Limits and contradictions of capital in nature

César Enrique Pineda Ramírez[a]

[a] Universidad Nacional Autónoma de México (UNAM), Instituto de Investigaciones Económicas (IIEC), Mexico. Postdoctoral Fellowship Program. IIEC fellow, 2020-2022, advised by Dr. Raúl Ornelas Bernal Ornelas Bernal.
Email address: cesar_e_pineda@politicas.unam.mx

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Abstract

This article addresses the main theses on the contradiction of capital in nature from three theoretical perspectives. These approaches provide elements for understanding the unsustainability of capitalism. The present article presents a synthesis of what is known as the capital/nature contradiction, based on homologies, complementarities, and consensuses between three theoretical approaches: *1)* the historical dynamics of capital; *2)* the productive-consumptive form of infinite growth, and *3)* the decoupling of accumulation periods versus cycles of renewal, adaptation, and assimilation of ecosystems.

Keywords: capitalist systems; Marxism; ecological economics; economics of the environment and ecology; environmental economics.

1. INTRODUCTION

In the midst of the global environmental crisis, the debate regarding the sustainability of capitalism remains open. Theoretical advancements are reconceptualizing the nature-capital relationship, as are public policies oriented towards energy transition and a green economy. There is now a clear recognition of the catastrophic consequences that climate change could cause to the world economy, as well as the need to avert climate change, which could also require measures that would plunge the economy into a deep crisis. In light of this, renewed attention is being given to the debate sparked by *The Limits to Growth* (Meadows *et al*., 1972).

This controversial public report raised early doubts about whether natural resources would be sufficient to sustain trends in population increase and continued economic growth. The research became a watershed moment in opening the debate on the possibility of the collapse of human civilization, thus proposing the end of certainties and the linearity of infinite growth on a finite planet. Although many of its premises are now partially obsolete, the current environmental crisis reopens the debate initiated by *The Limits of Growth*.

With much less media and political attention, ecological Marxism, as represented by James O'Connor (2001), outlined the thesis of a "second contradiction of capitalism" at the end of the 1980s. This author referred to the capital-labor contradiction, following Marx, as the "first general law of capitalist accumulation." He then formulated a second contradiction, postulating that capitalism undermines the very bases of its renewal by depredating and deteriorating the environment, making inputs and materials more and more expensive, exhausting them, leading capitalism itself into crisis.

The thesis was subjected to an environmentalist critique for viewing capital's relationship with nature as secondary to accumulation and labor, and for apparently concentrating much more on the economic impacts of environmental degradation than on the environment itself.

However, decades after Meadows and O'Connor's critiques, environmental degradation and its potential risks to human and non-human life have not only continued to accelerate but have even worsened. Is there an inherent contradiction between capital accumulation and environmental sustainability, and has capitalism reached its limits? Taking up O'Connor's well-known notion — here renamed the capital-nature contradiction, as a way of characterizing a central relationship of social reproduction —, this article analyzes the main theses of three theoretical traditions, thus allowing for a preliminary synthesis to support the aforementioned conceptualization.

Thus, ecological economics, eco-Marxism, and the world-ecology approach were chosen to analyze the functioning of contemporary capitalism, due to their critical position and scope. These three traditions share a common skepticism towards hegemonic thought, as well as a commitment to problematizing growth, capital, and its relationship with so-called nature. Environmental economics was disregarded because it derives from the tradition of neoclassical and marginalist economics, which do not question the relationship this paper seeks to study.

This article consists of three sections, each of which sheds light on the functioning of capitalism in regards to consumption, production, and accumulation phases. The three analytical dimensions revealed contributions of varying depth and scope in the selected theoretical traditions. Given this article's scope and objectives, each section critically presents some of these traditions' contributions and limits, focusing on the capital-nature contradiction and ignoring other less relevant aspects. Here, it is worth mentioning that each tradition takes a different position on the subject of capital-nature dualism.

In the final analysis, this article argues that the capital-nature contradiction should be understood at three theoretical levels: 1) in the logic of capital accumulation-appropriation; 2) in the form and structure of material market flows in their capitalist form, and; 3) in the decoupling between moments of economic accumulation and moments of geochemical and biotic renewal, assimilation, and adaptation. The conclusion presents the homologies, complementarities, and consensus between the selected traditions and the usefulness of the *contradiction-capital-nature* concept.

2. LIMITS RELATED TO CONSUMPTION

Ecological economics is a useful theoretical-epistemological critique of neoclassical economics and its premises as applied to environmental issues. Among its precursors in the 1960s were N. Georgescu Roegen and Herman Daly, who had a significant impact on US academics. It is worth mentioning here the subsequent advancements spearheaded by Joan Martínez Alier, as well as José Manuel Naredo, both academics from the Iberian Peninsula whose Spanish-language research has been influential in Latin America. Ecological economics focuses on the environment, rather than on nature, due to its closeness to environmental sciences. Although the term is not polysemic, environment as a physical medium, both shaped by humans and as a natural environment, is informed by the traditional dualism of separating the human and the non-human.

