# The Political Economy of Technoscience

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> *It would seem that the divine hand, both in its treatment of every human being and in its most grandiose workings, is bent on reminding us that the law of equilibrium is the fundamental law of the universe, for it rules everything that happens, all the plants that grow, every creature that breathes.*
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> (Marquis de Sade 1800, 239)

## INTRODUCTION: ON CONSERVATION AND INNOVATION

The following reflections explore the political economies of science and technoscience, philosophically conceived. Accordingly, the intent is not to simply situate scientific activity within the political economy of a society.[1] Instead, we are referring to the management of matter and energy, space and place and the housekeeping principles of researchers when they, literally, account for physical processes. We propose to observe how researchers manage matter or energy and how they negotiate space, surface area, and place, either by accommodating themselves to limits or constraints or by seeking to overcome such limits. This investigation brings to light the underlying assumption in much contemporary research practice of an unlimited technoscientific world of abundance and excess that challenges received certitudes of a limited world that rests firmly and solidly on physical conservation laws and a conception of space as a radically limited resource.

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[1] This is how this term has been used before in Mirowski and Sent 2001, in Mirowski 2004, as well as in Rose and Rose 1976. These authors offered a critique of a pure science that is interested only in truth and trades only in recognition of contributions towards the achievement of truth. Another common approach is to investigate the role of science and technology in economic growth, the relations between science, technology, the state, and capital, and science and development (for instance in Woods 2007; or also in Martin and Nightingale 2000).

In the context of a political economy of society this juxtaposition is far from being new: already in the first half of the twentieth century philosophers and sociologists like Werner Sombart and Georges Bataille contrasted two political economies around the notions of a limited world defined by conservation and an unlimited world that is defined by luxury, excess, abundance. In doing so, Sombart and Bataille both recognized the central role of science and technology in modern economies. Indeed, Bataille goes as far as substantiating his economic conception by referring to scientific models, most importantly the concept of biosphere: "The terrestrial sphere (to be exact, the biosphere*), which corresponds to the space available to life, is the only real limit" (Bataille 1991, 29).[2] Because Earth is exposed to a permanent input of solar radiation, there is always an excess of energy. As long as living organisms grow and proliferate and solar energy is properly absorbed, excess is minimal. However, this situation changes once the limit of growth is achieved: "…life […] enters into effervescence: Without exploding, its extreme exuberance pours out in a movement always bordering on explosion" (Bataille 1991, 30).[3] In a fully realized biosphere "… there is generally no growth but only a luxurious squandering of energy in every form" (Bataille 1991, 33). While humanity has successfully extended the limits to growth by investing in labor and technology, it also has immense power "to consume the excess of energy intensely and luxuriously" (Bataille1991, 64). These are the assumptions, which Bataille develops further when he regards the role of wealth and excess. In his so-called general economy the "limit to growth" opens a world of excess, which is an unavoidable aspect of all production and all transformations of matter. In contrast, a restricted or special economy takes "limits to growth" as a challenge to live productively within one's means and to gain surplus value from processing and reprocessing finite resources. But though he drew on scientific ideas to establish his conception of general economics, and though he distinguished the scientific, restricted economy of the economists from his avowedly non-scientific general economy, Bataille did not explicitly articulate a contrast between different ways of conceiving and exploring the world, between a general and a restricted political economy of science.

In the following we expand Bataille's conceptualization to develop a notion of a political economy of science. We then use this philosophical notion to contrast science and technoscience along the lines of Bataille's distinction between a restricted economics and a general economics. We identify the first with sciences that are constituted by conservation laws and therefore implicitly

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[2] Bataille uses references sparingly, but here ("*"), Bataille refers directly to the author who first conceptualized the term: "*See Vernadsky 1929, where some of the considerations that follow are outlined (from a different viewpoint)."

[3] Translation modified by A.S./A.N.

committed to an idea of limits to growth. In contrast, general economy can be identified with the technosciences that appear to adopt a principle of non-conservation, innovation, or infinite renewal - as exemplified, for instance, by the ambition to expand resources like “space” or “matter”.[4] We first observe an acknowledgment of limits that appears constitutive in 18th to 20th century conceptions of science, and in current attempts to exceed those limits. The classical conceptions of a conservative science appear across the disciplines in physics, chemistry, or ecology. Likewise the tendencies to exceed those limits characterize nano- as well as ecotechnologies.[5] The transition for physics, chemistry and ecology to nano- and ecotechnologies makes especially clear why we speak here of a political rather than moral or cognitive economy of the sciences and technosciences. Where one might first suspect that nanotechnologies and ecotechnologies are motivated by very different concerns, they prove to have in common to defy the notion of a limited world. This commonality lies in their treatment of space and matter, which can be adequately described in terms a political economy. What makes this a political, rather than a moral or cognitive economy[6] is the choice between adaptation to limits and a conquest of limits. This is eminently political when there is a promise of “green technologies”, when sustainability is offered as a substitute to conservation, when there is a search for inherently benign technologies that are safe by design, and when technosciences share the idea of enhancing material nature, be it by using nanotechnology to turn dead matter into smart material, be it through ecotechnological design of nature for instance in restoration biology or industrial ecology.[7]

By contrasting eco- and nanotechnological research programs with the house-keeping activities of traditionally constituted scientific disciplines, we therefore do not dwell on their obvious differences but highlight the political significance of different research practices regarding the management of matter or energy and space. These practices are not neutral. On the level of the norms of representation and ideals of production that govern scientific and technoscientific research they condition political choices. With respect to the restoration of nature or to global warming this

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[4] In ongoing debates about the limits of global resources, scientists have identified a “new scarcity“ in resource use. They focus especially on “the big three“ that are land use change (from cropland to industrial/urban land), emission of greenhouse gases, and extraction of materials (Bringezu 2009). These “big three“ are presented as a technological challenge rather than as a requirement to adapt.

