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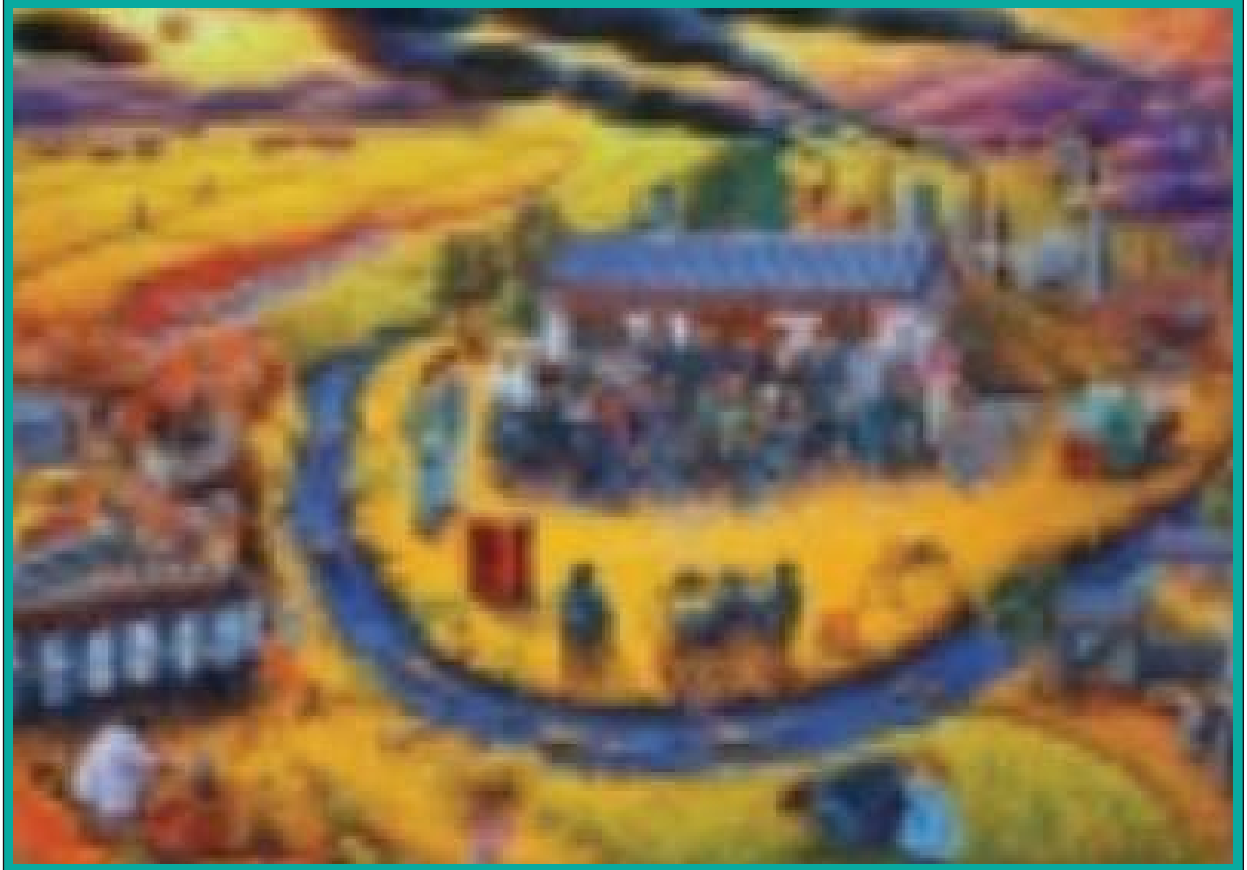

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The theory of unequal ecological exchange: a Marx-Odum dialectic

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A world-system analysis of the ecological rift generated by capitalism requires as one of its elements a developed theory of the unequal ecological exchange between center and periphery. After reviewing the literature on unequal exchange (both economic and ecological) from Ricardo and Marx to the present, a new approach is provided, based on a critical appropriation of systems ecologist Howard Odum's emergy (spelled with an m) analysis. Odum's contribution offers key elements of a wider dialectical synthesis, made possible in part by his intensive studies of Marx's political-economic critique of capitalism and by Marx's own theory of metabolic rift.

Keywords: unequal ecological exchange; energy; emergy; metabolic rift; capitalism; Marx; HT Odum; world-system

The search for a meaningful theory of ecological imperialism has become in many ways the holy grail of the ecological critique of the capitalist world system. From somewhat different but related standpoints, world-systems sociologists, development theorists, systems ecologists, ecological economists, environmental sociologists and environmental historians have all been searching for a consistent approach to this core problem, which is tied up with such crucial issues as the metabolic rift, unequal ecological exchange, ecological debt, ecological footprints, the resource curse, embodied carbon and global environmental justice.