Ecological economics presupposes that production is the transformation of energy and matter. Such processes are not merely processes of value exchange or quantitative gains through prices; they are material and energy flows governed by entropy, i.e., their conversion into heat and subsequent dissipation. When resources are transformed, they move from low to high entropy. When this transformation is complete, humans can no longer use these resources again. If energy is dissipated and matter is degraded, maintaining accelerated processes of its increasing consumption sooner or later leads to an *entropic deficit* (physical disorder and loss of productive potential). We see, therefore, that there are limits to the utilization of energy/matter.

Incorporating the second law of thermodynamics into economics is ecological economics' most important contribution, as in doing so it identifies the entropic limits of consumption. These limits are the foundations for thinking about the absolute limits of utilization/transformation of matter/energy: a *scarcity by degradation and depletion*.

The ecological economic critique of the dominant economic vision —neoclassical-environmental-Keynesian— points out how orthodox economics understands the circular flow of income as a closed, self-sufficient system and conceptualizes negative environmental impacts as externalities. This is the myth that "the economic process is a merry-go-round," rooted in the "mechanical" vision of economic theory (Roegen, 1975). To this must be added the criticism of the actual indexes used to measure wealth, such as the Gross Domestic Product (GDP), which do not consider the depletion and degradation of resources or the costs of their possible replacement.

Ecological economics posits that the inputs and outputs of matter-energy should be considered as part of an open system, incorporating both depletion and wear, as well as waste and impacts measured using alternative biophysical indicators (flow of materials, ecological footprint, etc.)

Another contribution from this perspective is the differentiation between *flux energies* and *stock energies*. The former is exemplified by solar energy and the latter by fossil fuels. Of course, stock energies are exhaustible and therefore limited. There is currently a vigorous debate surrounding their depletion.

Influenced by foundational texts such as *The End of Cheap Oil* (published in the 1990s),),[1] both ecological economics and eco-Marxism highlight the progressive increase in the price of stock energies, following the production ceiling theorized in the well-known peak oil theory, which, rather than explaining merely its absolute scarcity, projects its productive decline. This last phase would be characterized by diminishing returns resulting from a long-term downward trend in the quality of mining and oil deposits, necessitating greater capital investments. This scarcity, through competition and markets, contributes to absolute depletion, opening up the possibility of relative limits, i.e., for reasons that are not strictly geological.

The scarcity of non-renewable resources, then, is not only determined by price, nor by absolute exhaustion, but also by state-legal conditions, social rejection of or resistance to extractivism, financial speculation, and technoproductive conditions. We can therefore speak of socio-natural resources, a term proposed to include these social, historical, and multidimensional variables concerning the very notion of deposits (Sacher, 2014). But this progressive scarcity is also determined by the volume of their consumption, which, far from being a linear and direct effect of population increase, can be explained by exchanges in the global market.

Daly (1999) identified the clear separation between population size and per capita resource use, making evident the extreme polarization of consumption between poor and rich countries. In a similar vein, Martínez Alier highlights the problem of commodity exports that exclude environmental costs from their prices. Thus, this asymmetry constitutes not only a transfer of value in terms of labor time from the exporting countries to the central economies, but also an extreme inequality in the distribution of ecological impacts and their costs in the producing countries. In other words, this is ecological price dumping, with goods being sold below the full costs of production. This reality gave birth to the notion of *ecologically unequal trade*, resulting from developing countries' inability to include negative externalities in their prices, as well as the renewal time of natural resources, which is much longer than the industrial processing of northern or developed countries. Seen in this light, it can be argued that the global North owes an ecological debt to the global South (Martinez and Roca, 2016).

Unequal ecological exchange also highlights the global North's dependence on access to low-cost matter-energy coming from the South, as economies and territories in the North lack the materials resources to satisfy the high level of consumption and general welfare of developed economies. This ecological deficit results from a physical trade balance, i.e., one measured in tons of resources. This unequal exchange currently includes the return of

material waste —a growing market for the exportation of plastic, chemical, and toxic waste— out of developed countries, as well as the carbon emissions hidden in investments.