[5] Here we focus on the latter. Ecotechnologies are disciplines like industrial ecology or restoration ecology and other research fields dealing with the modeling and management of resources. As to nanotechnologies see Nordmann 2010.

[6] On the notion of a moral economy of science see Daston 1995. Ernst Mach argued that concepts serve to economize the multiplicity of sensations (Mach 1959).

[7] The choice between adaption to and conquest of limits is politically salient especially in current debates about the proper response to global warming where adaptionist proposals are countered by the hope that new technologies (including geoengineering) can sustain further economic growth.

includes the choice between mitigation or adaptation and expansion of capacity through geo-engineering.[8]

## PRINCIPLES FOR ECONOMIC AND SCIENTIFIC KNOWLEDGE

Since there does not appear to be anywhere a scientific dispute about the validity or, indeed, necessity of conservation principles, it sounds strange, at first, that there should be a difference between the conservative sciences and non-conservative technosciences with their pursuit of innovation or infinite renewal.

Though conservation principles are as old as science itself, Antoine Lavoisier's formulation of the conservation of matter holds special place because it provides an obvious case of scientific reason acting as a law-giver to nature:[9] "in all the operations of art and nature, nothing is created; [...] the quality and quantity of the elements remain precisely the same and nothing takes place beyond changes and modifications in the combination of these elements" (Lavoisier 1952, 41). Lavoisier continues by pointing out that this principle usefully serves as a standard for chemical experimentation and hypothesis-formation: Every experiment must submit to the housekeeping authority of the scale that demands a complete account of the entire quantity of matter before and after the experiment. Only such experiments are admitted and only such hypotheses, that meet this demand (Bensaude-Vincent 1992).

This reliance of scientific knowledge on conservation principles was challenged by Georges Bataille. As noted above, the economists' restricted or special economy provides an account of supply and demand in a closed world: Just like the Lavoisian chemist, economic theorists represent the world by way of accountancy: Restricted or special economics from Adam Smith to Karl Marx to John Maynard Keynes considers how wealth becomes concentrated and distributed, it looks at the circulation of goods and currencies, at the balancing of cost and price, of demand and supply. The creation of wealth and even of "surplus value" is accounted for in terms of extraction of material and human resources. In contrast, Bataille's general and unrestricted economics celebrates

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[8] We are not claiming that a scientist who works within the narrow confines of conservation laws is thereby committed to the conservation of natural resources. We are claiming instead – though we cannot substantiate it here – that the conduct and principles of the sciences and technosciences condition deliberations about the resources and capacities of planet Earth.

[9] The implicit reference to Kant is meant to underscore that conservation principles create conditions for the possibility of representation; we therefore refer to them also as norms of representation. This is not the place to provide a systematic account of how these principles are constitutive of science – where science is taken to aim for theoretical representations of features of the world. For present purposes it is enough if there central, often unquestioned status is acknowledged.

excess and waste and interprets them as gifts of the sun. [10] This creative aspect of excess and waste appears in the thought of economist Joseph Schumpeter who explicitly refers to Sombart (and Nietzsche) when he proposes that “creative destruction” is a basic economic process. But Bataille did not simply propose a different theory but a different and explicitly non-scientific form of knowledge-production. Since he understood the role and function of restrictive conservation principles as conditions for scientific knowledge, he points out that with restricted and general economics also come two kinds of knowledge. The scientific knowledge of special economics is born from an anxious concern for particular facts and is characterized somewhat stereotypically by coldness and calculation as everything needs to be accounted for. According to Bataille, it “merely generalizes isolated situations” and “does not take into consideration a play of energy that is not limited by any particular end”, and it thus does not consider “the play of living matter in general, involved in the movement of light of which it is the result” (Bataille 1991, 22f.).[11] This play of energy is excessive in that it exceeds the accountants’ balance and produces a surplus. It is therefore not the subject of conventional scientific knowledge and Bataille hints accordingly that he wants to add to the wealth of knowledge even as he must fail at being scientific (Bataille 1991, 10f.): A general economics that takes as its model the sun’s gift of energy to the earth does not account for the creation of wealth or of knowledge as a mere redistribution or re-presentation of available resources but views all wealth-production, including that of knowledge, as a sign of abundance, excess, and general surplus – as something that must be squandered and cannot be earned. Thus, when Bataille pursues his general economics he follows the movement of energy from geophysics through biology into society not in terms of income and matching expenditure but in terms of excess and destruction. On Bataille’s terms then, scientific knowledge like that of Lavoisier depends on the counterfactual construction of special and limited principles of conservation within the more general movement of unlimited energy: Within the thermodynamically open system “Earth”, chemical laboratories are established as closed systems for the sake of the scientific presentation and representation of isolated facts. Since the excessive movement of a general economy of nature and society tends to undermine the creation of isolated closed systems and thereby human interests in intellectual mastery and technical control, the special sciences satisfy those interests for better or worse.

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[10] These characterizations do not do justice to the current state of economics as a science and technoscience. Bataille’s caricature of restricted economics agrees with classical economics, especially in so far as it aims to become properly scientific by producing general testable models of economic exchange (indeed, the very notion of exchange – as opposed to that of the gift – is based on conservation rather than excess).

[11] Again, we slightly altered the wording of the translation.