Over the last decade, two bodies of work have emerged in sociology addressing ecological imperialism: (1) metabolic-rift analysis and (2) studies of unequal ecological exchange (sometimes called 'ecologically unequal exchange').[1] In the first of these, as Schneider and McMichael (2010, 461) state, 'Marx's concept of the "metabolic rift" … in the context of an international peasant mobilisation embracing the science of ecology … has become the focal point of attempts to restore forms of agriculture that are environmentally and socially sustainable', transcending relations that are widely viewed to be the product of ecological imperialism. Works in this tradition include such important contributions as: Foster 1999, 2000, Moore 2000, 2011a, Burkett 2006, Clausen 2007, Wittman 2009, Foster *et al*. 2010, Schneider and McMichael 2010, Gunderson 2011,

[1]Neither the metabolic rift, which is associated with contradictions in the human metabolism with nature, nor unequal ecological exchange, which arises from the disparities between relatively urban/industrialized and rural/underdeveloped regions, is exclusively concerned with North-South imperialism, since the effects are internal to given nations/regions as well. Here, however, we will be looking at these theories specifically in relation to imperialism, i.e. in terms of the global metabolic rift, and global unequal ecological exchange.

Dobrovolski 2012. Alongside this research on the metabolic rift, a second, related literature emerged consisting of a number of pioneering empirical-historical studies directed at the unequal ecological exchange relations between core and periphery of the capitalist world economy, in an attempt to gauge the ecological disadvantages that have been systematically imposed on the periphery (e.g. Hornborg 2006, 2011, Jorgenson 2006, Jorgenson and Rice 2007, Lawrence 2009, Jorgenson and Clark 2009, 2012, Jorgenson *et al*. 2009, Clark and Foster 2009).

The obvious question that arises from these two literatures, taken together, is: to what extent is unequal ecological exchange a source of the global metabolic rift, with the 'free environment' of the periphery being sacrificed on the altar of the gods of profit and accumulation in the center? The present contribution attempts to help develop an answer to this question by providing the basis for a more comprehensive theory of unequal ecological exchange – since much of the problem at present, we argue, lies in the under-theorization of this key concept.[2]

The possibility of a more comprehensive theoretical and empirical approach to the unequal-exchange issue, we believe, is offered through a critical engagement with the work of systems ecologist Howard T. Odum. In a series of studies mainly over a two-decade period (1983–2002), Odum (1988, 1996, 2007, Odum and Arding 1991, Odum and Odum 2001) developed an illuminating theory of what he called 'imperial capitalism', in which embodied energy (emergy) exchanged was shown typically to be 'several hundred percent higher' per dollar for the peripheral, primary resource-exporting countries than for their core counterparts (Odum 2007, 276–7).

Our approach to Odum's analysis, we stress at the outset, is not an uncritical one, but rather a 'critical appropriation', somewhat akin to Marx's response to the physiocrats (Burkett 2006, 35). Odum's sophisticated scientific approach to systems ecology can be seen as falling prey at times to a kind of physico-reductionism, when viewed from the wider standpoints of natural evolution and historical society. But like much of systems theory it can also be viewed as a holistic attempt to break out of the crude reductionism that has plagued so much of modern science (Levins 2008). 'Systems science', at its best, is 'a technical application of holistic, materialist philosophy' (Golley 1993, 33).

Odum's theory of unequal ecological exchange, we will argue, is largely free from the reductionism that plagues his overarching systems theory, since the former rests mainly on the extent to which nations or regions draw on their 'free environment' in their economic activity, and the global inequalities with which this is associated. It thus is closely related to Marx's analysis of capitalism's metabolic rift. Although there is no single measure for unequal ecological exchange in all of its manifold historical and qualitative dimensions – how do we begin to quantify the loss of even a single species? – Odum's emergy (spelled with an m) approach sought to create a common metric for energy used in production and to explore relations of unequal ecological exchange in this regard. Odum thus provided a mode of analysis and an empirical indicator with which to gauge the vast ecological gains realized by the center capitalist states, and the corresponding losses inflicted on the periphery.

[2]Our goal here is merely to *open the door* to what we hope will eventually be a comprehensive theory – one that would need to be integrated with issues of history, geography and co-evolutionary development, encompassing the whole formation of the world-capitalist system, including its \historical logic and crises.

While at times Odum (1983, 252) seemed to argue for an 'energy theory of value', he explained on numerous occasions that emergy analysis was not meant as an energy theory of economic/monetary value, but rather an attempt to gauge *real* wealth in terms of energy. The goal here was to find a material-ecological basis for the critique of the capitalist economy and orthodox, neoclassical economics. The success of this endeavor was necessarily limited, since the world of nature and of production in general is so complex and variegated as to raise fundamental problems of incommensurability facing anyone attempting to bring it within a single measure, such as energy accounting. Nevertheless, Odum's analysis highlighted the ecological-economic contradictions of the capitalist system and pulled the legs out from under neoclassical economics' scientific claims.

What makes an approach to unequal ecological exchange drawing critically on Odum's analysis especially intriguing, in our view, is that it represents a crucial interface between ecological science and Marxian theory. Odum, along with David Scienceman, was engaged in a continual dialogue with Marxian theory for around two decades, from 1983 on, resulting not only in in-depth studies into the work of Marx himself, but also of various Marxist theorists of unequal (economic) exchange, such as Becker (1977) and Amin (1976) (see Odum 1983, 265, Scienceman 1987, 1989, 1992, Odum and Scienceman 2005). Attention to Marx's work grew rather than diminished as Odum's analysis advanced, with particular reference to the logic of unequal-exchange relations. The Marx-Odum connection, moreover, was made possible by Marx's own deep concern with the problem of the metabolic rift between human society and the natural environment, and hence the way in which his work was embedded in an ecological critique.

