lower the temperature of the heated subsystem compared to its environment, the less useful, the less 'available'.

As a result, the physical world of production and waste generation, in contrast to the economic side of value generation, is not circular. In a closed system, as the planet Earth is, matter will never be lost, but all materials will irrevocably degrade into less and less available forms. The same is true for energy. The First Law states that energy will never be lost, but the Second Law makes it ever less available for doing work. There is one exception: with regard to energy, as opposed to matter, the Earth is not a closed system: the sun provides a continuous source of energy. Economists have long denied the dependence of value creation processes on the unavoidable continuous degradation of materials into less available forms and the limits set by the availability of solar energy.

Economists tend to think in endless circular processes of value creation. However, Thermodynamics tells us that, in a closed system, in the end physical processes are linear, not circular: from low entropy states into high entropy states. As a result, material resources and (fossil) energy, in forms that are useful in the economy, will decline. The second law of thermodynamics makes it impossible to bring them into circular flows. Georgescu-Roegen warns, in this context, against exaggerated expectations of recycling. Not only does he point at the huge amounts of energy needed to extract useful materials from waste. He also points at the time needed: "Perhaps, we could recycle everything if and only if we could dispose not only of a limitless amount of energy but also of an infinite time" (Georgescu-Roegen 1986: …).

1.2.2 Steady-State Economics

Herman Daly, an economist known for his work (and his conflicts) at the World Bank in the 1970s and his publications on ecological economy, built on Georgescu-Roegen's ideas in his book *Steady State Economics* (Daly, 1977). He showed the inescapable physical and ecological realities that should be taken into account when designing and implementing strategies for 'sustainability'. His publications, to a considerable part, can be seen as an attempt to convince economists, especially those at key positions in organisations such as the World Bank, to take the physical conditions under which the economy works, already addressed at a high level of abstraction in Georgescu Roegen's work, seriously in their recommendations for practical policies and projects.

Daly describes the physical dimensions of the economy as "an open subsystem of our finite and closed ecosystem, which is both the supplier of its low-entropy raw materials and the recipients of its high-entropy wastes." (Daly 1986, ….). Daly basically repeats the inescapable truths brought forward earlier by Georgescu-Roegen: in physical terms the economic process, 'throughput', is inextricably linked to increasing entropy, to the depletion of natural resources and to waste generation (including pollution). A central topic in Daly's approach is the relative (physical) size of the economy relative to the physical world as a whole. He argues that as long as the economy was small in relation to the physical world, the interactions between the two could be denied: ample availability of resources and sufficient capacity to absorb waste streams and pollution. Economic science could disregard these interactions in their theories and models, which however is no longer the case in an economy that continuously growths in relative size.

In this vision, the only way to limit resource depletion and waste generation is to limit throughput, to reduce the size of the economic subsystem relative to the physical-ecological system. Daly translates 'sustainability' (see next chapter) into the economics of a steady state, in which the aggregate throughput is kept constant, at a 'sustainable' level. In his vision, this constant throughput may be used in different ways. Improving the value of this constant throughput, in Daly's terminology, is 'development', not 'growth'.

Daly's 'steady state' should not be confused with either a no-growth scenario or with an economy that no longer leads to resource depletion or waste generation. Depending on the way the constant throughput is used, the economy may grow or shrink in classical GNP terms, but for Daly GNP is not an appropriate measure for development. A constant throughput economy is certainly not an end to resource depletion and it continues to produce waste. Any other scenario will violate the Second Law of Thermodynamics. Economies that do not deplete or do not create waste are physically impossible.

Not unlike Georgescu-Roegen's publications, Daly's work can be seen as a systematic attempt to criticise economic theory and economists for being blind for the physical and ecological conditions that are the basis for the economic process. Three important elements of this criticism are:

1. Economic theory neglects the importance of the scale of the economic subsystem relative to the physical and ecological system as a whole. By doing so, the question of optimal allocation within a given scale of the economy is systematically confused with the question of optimal scale.
2. Economic theory does not distinguish between two entirely different classes of added value. It does not see the added value added by nature before a material enters into the economic system. It only sees the man-made added value. As a result, it does not recognise the impossibility to compensate the loss of natural added value by adding man-made added value. By denying this im-

possibility, it constructs endless circular processes of value creation in conflict with physical realities.