It is now possible to see in which sense Bataille's general economy is "non-conservative", namely in the sense in which there are non-Euclidean geometries that include Euclidean geometry as a special case, or in the sense in which Gaston Bachelard speaks of non-Lavoisian chemistry (Bachelard 1968): Special economics appears as a limited case of a general economics that focuses on the way in which a special economy is constructed, just like non-Lavoisian chemistry follows the material processes of purification and experimental isolation that yield the kinds of substances and representations which then allow us to see nothing but recombinations of elements (Bensaude-Vincent 1992, Holmes 1989). From the point of view of general economics or non-Lavoisian chemistry, conservation principles ensure a constancy of nature as a necessary prerequisite to allow for scientific inference and representation. With this conception of conservation principles in mind, one will start seeing them in all efforts to scientifically represent the features and causal processes of the world: Ex nihilo nihil and natura non fecit saltus have dignified Latin names, telling us that nothing can come from nothing and that nature makes no leaps. So, aside from conservation of mass or energy, of charge or angular momentum, there is uniformitarianism or actualism, there is Newton's first law or axiom of motion, there is the principle of sufficient reason, and there are the so-called inductive principles which posit that the future will be like the past or that nature does not change. All of these speak of the world as a limited whole in which nothing is created and where all change is a redistribution of what is already available. All of these notions are introduced as prerequisites for scientific representation; they are representational norms that structure a domain of phenomena such that objective knowledge about it becomes possible.[12]

The technosciences surrender this supposition of a limited and balanced world – they acknowledge limits only to discover a world of excess and technical possibility within and beyond them. However, if technoscience is to science somewhat as Bataille's unrestricted economics of excess is to a special economics of limits, this does not amount to a scientific revolution or paradigm shift in science where the new paradigm is non-conservative. If the argument so far is correct, there can be no such thing as a Kuhnian paradigm that is not constituted by one conservation principle or another. For the same reason, this shift does not involve a dispute about the standing of conservation laws: By definition, these are pretty much beyond dispute. Whenever technoscientists turn to the business of representation or explanation, they will be careful not to violate the conservation principles that serve as the representational norms in their community. The claim that technosciences are non-conservative does not refer to agreements or disagreements about

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[12] See note 9 above.

principles but about the idea of novelty, creativity, perhaps transcendence that is implied in the making and building of things, in the acquisition of capabilities for the control of phenomena, in shaping or disclosing a new world. Instead of a paradigm shift, technoscience stands for an embrace of the technological or constructive character of science – and Lavoisier's principle that nothing is created in art and nature has always perhaps meant one thing for a science of nature which is enabled by its housekeeping practices and something quite different for art or technology that see this principle as a constraint and challenge to probe or even transgress the implied limit to creativity and novelty.

So, while there are various ways in which the technosciences are dedicated to a transgression of limits, we here pursue just one of these ways, namely the pleasureful transgression of a limited or restricted economy of science that assumes finite resources, towards an unlimited or general economy that celebrates the production and consumption of excess.

## THE BLUE PLANET – AN AMBIVALENT ICON

The very first photographs of the planet Earth were produced in 1968 during the Apollo 8 mission. These photographs quickly became icons for our notion of Earth as a limited whole, our blue planet as a jewel in the skies, of astounding beauty and vulnerability, a precious object of care. The rather small spaceship Apollo 8, a carefully crafted ecological cabin in its own right, here encountered spaceship Earth with its precious cargo and limited carrying capacity. This icon assumed a powerful role in the environmental movement and still figures prominently in a discourse of limits - limited resources and limits to growth, limits of space for exploding populations and limits of stability of fragile systems.[13] And yet, this image signifies not only the planet as a self-contained system and bounded space but also as a cipher of exuberance and boundless possibility.

A first indication of this ambivalence is the simple fact that this first photographic representation of the whole planet depended on space travel, and space travel may well be a paradigmatic technoscientific research activity. It encompasses travel into outer space along with travel into biospheres, nanospace or cyberspace where the latter includes the spatial reorganization of our workplaces, recreational spaces or homes through ambient web or ubiquitous computing technologies. All these are highly knowledge-intensive research activities but they do not advance claims to truth or to represent some constant feature of the world. Instead these research activities produce knowledge of basic capabilities of visualization, manipulation, and control. These

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[13] For a comprehensive history of "spaceship earth" as an icon of the environmental age, see Höhler forthcoming.

knowledge claims consist in statements of the sort: look what we have done, where we have gone, how we visualized or modeled something, or what we built. Instead of representing within the limited framework of a zero-sum game and instead of merely transforming some configuration of matter and energy into another (Latour 1990),[14] this research comes with the promise of genuine novelty, potentiality, and transcendence - if we can do this, then maybe we could also do this, and if we succeed, there will be more than there was before and maybe enough even for everyone to share and to create a win-win situation that knows no risks and no losers. Such promises attend any kind of space travel since it is supposed to disclose new opportunities and to make room for everyone. The first visual encounter, then, with the blue planet as a limited whole took place during a technological endeavor to surpass this limited whole.

## WHAT DOES EARTH DO WITH THE ENERGY IT RECEIVES?

As we explore this ambivalence, it is worth noting that the startling radiance of planet earth came to the fore within a discourse on limits long before the environmental movement and that the encounter with the blue planet did not require the photographic opportunities that came with the Apollo mission. In 1885, physicist Heinrich Hertz delivered his inaugural lecture at Karlsruhe university where he asked the question "what […] does the Earth do with the energy it receives" from the sun?