In this contribution, we thus seek to point to the general theoretical foundations of what we are referring to tentatively as a Marx-Odum dialectic in the treatment of unequal ecological exchange – tied to a more general critique of capitalism's metabolic rift (Foster 1999, 2000, Burkett 2006, Foster *et al*. 2010, Schneider and McMichael 2010, Moore 2011a).[3] In order to do this it is necessary to trace out the theoretical development of both unequal economic exchange and unequal ecological exchange from the nineteenth century to the present, and show how Odum's analysis, though emerging out of physical science, represents a serious attempt to interface with Marxian and world-system analysis. In this way we hope to contribute to the eventual development of a broader world-system/earth-system analysis.

The theory of unequal economic exchange

Although our chief concern here is with unequal ecological exchange rather than unequal economic exchange, the logical and historical relationship between the two is so intertwined as to necessitate a brief history of the latter. The issue of unequal economic exchange, particularly in international transactions, was a problem intrinsic to classical political economy.[4] Most of the major contributors to classical political economy – Smith,

[3]In this paper we are primarily concerned with advancing a more critical and cohesive approach to the concept of unequal ecological exchange, while emphasizing the potential synthesis with Marx's metabolic rift approach. It is beyond the confines of our study here to address the question of recent important criticism/critical extensions of Marx's concept of the metabolic rift itself. In this regard see Schneider and McMichael (2010) and Moore (2011).

[4]In what follows we take it for granted that all of the major Marxian theories of imperialism – e.g. those of Marx ([1863–65] 1981), Luxemburg ([1913] 2003), Bukharin ([1915] 1973), Lenin ([1916] 1939), Amin (1977a), Emmanuel (1972), Baran (1957), Magdoff (1978), and Harvey

Ricardo, J.S. Mill and Marx – wrote extensively on colonialism and the question of the pillage during the mercantilist era of what is now known as the third world (Winch 1965). For liberal political economists, such as Smith ([1776] 1937), Ricardo ([1817] 1951) and Mill ([1829–30] 1877), criticism of colonial practices was part of a general theoretical defense of free trade.

The theory of unequal exchange itself arose, ironically, out of the Ricardian theory of international trade (Ricardo [1817] 1951, 128–49). Ricardo's famous theory of comparative advantages in international exchange relations was originally illustrated using a two-production sector, two-country model – wine and cloth in Portugal and England. Portugal, in Ricardo's example, produced both wine and cloth more efficiently, i.e. with less total labor time than England, and thus had an absolute advantage over England in the production of both commodities. Nevertheless, Portugal had a comparative advantage in making wine over cloth, since it was most efficient in producing the former, while England had a comparative advantage in producing cloth over wine. Under these circumstances, both countries would be best off, he demonstrated, if they each specialized in trading that product in which they were relatively most efficient – in Portugal's case wine, in England's cloth. The result would be to provide the maximum benefit in terms of the total use values produced (cloth and wine) for both countries (see Hunt and Lautzenheiser 2011, 119–20). This theory still remains the basis of mainstream international trade theory, repeated in every introductory economics textbook.

In presenting his theory of comparative advantages and international trade, Ricardo inverted his usual economic standpoint, developing an argument that was based not on value generated in production and the formation of prices of production, but rather on supply and demand. Rooting his argument in the then-realistic assumption of the international immobility of capital and labor, Ricardo saw trade in the international realm as dictating to production rather than the other way around (Amin 1977a, 184). This inversion of the argument of classical economics diverted attention from the fact, well recognized by Ricardo ([1817] 1951, 135–6), Mill ([1829–30] 1877, 2) and Marx ([1861–63] 1971, 105–6), that the reality behind the Ricardian comparative advantage theory was one of unequal exchange (associated with differing productivities and labor intensities in different countries). Hence, Ricardo ([1817] 1951, 135–6) himself acknowledged as part of his theory that trade would result in one country receiving less labor for more, while the other country would be gaining more labor for less, reflecting the greater intensity and productivity of labor in one country as opposed to the other. 'All that this theory [the Ricardian theory of comparative advantages in international trade] allows us to state', Amin (1976, 134–5) sums up, 'is that, at a given moment, the distribution of levels of productivity being what it is, it is to the interest of the two countries to effect an exchange, even though it is unequal'.

For Marx – although he did not write his planned volume on the world economy and crises (see Rosdolsky 1977, 12, Lebowitz 1992), and did not develop his ideas fully on the subject – the reality of unequal economic exchange was obviously of great importance. 'Even according to Ricardo's theory', Marx ([1861–63] 1971, 105–6) noted, 'three days'

(2003) – are integrally related to theories of unequal exchange. However, our treatment of imperialism here is necessarily confined to those points where unequal-exchange theory (both economic and ecological) overlaps with the larger Marxian theory of imperialism. Although a wider synthesis of unequal-exchange analysis with imperialism theory as a whole is, in our view, essential, such an overall synthesis is beyond the limits of our present paper – which may serve, however, to lay some of the crucial foundations for a more unified theory.