Greenhouse gas emissions in some emerging countries partly result from the demand of developed countries. These economies are comparatively classified as emitters, yet are in reality importers, i.e., part of their own emissions result from the demand of developed countries. This reality conceals the fact that developed countries are the main causes of *translimitation of socio-resource consumption (environmental overshoot).*

Capital has always depended on formally extra-economic relations of imperial violence to guarantee unlimited access to nature. Eco-Marxism further develops this premise. The material basis of the expansion of the market and capital was unlimited access to matter/energy from the South, relying first on colonial relations, then on industrial monopoly, and, finally, on globalizing hegemony, relations that can be synthesized in the notion of *ecological imperialism* (Clark and Foster, 2009). These processes enabled the asymmetrical relationships that constitute and shape the global market, enabling the high standard of living in the capitalist centers.

Contemporary academic inquiry foregrounds the well-known asymmetry of the global economy and its center-periphery relations, analyzing the situation from an environmental perspective. Additionally, contemporary debates cite as central the well-known extraction of strategic resources, a process which takes several forms: in an asymmetrical transfer of food —from South to North and increasingly to China—; in an acute disparity of CO2 emissions —between global North and South—; in the massive export of waste —from the West to Southeast Asia and sub-Saharan Africa—; in an unbalanced extraction of natural resources due to the territorial insufficiency of Europe and Japan; and in the over-consumption of the US.

The asymmetry of consumption is a polarization of both income and inequality, as estimates of carbon emissions in the top decile of the world's population range from 49% to 75% of total emissions, while the poorest 50% of the world produce only 10% of total CO2 (Gore *et al*., 2015; Oswald *et al*., 2020). Ecological imperialism and unequal ecological exchange involve what is known as *scarcity by hoarding*, via coercion, but also through extreme inequality.

It has long been known that this level and mode of consumption —motorized mobility, generalization of industrially processed food, high energy consumption per dwelling, hyper-urbanization— is unsustainable when scaled up to the global level.

However, the ecological asymmetry between center and periphery is restructured and complexified by several factors: emerging economies such as India or Brazil following the path of proletarianization, de-peasantization, and urbanization which demands matter/energy; the industrial take-off of new centers such as China; and the emulation of unsustainable lifestyles pushed to the limit in technological cities of sumptuary consumption with a high carbon footprint in the Middle East and Southeast Asia (e.g. Singapore, Hong Kong, and Dubai) (Moran *et al*., 2018).

However, as is also well known, capital also uses center-periphery asymmetries as a means of productive delocalization, displacing investments, factories, and production nodes to countries that offer comparative advantages in relation to labor. This *spatial solution*, based on the asymmetry of labor organization, is also mobilized in search of limited or weak compliance with environmental standards and following patterns of unequal access to land, biomass, and energy which, combined with long-distance trade, leads to a substantial increase in energy expenditure. The very shape of the market in its globalized, fragmented world scale and the movement of goods between oceans and continents leads to unprecedented energy waste.

This, of course, intensifies inter-capitalist and inter-state competition for resources, which aggravates relative scarcity via prices. Extractive and waste markets increasingly face what are called *socio-environmental barriers* or limits, i.e., global conflict over *distributive-ecological* costs. These socio-political limits include inter-state rivalry over global environmental regulations, especially on emissions and the consequences of climate change, which divides those affected in the South from the consolidated economies; the dispute between states over waste — such as the recent closure of the Chinese and Philippine markets to plastic waste from the West; the conflict between states, environmental organizations and socio-community movements against extractive and agro-industrial companies in much of the world, as well as the emerging global movement against climate change.

These disputes suggest a crisis of relative scarcity via the market, coercion, and socio-environmental struggles. The crisis of relative scarcity of social resources is political and social and does not only imply linear geological or availability depletions —as suggested by Malthus and Meadows—; likewise, although the magnitude and volume of non-renewable resource stocks are immense, they are insufficient to meet the growing demand for energy/material, which brings us ever closer to scarcity by degradation and to the absolute limits of resources.

However, it should be noted that, despite its significant impact on energy flows and ecological asymmetries, ecological economics does not problematize or theorize the origins of the hypertrophy of the demand for energy and matter. The industrial mode and its energy base do not in themselves explain the exponential growth of demand. Naredo (2019) cites the origins as being anchored in productivism and of course, capitalism. However, both Daly (1999) and Naredo (2019) seem to privilege subjective factors such as the ideology of growth or the theoretical omission of nature as a determinant of the unsustainability of market economies, without explaining consumption hypertrophy itself.

Ecological economics, by critically analyzing consumption and its physical limits and calculating entropy and non-internalized costs, arrives at the logical conclusion of understanding degrowth as a way to make the market economy compatible with environmental sustainability. The proposed means to achieve this outcome is a stationary economy.

In other words, ecological economics foregrounds the incompatibility between growth and environment. The tension between capital and nature thus appears only indirectly and implicitly, through the impossibility of infinite growth on a finite planet. However, economic growth is dissociated from the critique of the logic of capital, and so the capital-nature contradiction does not appear directly in this tradition, and would only do so if it became

apparent that, as Schumpeter ([1943], 2010, p.168) argued, capitalism "is not stationary and can never be," in which case the contradiction of capitalism's sustainability becomes obvious.