> First, some of it is reflected back as light of unchanged form. One may doubt whether this part should really be considered as part of the energy resources of the Earth. But since our understanding of the totalbalancing process, which is similar to a budget, represents no more than a general picture, we can therefore say that this reflected energy must be considered part of the energy income utilized by the earth for illumination. This energy enables the Earth to circle the Sun not as a dark, invisible mass, but to stand out as a bright star among the other planets; from them Earth can be observed just as well as the other planets are visible from Earth. It represents, so to speak, the astronomical upkeep allowance of the Earth. […] Since this is a large amount, we may conclude for this reason that the illumination of the Earth is a brilliant one. (Hertz 1997, 40)

Heinrich Hertz is here considering a "total balancing process" which balances income against expenditure. As a physicist he is openly engaged in economic thinking and acknowledges this by likening his work to drawing up a budget. Indeed, the German title of the lecture refers to the "Energiehaushalt der Erde" which refers to the housekeeping that lies at the root of the very notion

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[14] When Latour points out that science is no zero-sum game, he does so to dissolve the conceit that science serves to represent a given world. According to Latour, all science turns out to be technoscience precisely in that humans and nature come together in the laboratory to create something new.

of “economy” and which makes evident that the “energy balance of the earth” results from a balancing of books and the equality of total income and total expenditure. As if to make sure that this is understood to be far more than a metaphor, Hertz follows the logic of budgeting to account for that part of the income of the sun that is reflected by the Earth’s atmosphere and he refers to this as the cost of illuminating the Earth in a particularly brilliant way. The English translation speaks here of an “upkeep allowance” which does not quite capture that Hertz alludes to an excessive expenditure that reflects and represents the enormous wealth of the Earth – the German expression for this expenditure is “Repräsentationskosten der Erde” that is an “upkeep allowance” for a royal court which powerfully represents itself by way of luxury and conspicuous waste.

Significantly, Hertz does not leave the framework of strict accountancy even as he exhibits an abundant wastefulness where the Earth writes off a third of its energy supply in order to keep up a good appearance. Indeed, Hertz expresses here only more clearly a political economy that manages matter and energy strictly in terms of conservation – in a limited world with limited resources nothing is created and nothing destroyed but everything becomes redistributed such that income and expenditure even out. Life within his world is a zero-sum game that revolves around trade-offs, benefits at a cost, winning at the expense of the losers. This is the general picture that Hertz is talking about and which forces him to account even for frivolous expenditures. However, though Hertz is forced by his bookkeeping method to account for all the energy and matter in the system under consideration, it is he who determined the boundaries of that system – he is looking neither at the earth, nor at the solar system, and he is also not drawing a box around the sun and the earth, but instead accounts for that part of the sun’s energy that is “intended for the earth” as well as all the energy that is already stored up in the earth (Hertz 1997, 41; see Kind 2005, Pelkowski 2008).

Quite in agreement with Wise and Smith’s work on energy and empire (Wise and Smith 1989), Hertz acknowledges that his housekeeping principles derive from considerations of the steam-engine as a technical system. Indeed, he refers to the steam-engine many times and likens the entire atmosphere, the whole earth, but also the sun to giant steam-engines (Hertz 1997, 41f., 43). One decisive characteristic of a steam-engine is that it is more or less efficient but that there is always a loss in the conversion of heat into work. Accordingly, he finds for the energy balance of the earth as a whole, for any specific machine, for a biological organism or a human life that incoming energy is converted into useful work but that energy will dissipate and become useless without getting lost over the course of this and further transformations. So even aside from the energy used to illuminate the earth, actual conversion processes always begin and end with luxury and waste: They begin with the largesse of the sun that generously squanders so much of its energy and ends with the dissipation of now-useless energy. But along the way the conversion of energy keeps the earth going and our steam-engines running, and as one moves between these scales, one becomes aware of the “insignificance of men in this economy” (Hertz 1997, 44).

Even as he considers technical systems, Hertz’ political economy and impersonal system of housekeeping is orientated to the epistemic demands of science, or, more particularly to practices of representation. That Hertz himself was quite aware of these demands is testified throughout the work of this philosophically astute physicist who had reflected in an earlier lecture-series on the constitution of matter and the status of conservation principles like that of the conservation of mass (Hertz 1999). In this book, Lavoisier appears as the founding father of modern science. Like Lavoisier, Hertz recognizes conservation principles as constitutive of scientific practice. He would have agreed with Larry Holmes and Bernadette Bensaude-Vincent who showed that Lavoisier structured the modern chemical laboratory through his proposals to institutionalize the conservation of mass in his apparatus and the associated employment of the scale: Lavoisier founded a political economy which establishes a specific manner of book keeping, of evaluating the exchange of matter. Accordingly, Heinrich Hertz pursued the question whether this conservation law is a law of nature that is true for all things at all times, or whether it is an a priori principle or representational device that underwrites practice and must not be abandoned even where it would appear that there has been an increase or loss of total mass (Hertz 1999, 115-116). Without it, at any rate, a certain kind of scientific knowledge would not be possible.

Following Hertz, this conservative picture of the world as a precondition of scientific knowledge was epitomized in Ludwig Wittgenstein’s Tractatus logico-philosophicus and it figures centrally in Emile Meyerson’s Identity and Reality (Wittgenstein 1922, Meyerson 1962). Though none of these scientists and philosophers were motivated by a concern for nature conservation or the fragility of ecosystems, it is easy to see that their way of thinking about limits that are constitutive of nature as an object of science gives rise to the injunction to live within our means and to accommodate ourselves to limited resources. Technology, on this account, is above all an ingenious ways to achieve more with limited means, and science might discover, to quote Hertz again, “roundabout ways, in which we can so direct the general flow of energy that [our machines] correspond to our established goals” (Hertz 1997, 39).