labour of one country can be exchanged against one of another country … . In this case, the richer country exploits the poorer one, even where the latter gains by the exchange, as John Stuart Mill explains in his *Some unsettled questions*.' In international trade, Marx ([1863–65] 1981, 345) observed in *Capital*, 'the privileged country receives more labour in exchange for less', thereby obtaining 'surplus profit', while, inversely, the poorer country 'gives more objectified labour in kind than it receives'. Likewise: 'Two nations may exchange according to the law of profit in such a way that both gain, but one is always defrauded … . One of the nations may continually appropriate for itself a part of the surplus labour of the other, giving back nothing for it in the exchange' (Marx [1857–58] 1973, 872). Related to this was the fact that 'the profit rate is generally higher there [in the periphery] on account of the lower degree of development, and so too is the exploitation of labour, through the use of slaves and coolies, etc.' (Marx ([1863–65] 1981, 345). Cheaper imports could thus raise the rate of profit in the metropolitan countries by reducing the costs of subsistence or of constant capital. It was therefore possible to see 'how one nation can grow rich at the expense of another' even under conditions of free trade, and the more so where monopolies and colonial relations apply (Marx [1848] 1963a, 223; see also Dobb 1945, 226–7, Rosdolsky 1977, 307–2).

If Marx laid the foundations of unequal exchange analysis, the articulation of a definite theory of unequal exchange is usually thought as having emerged with the work of the Austrian Marxist Otto Bauer, who argued:

> The capital of a more highly developed region has a higher organic composition, which means that in this more advanced area a larger quantity of constant capital corresponds to the same size of wage fund (variable capital) than in the backward area. Now Marx has taught that owing to the tendency to equalization of the rate of profit, it is not the labor of each of the two areas respectively that produces the surplus value taken by each area's capitalists: the totality of the surplus value produced by the workers of both areas will be shared between the capitalists of those two areas not in proportion to the amount of labor contributed in each but in proportion to the amount of capital invested in each. Since in the more highly developed area there is more capital to the same amount of labor, this area appropriates a larger share of the surplus value than would correspond to the amount of labor it has contributed … . Thus, the capitalists of the more highly developed areas not only exploit their own workers but also appropriate some of the surplus value produced in the less highly developed areas. If we consider the prices of commodities, each area receives in exchange as much as it has given. But if we look at the values involved we see that the things exchanged are not equivalent. (Bauer [1924] 2000, 200; translation following Emmanuel 1972, 175)

Bauer's argument necessarily departed from Ricardian theory of foreign trade premised on the international immobility of capital by pointing to the competitive equalization of profit rates between regions or countries, which could only occur on the basis of capital mobility. This approach to unequal exchange associated with the effects of differing organic compositions of capital has been called 'unequal exchange in the broad sense' (Emmanuel 1972, 167, Carchedi 1991, 222–5).

The notion that unequal exchange derived from differences in organic composition was one that received considerable support among Marxist economists, with Henryk Grossman notably following the main lines of Bauer's argument. 'International trade', Grossman ([1929] 1992, 170) argued:

> is not based on an exchange of equivalents because, as on the national market, there is a tendency for the rate of profit to be equalized. The commodities of the advanced capitalist country

> with the higher organic composition will therefore be sold at prices of production higher than value; those of the backward country at prices of production lower than value.

Such non-equivalent exchange theory played a significant role in Soviet debates on the economic relations between developed and underdeveloped regions (Preobrazhensky [1926] 1965, 5, 227, 262).

In the 1970s, a different but related theory of unequal exchange appeared in the work of Emmanuel (1972) and Amin (1976, 1977a) that viewed unequal exchange in its most appropriate designation not as arising primarily through differences in organic composition between countries, but rather from differences in wage levels and rates of surplus value – in those cases where the differences in wages were greater than the differences in productivities. For Emmanuel (1972, 167), this 'narrower' conception of wage-based unequal exchange was seen as rooted in the international mobility of capital and the international equalization of profits – together with the international immobility of labor. Transfer of free or 'hidden' value from high-wage to low-wage countries was viewed as occurring by means of the price mechanism (Emmanuel 1972, xxxiii–iv, 91, 160–1, 367, 381–3). Emmanuel's analysis stipulated that free trade conditions applied and strictly excluded monopoly as a consideration. 'As for the actions of the monopolies, of which the Marxist authors talk so much, this question is as remote from our subject as any other form of direct plunder of the underdeveloped countries by the rich and strong ones' (Emmanuel 1972, 93).

Emmanuel's rejection of monopoly and plunder as factors – given that his goal was to demonstrate the existence of unequal exchange even under free-trade conditions – made his theory less historically relevant, and led to a shift toward a more realistic, if less logically tight, theory of unequal exchange. This could already be seen in the broad tradition of dependency and world-system theory associated with Baran, Sweezy, Frank and Wallerstein (Brolin 2006, 70–1). It was in this wider, historical sense of unequal exchange that leading Marxist thinkers such as Paul Baran, Paul Sweezy and Ernesto 'Che' Guevara referred to unequal exchange in the early 1960s. Writing in 1964, Baran and Sweezy (1966, 15) explained:

> Unequal relations between the developed and underdeveloped countries result in the establishment of terms of trade which greatly favor the former at the expense of the latter. In this way wealth is transferred from the poor countries to the rich.