3. CONTRADICTIONS OF PRODUCTIVE FORCES: INFINITE ACCUMULATION

The ecological Marxism school identifies a contradiction between capital accumulation and nature. Eco-Marxism, for its part, studies the conditions of production, although it should be noted that it does so by breaking with several of the dogmas of orthodox Marxism. Following Marx, in the second half of the 19th century, Serge Podolinski and William Morris are perhaps the first authors whose thought approaches eco-socialism. Walter Benjamin's critique of progress in the 20th century was decisive; in the Frankfurt School, meanwhile, particularly salient is Alfred Schmidt's study of the concept of nature in Marx, which recognizes that, although he maintains a firmly objective and independent understanding of nature as external to humanity, he undoubtedly recognizes with equal conviction that while humans act externally on nature and modify it, the way humans modify nature is conditioned by work and their own nature. The sociohistorical human-nature dialectic, present in Marx, persists throughout the entire conceptual agenda of eco-Marxism.

The post-1968 context saw the emergence of the Greens in Germany, the nascent environmental movements, and the growth of negative environmental impacts, driving the reconsideration of several heterodox Marxist formulations, as demonstrated by scholars such as André Gorz or Manuel Sacristán. Subsequently, a truly eco-Marxist generation of academics emerged, including James O'Connor, John Bellamy Foster, Paul Burkett, and, more recently, Kohei Saito.

Marx is explicit regarding capital's expansive dynamics, stating that its only limit is capital itself, given that capitalist production constantly tends to surpass its own limits (Marx, 2009c). Capitalism is thus conceptualized as a process of material production that tends to exceed its limits. Essentially, capitalism is a productive mode with no capacity for self-limitation.

This assessment views the accumulation of capital as infinite, as producing an incessant demand for surplus value and positive rates of profit which, in turn, determined by competition and class struggle, leads to the constant revolution of productive forces. The advance of money in search of more money cyclically dominates and redesigns labor, production, consumption, and, subsequently, the relationship with nature in a growing process of *subsumption* — i.e., subordination to the logic of capital. The dynamics of capital are oriented towards expansion and are guided by incessant accumulation. Capital, as money that seeks to grow without end, is the very origin of the absence of limits. That is, if capital does not grow, it perishes.

Marx focused on the sociohistorical critique of economic categories. Behind abstractions such as commodity, money, and value, lie relations of exploitation and dispossession. These abstractions are social forms that appear standardized; however, these are not simply theoretical concepts, but rather *real abstractions,* as Sohn Rethel calls them (Gunn, 2005). These are fictions that condition lives and objective practical relationships. They do not originate in the minds of individuals, but in the social action of the market, of exchange, and economic actors, without a director to orchestrate the interactions. This is why Marx speaks of *self-valorization of value*, of an automatic subject, that is to say, of forced behavior of the agents of capital, obliged to reinvest, to infinitely add value, on pain of being excluded from the fabric of the market in its capitalist form.

However, as Marx (2009a, p. 239) argues "the substance of value is not at all the particular natural substance, but rather objectified labor." Value is thus blind to nature. Only labor creates value, not nature. Nevertheless, Marx emphatically attests that "labor is *not the source* of all wealth. *Nature* is just as much the source of use-values" (Engels and Marx, 1973, p. 9). Clearly, Marx critiques the reduction of value to material wealth, the vision of concrete and diverse labor as undifferentiated abstract labor and, therefore, quantifiable through time units. For Marx, the theoretical point of view that omits nature as the source of material wealth —a criticism directed at Smith and Ricardo, as well as at German social democracy— is ideological in nature. Furthermore, this perspective seeks to explain the contradictions of a productive logic that "only develops the techniques and the degree of combination of the social process of production by simultaneously undermining the original sources of all wealth – the soil and the worker." (Marx, 2019, p. 613).

Following this line of thought, it can be argued that value as an abstraction both captures and reduces labor as abstract labor to be controlled and, simultaneously, excludes nature from valorization. This exclusionary abstraction of the natural occurs simultaneously with the appropriation of the material wealth created by nature in the objective productive sequence. Just as value and price are abstractions that allow the illusion of a fictitious reciprocity in the purchase of labor power, the omission of nature in valorization allows the illusion of infinite availability and the apparent decoupling of value and capital from their materiality.

To infinite growth and the critique of economic categories in relation to nature, we must add a classic Marxist debate: the crisis of capitalism from the development of productive forces.