## FROM »OBEDIENCE« TO »TRANSGRESSION«

On the account presented so far, controlling and managing the flow of energy and matter is a concern that is virtually at the center of science and technology in the modern world. For the scientific enterprise, the conservation principles ensure the constancy of nature and thus enable scientific inference and representation. And it is assumed that only this constancy and lawfulness of nature underwrites the technological enterprise. This conception of technology as applied science implies that technological ambitions and experimental creativity will always be constrained by a scientific world-view. The prohibition of a perpetual motion machine is only the most evident example of this. Lavoisier's verdict about the limits on art and engineering and his view of experimentation emphasize that the scientist must literally surrender to the verdict of the experiment. Nature is invited into the laboratory as a witness who provides answers to our questions. Scientists, artists, engineers thus learn from nature not how to do or build things but which of their ideas are in accord with it.

But the supposed impossibility to create genuine novelty also produced ambivalence which found expression in formulations like these: "The victory over nature can only be achieved by way of obedience towards it" (Cassirer 1985, 60): If nature can be used for scientific and technological purposes precisely because of its lawfulness, do we therefore have to surrender to the world as it is or can we still overcome nature and liberate ourselves from our natural condition – just as the conquest of outer space was seen as an attempt to leave our earth-bound existence behind (Arendt 1998, 1)? Bacon's conception of the experiment as a new style of innovative practice reflects this ambivalence. It expressed an experimental spirit that demonstrated its power not only of determining what is and what is not in accord with nature. At the same time, the experiment appeared as a technology for innovation, as a tool for transgressing given natural limits.

In the classical or conservative idiom of "science and technology" the scientific assumption of a limited world sets limits for technology and experimental practice. Despite the noted ambivalence, it took a long time until the inverse relation received recognition: Only in the fairly recent idiom of "technoscience" the unbounded creative potential of technology sets the expectation that the world, too, is unlimited.[15] Accordingly, the idea of overcoming nature that is associated with creative experimental interventions comes to the fore. Instead of Lavoisier, it is now Francis Bacon who is claimed as a founding figure and becomes idealized in a one-sided way: Today's accounts of the Baconian experiment emphasize a spirit of creative experimentation that by and by conquered modern societies as it was adopted by artists, engineers, instrument makers, or social reformers. All of them share a creative desire in designing machinery, creating artwork, exploring the globe, or changing society. And indeed, even the idea of a perpetual machine makes its reappearance here and there (Dietzel, Ritter, et al. 2008).

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[15] For a strong claim regarding this inversion see Forman 2007.

## THE POWER IN THE EARTH

We will now take a closer look at this shift from the scientific conception of lawfulness and constancy as a limit on engineering to engineering practice as a model for the ability to exceed limits, including those that appear natural. This inversion is particularly evident in respect to the notion that there is a limit of space on Earth that constrains human civilization, including technology.

Economist Thomas Robert Malthus was convinced that man can not transgress the absolute limit given by nature and in saying this he referred not only to limited space on earth but also to other resources. In his famous "Essay on the Principle of Population, as it affects the future improvement of society" (Malthus 1798) he provides a clear and seemingly inescapable account that has not lost its power until today. Until at least the 1970s and probably beyond that, Malthus' population model fed into scientific ecology. It also influenced ecotechnologies like the "cabin ecology" of the 1950s and 60s and the development of the biosphere in the 1980s. Today, it serves as a basic assumption of ecological economics – an exemplar, to be sure, of what Bataille called special or restricted economics (Becker et al. 2007, 275-299). So, what does the so-called Malthusian law say and what makes it so particularly seductive for ecological concerns? It draws a causal connection between the growth of population, space as a limited resource and the availability of food production. In Malthus' logic, the scarcity of food resources is the absolute limit for societies, a scarcity that is implied by a lawful nature.

> I say, that the power of population is indefinitely greater than the power in the earth to produce subsistence for man. Population, when unchecked, increases in geometrical ratio. Subsistence increases only in an arithmetical ratio. […] By that law of our nature which makes food necessary to the life of man, the effects of these two unequal powers must be kept equal. […] Nature has scattered the seeds of life abroad with the most profuse and liberal hand. She has been comparatively sparing in the room, and the nourishment necessary to rear them. The germs of existence contained in this spot of earth, with ample food, and ample room to expand in, would fill millions of worlds in the course of a few thousand years. Necessity, that imperious all pervading law of nature, restrains them within the prescribed bounds. […] And the race of man cannot, by any efforts of reason, escape from it. (Malthus 1798, 13-15)

This law of nature, according to Malthus, is the immutable condition for the economy and governs the relation between humanity and nature.

> It accords with the most liberal spirit of philosophy, to suppose that no stone can fall, or a plant rise, without the immediate agency of divine power. But we know from experience, that these operations of what we call nature have been conducted almost invariably according to fixed laws. And since the world began, the causes of population and depopulation have probably been as constant as any of the laws of nature with which we are acquainted. (Malthus 1798, 127-128).

Moreover, the scope of action for accommodating the "great machine" society to nature is rather small because the lawful order of society is ultimately based on the force of human "self-love" which is again given by nature. The Malthusian society cannot change the actual relations between the rich and the poor, it is not even disposed to imagine societal change.