3. Related to the previous point, economic theory does not properly distinguish between natural capital and man-made capital. They can never be substitutes, as man-made capital always needs natural capital. You cannot substitute wood by saws.

In Daly's approach, it is important to keep the economy small enough to keep maintain nature's capacity to appropriately deal with the impacts of human activities. In other words, there is a need for maintaining a natural system, outside human control, that remains big enough to absorb the negative effects resulting from the human economy, including resource use and waste generation. As the natural system cannot grow, there are limits to the (physical) size of the economy. Daly's proposal is an economy of acceptable size that will not grow. Although Daly's idea of a 'steady-state economy' as a 'sustainable' solution is debatable (and has been subject to intensive debate), his contributions to laying a physical and ecological foundation under economic theory and practice are valid and will remain valid. They cannot be dismissed as subjective opinions or political statements. They are firmly based on physical realities as irrefutably formulated by the Laws of Thermodynamics.

1.2.3 It is not about Optimism versus Pessimism

The arguments put forward by Georgescu-Roegen, Daly and many others show the physical and ecological limits to economic activities and, as a result, the absolute limits to economic growth. Before such limits will be reached, there may be many more practical limits that may restrain economic activities much earlier. However, the physical limits are absolute and non-negotiable: the minimum energy needed to produce high quality iron from iron waste at the scrap yard is fixed. A very efficient process can approach that minimum. Other processes will use much more. That is where technological innovation comes in: increasing efficiency in the direction of the physically possible. Technological innovation will never be able to change such limits defined by nature. Unfortunately, in the discussion about economic growth and its (natural) limits, the distinction between limits set by nature and the limits set by technology have seldom been well separated. The result is a discussion between so-called 'technological optimists' and 'technological pessimists', as beautifully described in an article by Costanza (Costanza, 1989). Although there are many options to be more or less pessimistic about many uncertain factors such as mineral resource deposits or the efficiency of modern technologies, the assumption that there are physical limits to growth in a world with finite resources and with limited solar energy available has nothing to do with optimism or pessimism. This is what we know on the basis of indisputable science. Costanza, in the first article in Volume 1 of *Ecological Economics*, positions this new journal as follows:

> "*Ecological Economics* will encourage elaboration of these prudently pessimistic policies and issues, and compare them to alternative optimistic policies while trying to help reduce our uncertainty about the real state of the world vis a vis the ability of technology to circumvent fundamental resource and energy limits."

This is a beautiful sentence, but he seems to forget that technology will never circumvent really fundamental resource and energy limits, the physical limits.

1.3 THE ECONOMISTS: DEFENCE AND ABOVE ALL SILENCE

It is no surprise that the established economic discipline and the economists that were applying standard economic theory in their practical work in the public and private sector strongly opposed 'attacks' by relative outsiders such as Georgescu-Roegen and Daly. If they had taken the criticism brought forward by such authors seriously, it would not only have meant that some elements of their thinking needed revision. It had put the very foundations of their thinking on economic growth, optimal allocation and value creation at serious risk. As a consequence, this could have seriously undermined the practical value of their theories as a justification of policies and the concrete measures they included.

In this debate, 'Economic growth' became the central issue: is continued economic growth possible? Is it desirable or even necessary for solving problems of social and economic development? These questions were linked to discussions on the need of developed economies to grow to finance developments in other parts of the world. Other discussions related to the less developed countries' 'right to grow', also in terms of resources use. Changes in economic theory could easily have led to a situation that it could no longer be used to defend the positions taken by powerful players in the ongoing policy debate on these questions.

The economists who fiercely defended their positions apparently did not grasp the real content of what the critics said and wrote. The economists thought to hear a criticism of 'economic growth' as such, but closer scrutiny would have revealed that was not the message. The message was related, not to growth in the traditional economic sense, but to growth in the use of resources and growth in waste generation and pollution, in Daly's terminology, growth in throughput, especially relative to the carrying capacities of the environment. Daly's proposal of constant throughput, for example, did not necessarily imply less or zero economic growth, although it certainly put limits to realistic levels of economic growth.

That the economists were not ready to make the distinction between 'economic growth' and 'growth in throughput' could only be expected. In traditional economic theory, the physical world is absent. Through the 'spectacles' of a traditional economist, the problems as put forward by Georgescu-Roegen and Daly were invisible. Traditional economists could not see them. How could they understand what they did not see?