The enormous elasticity of capital derives from the technique that cyclically revolutionized the productive forces. Saito (2017), from an ecological Marxist perspective, resurrects an old debate within the Marxist tradition, which points to the obsolescence of the much-debated "law of the tendency of the rate of profit to fall," Marx's unfinished proposal (Heinrich, 2008). This thesis argues that the organic composition of capital —the ratio between the constant and variable capital— is radically being transformed due to the effects of competition, expelling labor power and increasingly and rapidly replacing it with innovations, causing the rate of profit to fall. According to Marx, this is due to the process by which constant capital increases more rapidly than living labor: "the creation of effective wealth becomes less dependent on the time of labor [...] but depends rather on the general state of science and the progress of technology" (Marx, 2009b, pp. 227-228).

Saito (2018), meanwhile, suggests interpreting the law of the tendency of the rate of profit to fall not as an inevitable path to the collapse of capitalism, but rather as the elastic potential of capital to escape its multiple crises, revolutionizing material aspects of the productive-consumptive process with both extensive and intensive strategies. Faced with the recurrent depletion of profits, capital can externalize costs into nature, since it does not have to pay for their consequences, and can resort to new forms of appropriation of matter-energy, extending its capacity to increase productivity without significantly impacting costs. However, capital can also expand its scale and the rate of capital turnover, which, in addition to the race to annihilate competitors via prices, creates trends towards production gigantism and accelerates the speed of exchanges.

This, in turn, results in an accelerated technological-productive increase, a hypertrophy of the productive forces, which not only exhausts resources linearly, but also intervenes in and radically transforms nature in a historically unprecedented way.

Understanding material and energy resources as unlimited can be achieved not only by appropriating the resources of others, i.e., hoarding and producing relative scarcity (expansively), but also by opening natural boundaries that once seemed to constitute an absolute limit of depletion (intensively), through the translimitation of such boundaries: increasing intervention either to *remake nature* (O'Connor, 2001), or to *produce nature* (Smith, 2006). Producing nature implies going beyond an understanding of nature as a vein of resources and implies its reinvention and reorganization via labor processes, guided by the logic of capital accumulation.

This argument leads us to see technological revolutions not only as the product of competition, discovery, and technological-scientific progress, but also as capital's inevitable response to its own productive exhaustion. Understood in this way, capital would constantly exhaust profit rates for ecological reasons, starting from the formation of the global market in the 16th century (Moore, 2017a). Each cycle of capital accelerates wealth production, in constant waves of socio-ecological depletions that also imply recurrent cycles of geographical expansion. At the beginning of each cycle, "when capitalists can set in motion small amounts of capital and large appropriate volumes of unpaid labor/energy, production costs fall and the rate of profit rises" (Moore, 2015, p. 101), there is, according to Moore, an *ecological surplus* that tends to decrease in each cycle.

The expansion of capital as the cyclical capture and reorganization of productive forces is made possible by the unpaid labor of nature or through access to cheap nature (Saito, 2018; Moore, 2017a). The ecological crisis is not a market failure, but the result of the triumph of capitalist logic.

This reality is the source of a current contradiction, in the sense that by depending less and less on human labor, this technoproductive capacity increasingly depends on the incessant appropriation, at overwhelming magnitudes, of the energy of other natural forces for its ceaseless functioning, above all, on those natural forces whose energetic power allows for production to be multiplied exponentially, a requirement that fossil fuels had more than satisfied. From here, we can observe another contradictory dimension — while the capacity of *natural translimitation* or production of nature increases, the ecological surplus, however, declines. Capital emancipates itself from human labor/energy but increasingly relies on non-human forces.

Technological advances can increase energy efficiency in production and consumption per unit of commodity; however, the unlimited growth of unit sales neutralizes that advance by the scale and pace of total production. There is increasing efficiency in energy use, but also increasing demand. In turn, the consumer, having access to a more energy-efficient commodity, may end up using even more energy (Jevons Paradox) due to reduced costs.

Technoproductive power can generate less waste or replace waste products with less aggressive materials, but the volume of its production grows in a way that is unstoppable. Furthermore, technoproductive power can also generate apparent solutions for the substitution of energy sources which, however, when in terms of energy efficiency may turn out to be irrational solutions due to the greater expense required to create substitute energy units, combined with their indirect environmental impacts.

The open debate is not whether this technoproductive power can create substitutes for energy/matter consumption, as it is obvious that it can do so; but whether it can do so in a sustainable manner, being subject to the techno-productive rhythm and intensity that it makes possible.

In summary, ecological Marxism focuses on the dynamics of capital and its constant revolution of productive forces, and emphasizes forms of limitless accumulation as a central problematic in its relationship with nature. The most recent contributions speak of the constant revolution that exceeds and reorders its own boundaries based on an *abstract, cheap nature,* which sustains accumulation and growth in the present context. The contradiction of capital is that the transforming power that produces new nature as an escape from ecological exhaustion, generates the undermining and disordering of biotic relations. The capacity to intervene in nature, leveraged by the logic of capital, ends up undermining nature.