Yet, their analysis did not stop with mere trade but emphasized the manifold ways in which monopolistic multinational corporations created a net flow of surplus from the underdeveloped countries to the developed countries. Che wrote of 'prices forced on the backward countries by the law of value and the international relations of unequal exchange that result from the law of value'. The 'so-called deterioration of the terms of trade' was 'nothing but the result of the unequal exchange between countries producing raw materials and industrial countries, which dominate markets and impose the illusory justice of equal exchange of values'. Che argued that 'monopoly capital' now dominated the world, imposing its wider forms of exploitation and unequal exchange (Guevara 1997, 291, 302–3).

For Wallerstein (2004a, 28) 'unequal exchange' develops from a quasi-monopoly system involving 'politically strong' core states and their economically strong corporations

and is not easily distinguished from 'plunder'.[5] It was in this wider, historical sense – extending Emmanuel's earlier free-trade-based analysis to account for a reality in which monopoly played a central role – that unequal exchange became a generally accepted part of world-system theory (see, for example, Chase-Dunn 1998, 59).

The synthesis of these various traditions was left to Amin (1976, 1977a, 2010), who stressed that Emmanuel's work derived its importance from its focus on global wage inequality and the problem of 'international value'. Viewing actual historical conditions in terms of a world of increasingly 'generalized monopolies' (monopolistic multinational corporations), Amin (1977a, 2010, 2012) emphasized the tendency toward equality in organic composition of capital (i.e. productivities) worldwide, since the same technology was increasingly being employed everywhere. This nonetheless was accompanied by wage inequality, unequal rates of surplus value, and higher profits in the periphery than the center. These conditions pointed to a theory of unequal exchange as a global transfer of value or 'imperial rent' (Mandel 1975, 343–76, Köhler 1999, 2003, Amin 2010, 2012). Trade inequities were accompanied by numerous other forms of surplus extraction from the periphery – all, however, rooted finally in the wage differentials between the global North and global South.

Much of today's imperial rent remains disguised by exchange rates (as indicated by the difference between market-value exchange rates and purchasing-power parities) (See Smith 2012). Nevertheless, unequal exchange can be shown to be broadly measurable in order of magnitude (Amin 1980, 2012, Köhler 2003). Unequal economic exchange/imperial rent rests ultimately on the fact that the differences in wages between center and periphery are greater than the productivities, allowing extensive capture by the center economies of value created in the periphery (Amin 1977b, 6, Amin 2012, Smith 2012). This embodies the fundamental characteristic of all unequal economic exchange: the exchange of more labor for less.

The theory of unequal ecological exchange

Just as unequal economic exchange theory postulated the exchange of more labor for less, unequal ecological exchange theory had as its basis the exchange of more ecological use value (or nature's product) for less. Unequal ecological exchange was first raised as a major issue in the work of Liebig and Marx. From the 1840s to the 1860s, the great German chemist Justus von Liebig introduced a critique of industrial agriculture as practiced most fully in England, referring to this as a condition of '*Raubbau*' or the '*Raubsystem*' (Brock 1997, 177–8), i.e. a system of robbery or overexploitation of the land and agriculture at the behest of the new industrial capitalism emerging in the towns. In Liebig's view, the elementary soil nutrients, nitrogen, phosphorus and potassium, were being removed from the soil and sent to the cities in the form of food and fiber, where they ended up contributing to pollution rather than being re-circulated to the soil. The result was the systematic robbing of the soil of its nutrients. English agriculture, then, tried to compensate for this by importing bones from the catacombs and battlefields of Europe and guano from Peru. 'Great Britain', Liebig wrote,

> deprives all countries of the conditions of their fertility. It has raked up the battlefields of Leipsic, Waterloo, and the Crimea; it has consumed the bones of many generations accumulated in the catacombs of Sicily; and now annually destroys the food for future generation

[5]Wallerstein's initial position seems to have been closer to Emmanuel's. See Wallerstein (1974, 5).

> of three millions and a half of people. Like a vampire it hangs on the breast of Europe, and even the world, sucking its lifeblood. (Liebig quoted in Mårald 2002, 74)

Marx ([1863–65] 1981, 949, [1867] 1976, 283, 290, 636–9) developed Liebig's approach into a more systematic ecological critique of capitalism by designating the robbery of the earth as 'an irreparable rift in the interdependent process of social metabolism', or *metabolic rift*. Such conditions were, for Marx ([1867] 1976, 283, 290), the material counterpart of the capitalist organization of labor and production. It constituted the alienation of the 'metabolic interaction' between humanity and the earth, i.e. of the 'universal condition' of human existence.[6]

The metabolic rift under capitalism was connected to unequal ecological exchange. England, as the leading capitalist country at the center of a world-system, Marx stated, was 'the metropolis of landlordism and capitalism all over the world', drawing on the resources of the globe, with nations in the periphery often reduced to mere raw material providers. 'One part of the globe' is converted 'into a chiefly agricultural [and raw material] field of production for supplying the other part, which remains a pre-eminently industrial field'. Thus a whole nation, such as Ireland, could be turned into 'mere pasture land which provides the English market with meat and wool at the cheapest possible prices'. Indeed, Ireland was reduced by imperialist means to 'merely an agricultural district of England which happens to be divided by a wide stretch of water from the country for which it provides corn, wool, cattle and industrial and military recruits'. The resulting 'misuse' of 'certain portions of the globe' in the periphery of the system is thus determined by the accumulation imperatives of the center (Marx and Engels 1972, 290–2, Marx [1867] 1976, 579–80, 860, [1863–65] 1981, 753, 949, Clark and Foster 2012, 70). Marx ([1867] 1976, 860) illustrated the absolute robbery involved in the appropriation of the natural wealth of the one country by another by stating, 'England has indirectly exported the soil of Ireland, without even allowing the cultivators the means for replacing the constituents of the exhausted soil'.[7] Like Liebig, Marx pointed to the fact that England was forced to import guano in massive quantities from Peru (in a world-system of exploitation that also involved importing Chinese labor to dig the guano) in order to make up for the loss of nutrients in English fields (Clark and Foster 2012).