An amusing, if not depressing, anecdote on the realities in a large international institution, the World Bank, can be found in Daly's book *Beyond Growth* (Daly, 1996), where he describes the drafting of a manuscript with the title *Development and the Environment* in the early 1990s.

> "An early draft contained a diagram entitled 'The Relationship between the Economy and the Environment'. It consisted of a square labeled 'economy' with an arrow coming in labelled 'inputs' and an arrow going out labelled 'outputs' – nothing more. I suggested that the picture failed to show the environment, and that it would be good to have a large box containing the one depicted, to represent the environment. Then the relationship between the environment and the economy would be clear – specifically, that the economy is a subsystem of the environment and depends on the environment both as a source of raw material inputs and as a 'sink' for waste outputs. The next draft included the same diagram and text, but with an unlabeled box drawn around the economy like a picture frame. I commented that the larger box had to be labeled 'environment' or else it was merely decorative … … The next draft omitted the diagram altogether." (Daly 1996: 8)

As with the discussion that accompanied the *Limits to Growth Report*, discussed in the next session, there were hardly any systematic attempts at systematically criticising the publications that showed the links between the physical and the economic world on the basis of thermodynamic categories. The scarce reactions were defensive, justifying the continued use of standard economic theory without showing any more than superficial understanding for the issues raised by their critics who addressed the relationships between the physical and economic world.

Anyone with some basic knowledge of natural science understands that the limits posed by the Second Law of Thermodynamics are real and non-negotiable. The increase in entropy – i.e. the degradation of any material or form of energy from available to unavailable states – cannot be avoided. Technologies that claim otherwise are impossible. It is interesting to see that even prominent economists often do not recognise the absolute character of these physical limitations. A beautiful anecdote is given by Georgescu-Roegen.

> "Especially after the miraculous technological advances of the recent decades, our faith in technology … to go beyond or even to refute any known law became a general obsession. For a glaring example: I portrayed the working of the entropy law in an **isolated** system by an hourglass in which the stuff in the upper half stands for low entropy and by pouring down it degrades into high entropy (waste). To express the irrevocability of the process, I specified that, in contrast to the usual ones, the 'thermodynamic hourglass' cannot be turned over. Paul A. Samuelson, as he finally came to speak of entropy in the last edition authored by him alone of his celebrated textbook, **Economics** … asserted that 'Science can temporarily turn the [hour]glass over. … … Sir Arthur Eddington … advised that 'if your theory is found to be against the second law of thermodynamics … there is nothing for it but to collapse in deepest humiliation.' Albert Einstein also opined that thermodynamics 'is the only physical theory of universal content [that] will never be overthrown'. That is, heat will never pass by itself from the colder condenser to the hotter boiler." (Georgescu-Roegen 1986: 14)

The situation has not much changed between the early 1970s and today. The thermodynamic arguments brought forward by various authors at the time cannot be dismissed to be merely opinions, as also underlined in the above quote. They are irrefutable facts grounded in universally valid theories. Nonetheless, these facts are still being denied by economists and practitioners that base their actions on standard economic theory. [1]

The problem is not so much a conflict between economists and their critics. The problem was and is that the economists who are being criticised are keeping silent, without presenting any valid counter-argument. The discussion landscape today is a bit different from the situation in the 1970 or 1990s. Today the problem is not in the first place the defence of unrealistic economic theory against physical and ecological realities. The problem now looks even more serious: in the name of ecological improvement, concepts that not only violate basic laws of physics, but are completely unrealistic from an implementation perspective as well, such as 'circular economy' have become part and parcel of policies at the highest level and define national and international research and development agendas. This will be shown in Chapter 4.

[1] The situation is not very different today as when Daly may wrote in 1996 about the reactions to Georgescu's work: ""His challenge has not been met with reasoned refutation, but rather with silence" (Daly 1996, p. 192)

2. COMPUTER MODELS THAT SHOW LIMITS TO GROWTH:

2.1 THE LIMITS TO GROWTH REPORT

The Club of Rome was founded in 1968 as a global think tank with the mission "to act as a global catalyst for change through the identification and analysis of the crucial problems facing humanity and the communication of such problems to the most important public and private decision makers as well as to the general public". Its basic philosophy and working areas were defined in the 1970 report *The Predicament of Mankind – Quest for Structured Responses to Growing World-wide Complexities and Uncertainties* (Club of Rome, 1970). Despite its very abstract and general character, this document already shows the contours of an emerging agenda. The interesting list of so-called "continuous critical problems" on page 14 contains almost any macro-problem with potential global significance, including issues like population growth, environmental deterioration, pollution, resource investment alongside with all sorts of social, economic and political issues. The document describes the Club of Rome's objectives to work on what is called "today's problematique throughout the world". Objectives 1, 2 and 3 were formulated as follows:

1) To examine, as systematically as possible, the nature and configuration of the profound imbalances that define today's problematique throughout the world, and to attempt to determine the dynamics of the interactions which seemingly exacerbate the situation as a whole.
2) To develop an initial, coarse-grain, "model" or models of this dynamic situation in the expectation that such models will reveal both those systemic components that are most critical and those interactions that are most generally dangerous for the future.
3) To construct a "normative" overview from the foregoing models and to clarify the action implications --i.e., the political, social, economic, technological, institutional, etc., consequences --that such an overview might entail and substantiate.

The modelling work performed by Donella H. Meadows, Dennis Meadows, Jørgen Randers and William W. Behrens III for the Club of Rome, funded by the Volkswagen Foundation, can be seen as a first concrete attempt at putting those abstract objectives in practice. The objectives show a strong belief in the power of 'models' that describe complex and dynamic interaction. That is exactly what the Word-3 model tried to do: show five global variables and their mutual interaction. The report *Limits to Growth*, presenting the outcomes of the World-3 simulations was an unprecedented success: more than 30 million copies were sold in more than 30 translations. The use of (then) advanced computer modelling was a novelty and certainly contributed to the image of authority it had in circles of policy makers and the general public.

2.2 CLAIMS, ASSUMPTIONS AND OUTCOMES

The World-3 model was meant to model the interactions and the feedback loops between different variables. It used the so-called system dynamics modelling technique, originally developed by Jay Forrester at MIT in the late 1950s. System dynamics can be used to study the non-linear behaviour of complex systems. It basic elements are 'stocks' and 'flows' with may be connected by information links and time delays. The behaviour of complex systems may be counterintuitive in the sense that it is different from what one would expect at first sight. System dynamics was originally developed for technical applications and gradually applied in very different fields such as urban planning. By using system dynamics, the MIT made the World-3 model one of the best known examples of using this methodology, although being used in a context for which system dynamics was not primarily developed.

The World-3 model calculations were meant to present indications of the system's behavioural tendencies, not to present predictions or forecasts. The model examined the behaviour of five global variables: world population, industrialisation, pollution, food production and resource depletion. According to Turner (2008) the behaviour of the model can be understood to result from four key elements:

1. The existence of feedback loops, positive and negative, resulting in balanced steady-state results, exponential growth or oscillations;
2. The presence of resources, such as agricultural land, whose functions may be eroded or recovered depending on certain thresholds;
3. Delays in the signals from one part of the world system to another;
4. Treating the world economic system as a complete system of subsystems.

For details on the assumption made in the model, the reader is referred to the original publications. Here the results of the different scenario calculations are summarised.

1. The so-called 'standard run'
   This is a scenario where the trends for the period 1900-1970 continue in a 'business-as-usual' way. It shows continuing economic growth throughout the 20th century, continuing into the first decades of the 21st century. The scenario then shows an 'overshoot and collapse' of the global system halfway the 21st century as a direct consequence of natural resource scarcity and environmental pollution.
2. 'Comprehensive technology'
   By applying a package of technological solutions, the collapse of the global system can be postponed to later in the 21st century, but not prevented.
3. 'Stabilized world'
   Technological and social policies aim at reaching a state of equilibrium. "Examples of actions implemented in the World3 model include: perfect birth control and desired family size of two children; preference for consumption of services and health facilities and less toward material goods; pollution control technology; maintenance of agricultural land through diversion of capital from industrial use; and increased lifetime of industrial capital." (Turner 2008, p. 12).

The model calculations suggest that, unless measures are taken consistent with the measures proposed for the 'stabilized world' scenario, an 'overshoot and collapse' scenario cannot be avoided.

2.3 POSITIVE RESONANCE AND STRONG CRITICISM

In the socio-political climate of the early 1970s, the Club of Rome report had an enormous impact on public opinion. There was strong public support for its main message: action is needed to prevent that shortage of resources and uncontrolled pollution make the global economic system collapse.