4. CONTRADICTION OF THE MOMENTS OF CAPITAL AND THE MOMENTS OF NATURE

Moore (2015) works within the world-ecology school, incorporating elements of ecological Marxism, and initiated a new line of inquiry by questioning one of the most widely known theses of ecological Marxism: the *metabolic fracture* developed by Foster *et al.* (2010). This critique proposed an alternative episteme, taking him beyond both ecological economics and eco-Marxism while simultaneously attempting to revindicate their major contributions.

The man-nature relationship was synthesized within Marx's notion of *social metabolism*. The concept of *metabolism* is a fertile one, in terms of the dynamism of transformation, flows, and exchanges implicit within it, thus making the man-nature relationship dialectical and co-evolutionary in production and reproduction from a historical perspective.

Following this comes the well-known concept of *metabolic fracture,* as Foster proposed as an analytical category that —following Marx— identifies "an irreparable rift in the social metabolism" (Foster, 2000, p. 240). This implies a material estrangement of human beings from natural conditions; a rupture

with natural cycles and the separation between the countryside and the city resulting from a radical metabolic change caused by capitalist production (Foster *et al.,* 2010). Ecological economics, on the other hand, places greater emphasis on the separation of the natural energy cycles —seasonal, solar—and their replacement by fossil combustion cycles. In both perspectives, a gap opens up between productive conditions or the industrial energy base and nature. It is an energy-productive decoupling of natural cycles.

Moore is critical of the concept of rupture and questions the supposed externality of nature in relation to human activities. Moore, as an environmental historian —drawing on contributions from world-system analysis and Marxism— proposes a dialectical vision, based essentially on the idea that all species are reciprocal producers and products of the environment. He questions the view that civilizations impact the environment —seen as external consequences— and proposes an approach that he calls *world-ecology*, where capitalism is not only a mode of production or an economic form, but rather a historical mode of organizing nature and a *world ecological regime*. This understanding of the human-nature relationship focuses on the revision of the historic relation between "capital accumulation, the pursuit of power, and co-production with nature in a dialectical unity" (Moore, 2017b, p. 146).

Understood in this way, capitalism itself is an *ecology* that produces nature and, in turn, is co-produced by nature itself. "The mosaic of relations we call capitalism works through nature and nature works through that more limited area, capitalism" (Moore, 2015, p. 15).

As previously explained, Moore asserts that the basic problem of capitalism is that capital's demand for cheap nature increases faster than its capacity to secure it, although he contends that configuring nature as external and cheap turns its weakness into strength, by redefining its boundaries, and reorganizing its limits at each potential depletion: "historical capitalism has been able to resolve its recurrent crises because territorial and capitalist agencies have been able to extend the zone of appropriation faster than the zone of exploitation" (Moore, 2017b, p. 151). Thus, the lag process becomes more visible during moments of appropriation and expansion.

Moore argues that the mistake in conceptions of natural limits is to confuse material depletions with the depletion of accumulation strategies. Nevertheless, there are two dimensions of contradiction between capital and nature in Moore's work: the first regards the depletion of cheap nature. This is an internal contradiction of capital to find new frontiers, potentially exhausting the historical accumulation strategy because the asymmetry and moments of exploitation and appropriation could end. The other contradictory dimension is the accordance with the ecological-economic premise regarding economic moments and environment, or in ecological Marxism between moments of capital accumulation and moments of ecological renewal. The tension in this gap of temporalities will be clarified below.

Capital not only grows but also accelerates its circulation. The moment of circulation also presents itself as an obstacle. If capital, as Marx states, strives to "tear down every spatial barrier to intercourse, i.e. to exchange, and conquer the whole earth for its market, *it strives on the other side to annihilate this space with time*, i.e. to reduce to a minimum the time spent in motion from one place to another." (Marx, 2009b, p. 31). This, hand in hand with the development of productive forces, produces an insurmountable contradiction: the cycles of capital accumulation are faster than those of nature. This contradiction arises due to the lack of recognition of *nature's labor time* (Leff, 2019).

The factual contradiction implies that the rates of matter-biomass extraction-collection are faster than the rates of ecological renewal and productivity; that the rates of waste emission are higher than the natural capacities of ecosystemic assimilation, dilution, and disintegration; that the moments of ecosystemic modification are faster than moments of species adaptation; and that monetary and financial accumulation is decoupled from material production, pressuring the latter to follow the rhythm of the cycles of capital.