> […] [A] society constituted according to the most beautiful form that imagination can conceive, with benevolence for its moving principle, instead of self-love […] would, from the inevitable laws of nature […] degenerate into a society, constructed upon a plan not essentially different from that which prevails in every known state at present; I mean, a society divided into a class of proprietors, and a class of laborers, and with self-love for the main-spring of the great machine. (Malthus 1798, 207)

These in a sense anti-social elements of Malthus' philosophy might disguise the originality of his economic model, namely the identification nature as the resource of society which still informs economic and ecological thinking today. The ground for this persistence is that nature is imagined as a given and unchangeable source that stands in opposition to societal actors in society, including the trader and economist. Societies have to accommodate to this nature and the limits of technology are imagined accordingly – nature cannot possibly be conceived in a technological manner. Malthusian nature, characterized by an unavoidable logic of power and balance, shares its fundamental assumptions with other conservation principles. Both, the relation between economy and nature, but above all the economy of nature itself is construed as an inescapable necessity. An order is projected onto nature and this order corresponds to the form of scientific laws and of economic processes alike.

It is therefore hardly astonishing that the first and second laws of thermodynamics[16] have always played an important role in scientific ecology. "The basic process […] is the transfer of energy from one part of the ecosystem to another" wrote aquatic ecologist Raymond L. Lindeman, when he first described a lake as an energetically open ecosystem consisting of biotic and abiotic components (Lindeman 1942, 400). Energy from the sun is accumulated in organisms, so-called producers, by means of photosynthesis. A portion of this energy is transferred via consumption to the next levels, but most of the energy is lost either by respiration or decomposition. This first description of the transfer mechanisms in an ecological system in terms of the laws of thermodynamics was further developed in ecosystem theory and thus became an important conceptual reference in ecological economics as a scientifically certified description of nature.

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[16] This paper is not the place for presenting the argument in detail. Geogerscu-Roegen is one of the best known scholars who relied on the work of systems biologist Bertalanffy. Bertalanffy, in turn, began his career in the 1930s thinking about systems biology by adopting the two laws of thermodynamics to biology and transforming them into principles of Gestalt.

Lindeman’s model was by no means the first one to conceptualize natural systems outside the laboratory as quantitatively recordable entities. In 1926 already, Vladimir Ivanovich Vernadsky published a paper “on gaseous exchange of the earth’s crust” in which he treated geochemistry as a natural history of terrestrial chemical elements. This geochemical approach turned the whole globe into a scientific object, and from this Vernadsky’s concept of the biosphere[17] derived its heuristic power. The idea of control and balance is everywhere in play, since the objective of quantitatively describing the transfer of substances through a system is pursued by conceptualizing a biologically controlled flow of atoms in a specific geological site.[18] “All points oscillate around a certain fixed mean” was one of Vernadsky’s central statements that clearly expresses conservation principles (Vernadsky 1997, 225-227).

Regulatory feedback mechanisms played an important role in Vernadsky’s model; they structured conceptualizations of cyclical processes. In the 1940s this geochemical approach found its way into more general efforts of systems analysis in the context of the famous Macy conferences (1946-1953). The inaugural meeting of the group was called “feedback mechanisms and circular causal systems in biological and social systems”.[19] The very idea of a cyclical process and self-regulating feedback mechanisms constitutes a variant of conservation thinking – it serves as a norm of representation that constitutes scientific practice and also constitutes a specific scientific object, namely a kind of system, including the ecosystem. Just like Hertz’s steam engines or the post-Malthusian systems of agriculture, these systems can be more or less efficient in that they use the available space or the available energy more intensively. This intensification takes place strictly within the circulation of matter and energy: Malthus was “proven wrong” only because he underestimated what intensification could do, but on this account he is still considered right, in principle: There is a limit to intensification and this limit brings us up against Malthus’ unyielding, unforgiving nature. Some of the participants of the Macy conferences testify to this as they went on to develop what was later called General Systems Theory (GST).

Aside from neurophysiologist Ralph W. Gerard and ecologist George Evelyn Hutchinson who was also an important supporter of Lindeman’s thermodynamic ecosystem concept,[20] other major contributors to GST were biologist Ludwig von Bertalanffy, economist Kenneth E. Boulding who

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[17] The concept had already been invented by geographer Eduard Suess, but it was only Vernadsky who conceptualized the biosphere as it was taken up by Bataille and as we know it today.

[18] For a more detailed looking at Russian ecology through the biosphere theory, see Levit forthcoming, III.4.6.

[19] The Macy Conferences (with participants such as Norbert Wiener, John von Neumann, Warren McCulloch, Margaret Mead, or Heinz von Foerster) contributed decisively towards the dissemination of cybernetic approaches beyond the primarily technological applications into areas such as the social sciences, psychology, ecology, in general the human and life sciences. For more detail see Pias 2003.

[20] The formation of the GST is described in Gray and Rizzo 1973.

advocated in the 1960s the concept "carrying capacity", and biomathematician Anatol Rapoport whose thermodynamic models influenced ecological economics in the 1970s. Hutchinson's seminal paper on "Circular Causal Systems in Ecology" shows clearly that his "systems" are scientific objects that are to be studied and represented by scientific ecology. He developed an ecological theory using cybernetic terms of feedback mechanisms and circular causality, arguing that, within certain boundaries, ecosystems are "self-correcting" by means of "circular causal paths". The assumption of those regulating feedback systems as ecological theories forms the basis of both his biogeochemical and biodemographic approach.[21] Abiotic and biotic factors alike are looked at from the point of view of the extent to which their effect is to stabilize the equilibrium (Hutchinson 1948, 221-246).[22] The carbon cycle for instance can be described as being adjusted by the regulating effects of the oceans and the biological cycle.