But from the first day of its publication, there was strong criticism as well, criticisms on the assumptions behind the model and the data used, some of which were already addressed in the 'Commentary' added to the Report by the Club of Rome's Executive Committee (Club of Rome, 1972, p. 185-197.

1. The prediction of the 'overshoot and collapse' scenario, as a direct consequence of the methodology used.
2. The highly aggregated and simplified character of the model
3. The neglect of technological and scientific progress, especially lack of optimism on the availability of better pollution control
4. Lack of optimism on new resource deposits
5. The assumption that economic growth should be actively reduced: economic growth would rather be needed to create solutions.

Although the model builders and the Club of Rome representatives had to admit that there was some truth in a number of criticisms, they could, by presenting simple sensitivity analysis, easily show that changing the assumptions used in the model, in most cases, only led to relatively minor changes in the timing of critical events. It did not lead to scenarios in which such events could be avoided altogether. Even with considerable larger natural resource and energy deposits, relatively rapid depletion could not be avoided with ongoing growth in population and consumption, for example.

Whereas the Club of Rome could relatively easily defend itself against criticism on the assumptions made, for example on resource availability of pollution control (the above points 2, 3 and 4), it actually did not have convincing answers to the questions on methodological aspects (the above points 1 and 2). In its 'Commentary', the Executive Committee recognised the limitations of a highly aggregated model with a limited number of parameters. However, in their opinion, this would not make the exercise useless:

> "… it was generally recognized that, with a simple world model, it is possible to examine the effect of a change in basic assumptions or to simulate the effect of a change in policy to see how such changes influence the behaviour of the system over time" (Club of Rome, 1972: 186-187).

This answer is not convincing as it does not address the question whether the model is a satisfactory description of the real world. Are the situations of 'overshoot and collapse' a model artefact or something that we may expect in the real world. There was no answer to that question.

2.4 THE MODEL AND REALITY

At the time the Limits to Growth study was published, one could 'believe' in the results, on the basis of the plausibility of the assumptions and the suitability of the methodologies used, or one could dismiss it on the basis of faulty assumption or inappropriate methodologies. Among the educated public at least, there were many believers.

Today, more than 40 years after the calculations were made, the situation is different. In the present socio-political context, 'doomsday prophesies' generally do not have any chance to resonate in public discussions. Moreover, there is a persistent belief that the Club of Rome's 'predictions' have failed. The disaster they would have 'predicted' to take place in the 20th century has not become reality. This perception is based on two faulty assumptions.

1. The Limits to Growth study would have predicted a collapse before the end of the 20th century.
2. It is assumed that real developments are very different from, and much less problematic than, the scenarios described by the World-3 model.

The first assumption is based on two points of misunderstanding. Not only is it wrong to assume that the model calculations were meant to be 'predictions'. They were meant to gain insight in potential systems behaviour. Also the calculated collapse dates are reaching far into the 21st century. None of the scenarios had 'predicted' any major disaster in the 20th century.

The second assumption is based on even more serious misunderstandings. A study, published in 2008, has compared real developments after the Limits to Growth study with the scenarios presented in 1972. The study shows a surprisingly good match between the 'standard run' scenario and real developments. Of course, such a comparison is no scientific proof that the model was 'right', but it certainly disqualifies statements that real developments turned out to be very different from what the Limits to Growth study had originally suggested.

Data available on the developments between 1972 and 2015 could actually be used to support the statement that the scenario developing in reality is far more serious than what could be foreseen in 1972. There are good reasons to fear that the world today is already dangerously approaching a point of 'overshoot and collapse', a point that could not be predicted in any detail by the five-variables-model: CO_2 emission, global warming and the collapse of relevant systems in the economy. It is generally known that an increase of more than 2 ˚C can cause irreversible climate change and that we are running towards a scenario of far more than 2 ˚C global warming. The rather primitive World-3 model only contained the unspecific global variable 'pollution' and could therefore not yet include the specific threats of CO_2 emissions that we know today. If we built a World model today, we would not only add climate as separate factor, we would most probably include 'biodiversity' more explicitly. We know that there is a global biodiversity crisis today, not a threat of something happening in the distant future, but a systemic crisis developing now.