The complexity and interrelation of the earth system and its subsystems (atmosphere, hydrosphere, lithosphere, and biosphere), articulated via reciprocal and interdependent interactions, mean that the innumerable local changes in the patterns, flows, and components of particular areas and ecosystems can translate into environmental changes on a global scale. The logic of capital accelerates the organized and systematic manipulation, intervention, and linear extraction of productive forces on the components in each subsystem. The course of this radical transformation is beyond human control, and is therefore extremely unstable and dangerous.

However, the intersection between human activities and earth systems remains a hotly debated topic due to the controversial distinction between society and nature; since the emergence of *homo sapiens*, human action, interaction, and intervention have been components of ecosystems. Ecological economics dialogues with other disciplines that investigate limits and depletions.

One approach to limits within ecological economics is the notion of *planetary limits*. Borrowing from geosciences, biology, marine sciences, and other disciplines, planetary boundaries are conceptualized as scientifically based levels of human disruption of the earth system beyond which the functioning of that system can be substantially altered; they are safe fields of activity for human activity, depending on the capacity of the biosphere to recover from such perturbations and return to a stable state. These planetary boundaries are organized into nine terrestrial subsystems that can be affected by different processes.

Studies have shown that the transgression of planetary boundaries creates a substantial risk of destabilizing the Holocene in which modern societies have developed. Academics working in this discipline assert that freshwater consumption would be at a safe level; ocean acidification would be on the verge of being exceeded; the limits of land-use change and climate change would have been transgressed, entering a zone of risk; and that the biogeochemical cycles of phosphorus and nitrogen, as well as the integrity of the biosphere —due to accelerated loss of genetic diversity and species extinction— would not only have been exceeded, but would have entered a high-risk zone (Steffen *et al.*, 2015).

Despite being directly caused by human action, the planetary boundaries approach does not seek to explain the causes of such disturbances, and focuses instead on the biophysical and geochemical consequences; they warn of the risks involved in exceeding indicators that only implicitly describe human activity as contradictory in its interaction with nature, as they undermine the ecosystemic bases that sustain humanity, disrupting cycles that were autonomous from human action, i.e., external. But this externality is problematic.

The human-nature relationship is located first as a relationship of separation (thus conceived by the Cartesian dualism of modernity, where nature disappears from the center of human reflection and is externalized); as a *contradictory* relationship between economy and growth (in the tradition of the Club of Rome Report and ecological economics); as a dialectical relationship of social metabolism (of Marxism); or as a fracture of this metabolism, or as a split as Foster *et al*. (2010) put it.

Harvey, like Moore, questions the assumptions informing the society-nature separation and its external limits, arguing that "the ecosystem is constructed out of the contradictory unity of capital and nature [...] Capital is a working and evolving ecological system within which both nature and capital are constantly being produced and reproduced" (Harvey, 2014, pp. 242-243). While the totality of capitalism is indeed an ecosystem —as this view correctly posits— i.e., a species-environment relationship and a metabolism of exchanges of matter and energy in contradictory unity, not every ecosystem is a product of capital. Increasingly, however, capital is intervening in and reorganizing the larger ecosystem, the biosphere.

Here, it is worth asking whether this contradictory unity, which conceives nature as an exteriority and where value is blind in the process of valorization while simultaneously being eco-dependent, has come to an end, given that the expansion and reformulation of the boundaries of the logic of capital are about to lead to the reorganization of the biosphere as a whole. It would be the end of the era of the appropriation of abstract nature, in the sense that externalization had approached its biophysical limits, not only by reaching the entire globe, but also because the acceleration of the times of accumulation could no longer be sustained by nature's moments of renewal and regeneration. It would not only be a crisis of expansion but of intensification.

The living contradictions of capital, in its relationships with the rhythms and moments of terrestrial subsystems, have become increasingly intense, producing feedback loops and becoming unmanageable. The radical alteration that produces new ecosystems, via its internal contradiction of the mode and rhythm of remaking nature, has become a vector of extinction. Capital, as a historical-material process, is today a factor of extinction of the living.

Capitalism has, arguably, reached an *internal crisis of the historical mode of appropriation and reorganization of nature in its capitalist form* that undermines the stability of conditions from which human reproduction has been carried out until now. Simultaneously, this crisis is external to the ecosystems co-produced by capital, altering life itself in the entire biosphere. Such changes will, unquestionably, result in capital's downfall.

5. CONCLUSIONS

After studying the three theoretical traditions, it can be summarized that the central contradiction theorized by ecological economics is growth versus environment, while the discipline's method is the study of energy and material and bio-physical flows, concluding that growth in its present form is unsustainable. An inherent contradiction between capital and nature only, appears implicitly, if growth is considered as an essential feature of capitalism. The contradiction, in this case, then, is growth.