Marx saw production as a flow of both material use values and exchange values or, simply, values. He used the term 'metabolism' (*Stoffwechsel*) to refer to the material exchange (the exchange of matter-energy) that always accompanied monetary exchange of value (Marx [1879–80] 1974, 209). Such material exchange was associated with the production of use values, representing the material conditions of production in general, as opposed to exchange value (value). A social 'use value' is quite literally for Marx ([1867] 1976, 287) a 'piece of natural material adapted to human needs by means of a change in its form'. It was this twofold aspect of his analysis – as material-physical and value-related – that allowed Marx to perceive the contradictions between use value and exchange value and between the accumulation process and natural-material conditions

[6]Martinez-Alier (2002, 214) refers to the unequal exchange concept as 'building on earlier notions such as *Raubwirtschaft* or "plunder economy"'. It is important to note that Weber too followed Liebig and Marx in raising the question of *Raubbau* as it related to the robbing of the earth by capitalist industry. See Foster and Holleman (2012, 1650–5).

[7]Marx's argument here contradicts Hornborg's (2006, 169) contention that 'Marx was probably too focused on the exploitation of labor to see that unequal exchange could also take the form of draining another society's natural resources'.

(Marx [1879–80] 1974, 208–10). In Marxian theory, this has been understood as constituting the dual value problems: 'the qualitative value problem' and the 'quantitative value problem' (Sweezy 1942, 23–55). Unequal economic exchange is mainly concerned with a quantitative value problem related to exchange-value relations (and a break in this at the international level), while unequal ecological exchange is chiefly concerned with use-value relations and real wealth (including the contradictions between use value and exchange value).[8]

Marx ([1867] 1976, 290) emphasized that human production still employed 'many means of production which are provided directly by nature and do not represent any combination of natural substances with human labour'. Such direct products of nature, the result of nature's work, were treated under capitalism, he pointed out (following the classical political economists who had preceded him), as 'free gifts' that did not enter into the value process of the system.

Consistent with this, Marx drew a distinction between real 'wealth', to which both nature and labor contributed, and value, where only labor was taken into account (Marx [1875] 1938, 3, [1867] 1976, 134, Foster *et al*. 2010, 61–4).[9] It was the inherently one-sided nature of the value calculus of capitalist production that led to the robbing of nature – that is, the failure to provide for the full 'restoration' of what had been taken from the earth. 'Capitalist production', he wrote, 'only develops … by simultaneously undermining the original sources of all wealth – the soil and the worker' (Marx [1867] 1976, 134, 636–9).

Recent scholarship (Burkett and Foster 2006, 2008, Wendling 2009) has shown the extent to which Marx integrated his political economic analysis with the new conception of thermodynamics appearing in his time, as reflected in his argument on metabolism.[10] It is hardly surprising, therefore, that most early forms of ecological economics were heavily indebted to Marx (Martinez-Alier 1987).

Marx's treatment of unequal exchange, imperialism and the global metabolic rift meant that the notion of unequal ecological exchange arose periodically in Marxian political economy – although its role within the Marxian critique was minor prior to the 1970s.

[8]Marx's value analysis is often seen too narrowly in terms of the quantitative-value problem, and thus related simply to exchange value (or to 'value' viewed simply in its quantitative aspect). However, no less crucial to Marx's entire value-theoretic framework is use value (related to production in general and to *real wealth*). Wealth, in Marx's analysis, is derived from both nature and labor (as distinct from 'value' under capitalism which comes only from labor). Thus, in order fully to grasp Marx's value-theoretic framework, it is necessary to incorporate the qualitative-value problem and the contradictions between (a) exchange value and use value and (b) 'value' and real wealth. (See Lebowitz 2009, 163–6, Foster, Clark, and York 2010, 61–4.) The brilliance of Odum's (and Scienceman's) analysis, as we shall see, is that it grasped this larger value-theoretic dialectic of Marx's political economy, leading to an argument on the contradiction between real wealth and capitalist value relations that in many ways paralleled Marx's own – and which becomes the key to a dialectical analysis of unequal ecological exchange.

[9]As Heinrich (2012, 42) explains, 'Things that are not products of labor', in Marx's theory, 'do not possess a "value". If they're exchanged, they have an exchange value or price, but no value, and this exchange value has to then be explained separately'. This sets up a situation where capitalism, as an economic system based on labor values, systematically robs nature, in the sense that no value is accorded to what are referred to in economics as nature's 'free gifts' and hence its reproduction is not provided for.