In this context, it is alarming to see that there is a dominant perception that the 'doomsday prophesies' presented by the Club of Rome many years ago, similar to the hysteria about 'acid rain' and 'dying forests' ('Waldsterben'), should be seen as a typical expression of the 'Zeitgeist' of the time, were based on wrong assumptions and wrong methodologies, and have not materialised in the real world. Evidently, they were based on many assumptions that were not completely right and partly totally wrong. Today one would certainly not use the same methodologies and modelling techniques. However, the global problems related to resources and pollution (including climate change and biodiversity loss) are certainly not less serious today than those addressed by the Club of Rome in 1972 on the basis of their primitive computer calculations. They may even be far more serious.

3. DENYING REALITY - AVOIDING THE QUESTION

Two very different approaches that forced economists, policy makers and the general public to question the blessings and curses of economic growth – or more precisely growth in the economy's throughput – were highlighted to show the roots of a debate that took off in the early 1970 and that, more than forty years later, has not come to a conclusion. The first approach criticised standard economic theory for their complete disregard of the physical and ecological world. The authors representing that approach could, on the basis of common-sense thermodynamic realities, point at the fundamental differences between natural and man-made capital, the illusions of endless energy and material loops and the resulting natural limits to expanding the physical size of the economy relative to the environment. The second approach used relatively simple computer models to show the feed-back loops between different parts of different sub-system of the global economy, explicitly taking the limitations of resource availability and the negative influences of pollution into account.

The messages conveyed by the two approaches remain valid today. The arguments on the basis of thermodynamic realities have not been and cannot be refuted. They are not opinions, but unavoidable realities. In contrast, there are good reasons to criticise the Limits to Growth study and the World-3 model on which it was based for the quality of its data and the methodology used. Nevertheless, the Club of Rome's main messages at the time cannot be disqualified by pointing at developments in the real world. These developments are not less alarming than what the Club of Rome 'predicted'. There are good reasons to be even more alarmed.

One could naively assume that, as a result of the continued validity of the recommendations made by representatives of the two approaches highlighted here, these recommendations would have been taken seriously. This is not the case. The fundamental criticism of economics has not led to any demonstrable change in mainstream economic theory and the way economists look at limitations posed by the environment on economic growth. As was mentioned earlier in this chapter, the arguments put forward by the critics were not (and could not be) dismissed on the basis of scientific arguments. The economic discipline just kept silent.

It is not much different with the message from the Limits to Growth study. As was shown above, real developments today are certainly not much better than what Limits to Growth assumed on the basis of its baseline scenario. However, we see a massive denial of the supporting evidence. The popular story today, not supported by any counter-evidence is that the 'doomsday prophesies' were overly pessimistic and factually wrong.

How can we understand this discrepancy between evidence available and dominant perceptions? Of course, it is naïve to believe that it is sufficient for arguments to be true to become acceptable. Why should the economic discipline accept criticism from outside its own world, thereby eroding its own authority? Why would a World Bank accept insights that could undermine their position in debates about economic growth and development?

Many dominant players had, and still have, good reasons to avoid discussions on the validity of the theories that continue to justify their policies and actions. In the debate about 'Limits to Growth' a persistent pattern can be seen. To avoid debates on answers to the question such as "Is there a need to limit growth now or in the future?" and "What instruments can be used to limit growth", it appears to be a better strategy to dismiss the question as being irrelevant or to change the question so that it becomes less threatening.

Especially in early attempts at criticising or even ridiculing the 'Limits to Growth' report, there were attempts to stress the overwhelming weaknesses in data and methodology, and thereby not only dismiss the study outcomes but the underlying questions as well. It is a common rhetoric trick: to attack the answers to get the question from the table. In that sense, the undeniable weaknesses of the 'Limits to Growth' study may have provided ample ammunition to fight the underlying question: "Will there be limits to growth, considering the finite character of resources and the finite carrying capacity of the earth to absorb waste and pollution?"

Dismissing the question by ridiculing the answer is one strategy. A second strategy, which can be very effective and that was extensively used in the 'Limits to Growth' and 'sustainability' discussion, is to change the question to a more comfortable question. This is what we see in moving away from the strict physical and ecological barriers to growth to the 'sustainability' concept, originally designed to explicitly address, apart from the ecological aspect, the development aspect, which then developed in the concept based on three pillars: ecological, social and economic or, in more popular terms: planet, people and profit. In the next chapter, it will be shown how this move not only took the sting out of the unpleasant 'Limits to Growth' question, but did this at the risk of obscuring rather than addressing the real problems in the relation between economy and ecology.

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