As we have seen, Marx theorized the capital-nature relation as a contradictory unit of social metabolism, something which eco-Marxism for its part, conceptualizes as the second contradiction of capitalism (O'Connor) and metabolic fracture (Foster). Foster posits that the rupture of natural cycles constitutes an unsalvageable rupture between the logic of accumulation and ecosystemic processes. His approach is at once material, social, and historical, following in Marx's footsteps. The contradiction is infinite accumulation, while the contradiction in the metabolic fracture is separation.

Moore's great contribution was to question the abstract separation of the human-nature duality, thus deepening the dialectical relationship between nature as a producer of humans and humans as producers of the environment. The world-ecology school, meanwhile, proposes conceiving of metabolic fractures not merely as moments of ruptures of natural cycles, but rather as historical sequences of reiterative socio-ecological crises: the living contradiction between capital and nature, and between the lag of expansion and reorganization of natural frontiers, defines capitalist expansion the world over. The capital-nature contradiction implies not only a weakening of capitalism, but the possibility of reconfiguring and expanding capital. The capital-nature contradiction is not a systemic weakness, then, but rather a necessary precondition of capitalism, one unsustainable in the long term.

These schools of thought diverge in their respective theoretical-epistemic methods for thinking about the human-nature relation and, in turn, for unveiling the contradiction present within it. At one end of the theoretical spectrum is the notion of a material economy consisting of energetic and biophysical flows that privileges consumption and expenditure, and, on the other extreme, is a material-relational, socio-historical understanding that foregrounds the social and socio-ecological antagonism of economic expansion. They share, however, a critical approach to hegemonic economics, and to environmental economic modes of theoretical construction, i.e., the postulates of neoclassical economics.

Beyond the possible theoretical complementarity across schools asserted by some authors, there stands out a certain potential homology between theoretical levels regarding the capital-nature contradiction.

Here, homology refers to the fact that the study of distinct theoretical-epistemological components, subsequently organized into separate blocks of abstraction, reveals that these blocks are premised on shared assumptions regarding the centrality of the economy and the environment, on the one hand, and of capital and nature, on the other. Each block occupies a different level of analysis and shows a distinct form of relative integration, which can serve to illustrate the logic common between the three. The three abstract-theoretical blocks are as follows:

a) Several postulates of eco-Marxism and world-ecology are understood as a possible *homology on the logic of capital*: a contradiction between value and use-value, between monetary wealth and material wealth, i.e., a historical contradiction that polarizes through the expansion of capital; a supra-ecological appearance, but an eco-dependent essence; a conception of value that de-values nature, but objectively appropriates it, in process of reduction and capture as abstract nature; a living contradiction between decreasing ecological surplus and profits and the incessant and expansive search for profit and accumulation; hypertrophied productive forces with technological capacity of growing intervention that radically rearranges nature and produces ecosystems; a productive-consumptive system based on geographic expansion, the appropriation-translimitation of nature, and acceleration of circulation incapable of self-limitation and; a contradiction that allows the expansion of capital in successive cycles of expansion and reconfiguration of nature. *The contradiction of capital in nature as an inherent part of the logic and historical dynamics of capital itself*.

b) At the next level of analysis, it can be argued that there is *complementarity* between the three traditions in their understandings of the structure of the capitalist economy and its biophysical consequences: the growing demand for energy-matter, driven by the logic of accumulation, is not also due to fossil energy systems, but rather emanates from the scale of the world market, from productive delocalization, from urban and class consumptive growth, from energy-productive waste by volume, from the hoarding of resources through ecological imperialism and unequal ecological exchange; from the centralization of capital in mega-corporations and financialization whose global exchanges and investment needs push to gigantism and overreach. *The contradiction of capital in nature is found in the totality of its productive-consumptive form that produces endless growth.*

c) A consensus can be observed, albeit from different perspectives and different conceptualizations in each of the traditions, on the disjunction of ecosystemic moments and the logic of the economy or capitalism. *The contradiction of capital-nature or between the economy and the environment is found in the progressive decoupling of the times of accumulation from the cycles of renewal, adaptation, and assimilation of ecosystems.* Despite the controversy over this term, it can be argued that the growing gap between natural and accumulation moments does indeed originate in an irremediable *metabolic contradiction* within the logic of capital. Historical-environmental crisis is simultaneously one single and two separate processes at the same time, because capitalism, as an economic system which has come to occupy the biosphere, is a way of remaking nature whose logic tends to undermine the basis of its renewal.

The capital-nature contradiction can be synthesized as a theoretical concept, with analytical density explained by the logic of the incessant accumulation of capital, by the form of global production-consumption structures and exchanges, as well as by the metabolic contradiction of accumulation moments and cycles of renewal of nature. The capital-nature contradiction, a "living" contradiction, demands further research which transcends the agenda of renewable energies, market mechanisms, and technological confidence, and seeks to design alternative productive-consumptive modes, in contrast to the unsustainable current modes of production and accumulation.

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