[10]However, Marx and Engels's very extensive studies of thermodynamics were not generally known until recently, even to those studying ecological economics. Thus less than a decade ago Hornborg (2006, 164) wrote that Marx was 'ignorant … of thermodynamics'.

For Galeano (1973, 72), production was so organized in colonial and neocolonial Latin America as to constitute 'a sieve for the draining-off of natural wealth' to the benefit of the colonizers. Emmanuel (1976) contended that the advanced capitalist countries were using up the ecological commons, ridding 'themselves of their wastes by dumping them into the sea or the air', which was possible because they were 'the only ones doing it' (72–3). Amin (1977a, 212) commented explicitly on 'a whole series of "unequal exchanges"' related to ecological factors existing side by side with the unequal exchange of labor. Such 'other forms of unequal exchange' were for Amin (1977a, 212) crucial to understanding the role that the extraction of natural resources from the periphery played in the overall analysis of imperialism:

> The capitalist system makes use of the precapitalist forms of appropriation that are current in the countries of the periphery in order to *not* to pay for the upkeep of the land. Systematic destruction of soils is a major factor of long-term impoverishment for the dependent countries. (Amin 1976, 154)

If Marxian political economy naturally led to theories of unequal ecological exchange, what is generally seen as the 'Malthusian' tradition (related specifically to carrying capacity) generated an approach that was in many ways overlapping.[11] In 1965, Georg Borgström, a food scientist at Michigan State University, published his book *The hungry planet*, which devoted a chapter to what he called 'ghost acreage'. What allowed some countries to overshoot their available land or ecological base was the import of food from elsewhere – other countries or the sea. Such 'ghost acres' permitted wealthy countries, like the Netherlands, to develop population density and industrialized production while having an inadequate agricultural base (and allowed them to draw on tropical products). In the poorer countries, meanwhile, committing this 'ghost acreage' to production for export to the rich countries decreased the food acreage available for local subsistence (Borgström 1965, 74–90, Catton 1982, 38–44). The idea of 'ghost acres' in terms of land was, Borgström (1965, 74–5) argued, aimed at providing a 'commensurate gauge' with which to record ecological usage. Thus he was concerned with 'devising methods whereby the use of commercial fertilizers and the energy inputs' used in agriculture could be 'computed in corresponding terms and added to the ghost acreages'. This approach can be regarded as a forerunner of ecological footprint analysis.

Within sociology, the issue of unequal ecological exchange is often seen as being brought to the forefront by Bunker's (1985) study, *Underdeveloping the Amazon: extraction, unequal exchange, and the failure of the modern state*. Bunker sought to incorporate 'mode of extraction' as the counterpart of the 'mode of production'. The unequal exchange of energy and materials occurred to the detriment of extractive economies or 'extreme peripheries'. 'There are', he wrote,

> multiple inequalities in international exchange. One, certainly, results from the differential wages of labor. Another, however, is in the transfer of the natural value in the raw resources from periphery to center … . The outward flows of energy and the absence of consumption-production linkages combine with the instability of external demand and with the depletion of site-specific natural resources to prevent the storage of energy in useful physical and social forms in

[11]Malthus's own work, including his well-known population theory, had nothing to do with notions of ecological carrying capacity of the earth and was in many ways anti-ecological in its thrust. See Foster (2000, 81–110).

> the periphery, and leave it increasingly vulnerable to domination by energy-intensifying social formations at the core. Finally, if the resources do not renew themselves naturally, the inequality of the exchange is intensified by the loss of resources and by the disruption of associated natural energy flows in the periphery itself. (Bunker 1985, 45)

Chase-Dunn (1998, 234) saw Bunker's analysis as a turning point in developing a theory of unequal ecological exchange, observing:

> Use values are lost to the [underdeveloped, extractive] region both through exports of the resources and through the disruption of the ecosystems from which they are extracted. Unequal exchange of labor is accompanied by the unequal exchange of matter and energy.

Still, despite the insights of such varied analysts, the problem of developing a coherent theoretical and empirical approach to the issue of unequal ecological exchange has remained. Some world-system theorists (e.g. Frank 2006) usefully argued that the dominant nineteenth-century world system was a dissipative structure imposing entropy on its periphery. But clear conceptual frameworks illustrating and operationalizing this were lacking.

A major breakthrough came with the development of ecological footprint analysis in the 1990s (Rees 1992, Wackernagel and Rees 1996). The ecological footprint was devised as the inverse of the old carrying capacity notion of ecology. Instead of asking, as in the analysis of carrying capacity, how much population or environmental load a particular unit of land would support, the ecological footprint inverted the question, asking how much land was required to support a particular environmental load, or a given population with a given per capita consumption. Land, measured in hectares, thus became a common metric for the extent of environmental services that went into providing a given consumption level on an indefinite basis.

Ecological footprint analysis has facilitated inquiries into the ecological impacts of nations by capturing the larger 'footprint' extending beyond national borders (York *et al*. 2003). This made it possible to determine the extent to which a given region or country overshot its own land/resources, relying on an environmental deficit or overdraft – or, alternatively 'environmental load displacement' – with respect to the rest of the globe (Wackernagel and Rees 1996, 48–55, Hornborg 2011, 14–20). By providing a basis, however limited, for measuring ecological consumption from the individual level all the way up to the world system, ecological footprint analysis, as Amin (2009) has insisted, made possible a more trenchant use-value-based critique of capitalist accumulation.