By means of these powerful theoretical tools, ecology had become the authorized science to describe and explain not only the environment of a single organism, of populations or communities but mainly geographically larger systems, including earth as a whole. Thus, ecological theories seemed to provide the ideal tool box to manage any sort of environments, just as cybernetics and general systems theory provided a tool box to understand, manage, perhaps optimize the behavior of machines and other technical systems. In this transition from understanding to managing systems, "system" became an ambivalent term with a scientific as well as technical dimension. On the one hand, "system" served as a general representational device for describing and explaining nature and technology as self-contained, conservative, cyclical and self-regulatory processes. On the other hand, if nature shares with technological systems that it operates in a certain way, this leads to a technical notion of functional systems with performance parameters that can be managed, adjusted, optimized. The powerful promise of GST thus involved a shift from theoretical ecology, based on mathematical modeling, to issues of controlling and managing systems that contain living organisms - a shift from scientific ecology to ecotechnologies such as "space biology" or "cabin ecology".[23]

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[21] Astrid Schwarz offers a closer look at the beginnings of systems theory in biology and ecology with a special emphasis on the concept of Gestalt, Schwarz 1996, 35-45. A detailed story of systems theory in early ecology is given in Voigt forthcoming, III.3.1.

[22] George Evelyn Hutchinson participated in a number of Macy conferences and published in 1948 the paper "Circular causal systems in Ecology".

[23] On the subject of "space biology" see, for example, Hanrahan and Bushnell 1960, as well as a host of magazine articles in, among others, *Missiles and Rockets*, *Astronautics*, *American Biology Teacher* or in the *British Interplanetary Society Journal*. On "cabin ecology" specifically, see especially Calloway 1965 and Calloway 1967.

## EXCEEDING THE LIMITS TO GROWTH

We have seen that feedback-cycles and self-regulation played an important role in the development of systems theories. The notion of "self-organization" is sometimes identified with this and sometimes implies an added dimension of emergence and creativity. In contrast to the conservative general systems of the cyberneticists, self-organizing systems are said to create genuine, often surprising novelty – they take the system to a new level and move beyond intensification to innovation.[24] On the one hand, then, self-organization harks back to the model of a well-balanced and rather conservative nature that accommodates itself within given limits. But on the other hand self-organization opens the door to an image of nature that appears to be emergent and creative. The corresponding model is based on a political economy of technoscience that takes the seemingly unbounded technological creation of genuine novelty as a paradigm of nature. Technoscience does not accommodate itself in a limited world but seeks to expand those limits by disclosing new space and new resources.

Space travel like the Apollo program serves to disclose new space and new resources, and it does so by way of conspicuous consumption and – some would argue - an orgy of excess: The resources invested in the Apollo program cannot be accounted for; perhaps they are wasted or perhaps they bring infinite gain, and in the meantime they might be written off as a kind of national fireworks that deliver glorious pictures of the galaxies and the blue planet earth. On the level of research, this program was taken up by cabin ecology and biosphere design. Technoscientifically, the disclosure of new space and new resources corresponds to the construction, literally, of space-ship cabins that enable the discovery of new worlds beyond the biosphere. The idea behind "exceeding containment" was to construct a closed space that would be suitable for the maintenance of life and thus help to escape earthly confinement. What was to be created, then, was a perfectly controlled space at the limits of intensification – self-sustaining as nearly without loss as possible. This exercise in total control served to minimize reliance on the special conditions of life on Earth and to go beyond the absolute limit of space that was set by the biosphere.

All this can be seen in the story of the emergence of cabin ecology as a field of research with legions of technicians and scientists working on the technical and conceptual implementation of water, nutrient and gas cycles. This serious scientific-technological research program began in the

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[24] To do justice to this claim, one would need to take a close look at the role of conservation principles in the argument e.g. of Prigogine and Stengers 1984. To be sure, in order to scientifically represent and explain self-organizing systems, such principles will have to be evoked. And yet, these systems signify that nature can grow beyond itself and the emergence of order thus recalls 19th century arguments about a dynamics of nature that eludes the mechanics of representation.

1950s with the dream of developing outer space as an unlimited spatial resource by establishing human settlements in Earth's orbit or even colonizing Mars.[25] The technical conception of constructed ecosystems for space travel took on added significance when in the 1960s the entire planet became visible as a spaceship that needs to maintain conditions of life for a human population. "Spaceship Earth" was no longer associated with space travel but increasingly with the emerging environmental discourse. The 1968 Apollo image of the blue planet brought into view not only the Earth as an enclosed and, above all, limited space but along with that the various scientific parameters for describing space (closed-loop cycles, stability, "carrying capacity", and so on). Thus the "spaceship" became the rational model for the global management of Earth, but one in which humans could suddenly turn into an irritant by producing too much CO2 or waste. Humans became a form of "pollution" on Earth, spreading like a disease and putting Gaia in mortal danger – as ecologist James Lovelock put it (Lovelock 1996). With economist K. E. Boulding the "spaceship" underwent a transformation. The actual, technical model of space-travel for astronauts was now projected onto the planet as an object of management. Boulding turned the cabin or spaceship into a macroeconomic model in which carrying capacity played a major role and the limitation of space became identified with all other resource-limitations: "the earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy" (Boulding 1966, 34).[26]

This "economy of the spaceship earth" came to underpin the concerns expressed in the Club of Rome report on the "Limits to Growth". And as with cabin ecology in particular, the envisioned control by a few parameters of spaceship earth and of planet earth as a total world model implies a form of excess. Travel into outer space, the current conquest of nanospace, and this project of managing the blue planet share the idea that space itself can be used to exert technical control: Within the conservative framework of an absolutely limited Malthusian earth, the notion of "carrying capacity" equated available surface area with available space. For example, alarmist images of how much standing room is taken up by all the inhabitants of the Earth translated into political calls for population control underlined by scientific models. The use of space for technical

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[25] See for instance Clarke 1951. The program still has strong technological as well as imaginary potential. It plays a role in recent space experiments as well as trend-setting "eco-design" prototypes. A good example for the first case is the ongoing research project to develop "aquatic modules for biogenerative life support systems: Developmental aspects based on the space flight results of the C.E.B.A.S. mini-module" (Blüm 2003). For an eco-design product see the air purifier "Bel-Air" (2007), developed by Matthieu Lehanneur and David Edwards (Harvard University and Le Laboratoire Paris). It is based on a technology that was originally developed by NASA to improve the air quality on board space shuttles (Barbera and Cozzo 2009, 56).

[26] See also Höhler and Luks 2006.

control came into its own when available surface area became divorced from available space with the notion of the "ecological footprint". It also serves to send alarmist messages about the land use required to sustain a single citizen of the US or of India. The measure of the ecological footprint signals that we live far beyond our means. At the same time, somewhat paradoxically, it also signals that we can live far beyond our means: The sum of ecological footprints already exceeds the available surface area on Earth by a factor of 1.4 – and it is simultaneously the worry of limits-to-growth environmentalists and the hope of technoscientific researchers that this factor will become bigger in years to come. One way of doing so is to productively exploit the fact that at the nanoscale surface area is immensely large in relation to bulk. Ever since Richard Feynman's call in 1959 to enter a new field of technological possibility by discovering "plenty of room" at the bottom, this nanotechnological project is not viewed as a more intensive exploitation of an available resource but as the discovery of an entirely new space of action that permits a form of engineering which draws on the creative processes of nature.

While excess in molecular biology or in nanotechnology involves shaping the world atom by atom or molecule by molecule, ecotechnology produces excess through manipulation and enhancement of the cybernetic world machine. Today, scientific expertise about the limits to growth serves as a starting point and technological challenge to the so-called sustainability sciences and related technological fields which are primarily concerned with the control, discovery, and constant renewal of resources. The declaration of the recently founded World Resource Forum is a good example for this kind of agenda. "Traditional environmental technologies are no longer enough […]. We call for a new global strategy for governing the use of natural resources […]. By combining efficiency and resource productivity targets with sufficiency norms evolved through participative mechanisms, it should be possible to avoid the traditional type of growth."[27] This is a conceptualization of limits that already points at its transgression and therefore exhibits a similar ambivalence as the notion of the self-regulating system. The World Resource Forum asserts that the acknowledgment of limits of resources creates possibilities for escaping these limits by means of efficiency in the sense of enhanced systems performance. This kind of efficiency is to result not primarily from conservation and the avoidance of waste but from technological as well as societal innovation ("participative mechanisms").[28] This program corresponds to a new environmental

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[27] For more detail see www.worldresourcesforum.org/wrf_declaration (01-15-10).The WRF was founded in Davos, Switzerland, in September 2009.

[28] A vivid illustration of this was provided in a large exhibit curated by the German Max Planck Society for basic research. It presented as a point of departure a reminder of resource limits. From then on, however, it featured the power of the technosciences to go beyond these limits: "we must grow beyond ourselves" (Max Planck Gesellschaft 2009, 181 and 187).

movement that embraces technological innovation and that refers for this, in particular, to the luxurious gifts of energy from the sun. “We should see in hubris not solely what is negative and destructive but also what is positive and creative: the aspiration to imagine new realities, create new values, and reach new heights of human possibility.”[29]

## CONCLUSION

Are we confined to Venadsky’s conservative biosphere or does the generous gift of the sun produce an abundance and concentration of wealth that needs to be released in the form of excess, waste, and creative destruction – such that the technological problem of sustainable development is the control of how this release takes place: by way of exuberantly rising ocean levels, by grandiose geoengineering schemes, or by ever more and ever more “sustainable” production and consumption? Do we accommodate ideas of technological possibility within the framework of knowledge production in the special, restricted, “limited” sciences, or do we view technoscientific research as a productive, creative, “liberating” force of wealth-production? These questions return us to Georges Bataille’s reflections on restricted and general economics: How to conceptualize the transformation from a limited world of scarcity to a world of excess. And how to control the transformation from a special economics of zero-sum games and of supply balancing demand, to a general economics of luxurious abundance and abject waste?

This essay on some of the transformations undergone by the “blue planet” and “spaceship Earth” allowed us to simultaneously consider ecotechnologies and nanotechnologies as technosciences that do not accommodate to limits. In both cases we are dealing with space travel and the control of space as a technical resource (Nordmann 2004, Schwarz 2009). Ecotechnologies and nanotechnologies accept and incorporate arguments about limited growth and in response develop strategies of control that open up a boundless space – literally and metaphorically - of technical possibilities, for example by discovering vast new surface areas (nanomaterials research), by developing new forms of energy (hydrogen economy), by harnessing morphological and organismic potential (synthetic biology), or by designing the renewal of nature (restoration ecology).

There are various ways in which the technosciences seek a transgression of limits, for example, through the production of hybrids. Here we were interested in just one of these ways, namely the transgression of a limited or restricted economy of science that assumes finite resources and finite energy, towards an unlimited or general economy that celebrates the production and consumption of

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[29] Comment by Richard Florida (author of *Rise of the Creative Class)* on Nordhaus and Shellenberger 2006. For this and more such statements of praise see www.thebreakthrough.org/pressrev.shtml (01-15-10).

excess. This may have led us to the origin of technoscientific hype and hubris. More importantly, however, it led to a condition where the norms of representation that orient the sciences no longer shape our ideas of a constant and limited world. Instead, the explorative aspects of experimentation and the creative dimension of art and engineering provide an image of boundless technical innovation which suggests that the world itself is constantly renewable and an unlimited source of novelty.

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