The ecological footprint has inspired considerable empirical research, mainly within sociology, directly aimed at assessing unequal ecological exchange (e.g. Jorgenson 2006, Rice 2007, Lawrence 2009, Jorgenson *et al*. 2009, Jorgenson and Clark 2009, 2012, Bonds and Downey 2012). Ecological footprint analysis demonstrates that larger footprints are primarily a function of economic development, and do not match the ecological carrying capacities of particular nations. The more developed countries have larger ecological footprints but less domestic environmental degradation within their borders, while less developed countries have smaller footprints and more environmental degradation within their borders (Jorgenson 2006, 686). The obvious explanation for these disproportionalities in environmental impact is that the center capitalist countries rely heavily on importing resources from countries of the periphery, and engage in various forms of outsourcing of production and environmental load displacement (Rice 2007, 1370).

Yet, while useful in demonstrating the uneven ecological impact of nations, in terms of the environmental loads they require to support their consumption and the uneven

appropriation of global environmental space, the ecological footprint does not in itself measure actual material exchanges, the use-value transfer or the spatial origins of goods consumed (Jorgenson 2006, 689, Rice 2007, 1373).[12] World-system analysts and environmental sociologists concerned with unequal ecological exchange have therefore sought to connect the dots, employing price-based data to show that those less-developed countries with a relatively higher level of exports to developed countries have, at the same time, smaller ecological footprints and suffer disproportionate environmental degradation. In such analysis it is presumed, based on historical experience (see Jorgenson 2006, 691), that exports from the periphery are heavily weighted to natural-resource exports. However, the price-based data used in broad cross-national studies do not generally allow for disaggregation of the types (physical character) of goods traded, while exports from the global South are increasingly manufacturing-based, calling into question this assumption. The whole argument relies on broad inferences from price relations without a direct consideration of transfers of real wealth.

Indeed, the theory of unequal ecological exchange that emerged from such studies has been devised in a somewhat Procrustean manner to fit the empirical data available. Although recent studies in environmental sociology and ecological economics strongly point to the existence of ecologically unequal exchange, there are serious problems at the level of both empirical analysis and, more importantly, underlying theory. Existing approaches have relied on data in which the ecological (indeed physical) content of the goods is unknown and quantitative measures are in terms of prices rather than goods. As a result, very little is actually revealed in most current empirical studies of ecologically unequal exchange about the ecological nature of the exchange itself – in terms of matter, energy, resources, etc. The theory, which is harnessed to such empirical data, is vague and roundabout, drawing large generalizations about environmental load displacement, while failing to engage directly with what would logically constitute the core element in any theory of unequal ecological exchange: the exchange of more ecological wealth for less. For example, Jorgenson (2006, 691) tells us in a roundabout way what we already know: that

> developed countries with higher levels of resource consumption externalize their consumption-based environmental costs to less-developed countries, which increase levels of environmental degradation within the latter … . The majority of extracted materials as well as agricultural products and produced goods [of underdeveloped countries] are exported to and consumed in more-developed countries.

Despite the pioneering nature of such analyses, we learn little or nothing here about the processes involved or the real extent of the unequal exchange.

In short, the standard analyses of 'ecologically unequal exchange' are dependent largely on ecological-footprint analysis, arising from the traditional notions of carrying capacity. This is then coupled with an examination of trade relations in price terms (mostly with respect to the directionality of trade). All of this represents an attempt to establish broad correlations – as opposed to a historical-theoretical examination of the structures and processes of unequal ecological exchange within the world system. Despite the fact that the concepts of unequal economic exchange and unequal ecological exchange both arose from classical-Marxian theory, there is no direct recourse to classical-Marxian analysis,

[12]A step in the right direction has been the new, improved method of ecological footprint analysis developed by Wackernagel *et al*. (1999), where an attempt is made to include estimates of embodied energy of net-non-energy products.

beyond the inconsistent allusions of Bunker (1985, 34–7, 44–5), who rejects the labor theory of value (along with neoclassical theory) in favor of an undefined theory of 'natural value'. As a critique, the standard ecologically unequal exchange perspective therefore remains theoretically undeveloped, failing to make full use of the crucial use-value and exchange-value distinction of the classical-Marxian value-based perspective.

The main obstacle confronting empirical analysis within this theoretical domain is of course the problem of incommensurability: the lack of a common metric (Martinez-Alier 2002, 216–7) beyond price. The problem in conceiving processes of unequal exchange, as Hornborg (2006, 171) put it, is that

> most trade statistics are in monetary units, rather than invested labor time, energy, or hectares … . If invested energy (Odum and Arding 1991) or hectares (Wackernagel and Rees 1996) were counted instead of dollars, the significance of imports from the south would be recognized as much greater than that suggested by monetary measures.

In essence, the problem becomes the lack of a common metric (or a number of related common metrics) with which to begin to analyze unequal ecological exchange. It is here that Odum's analysis takes on significance.

Odum and real wealth analysis

Howard Odum and his older brother Eugene Odum are generally considered the foremost systems ecologists of the late twentieth century, having largely created the field (Hagen 1992, 122–145). They co-authored *The fundamentals of ecology*, the foundational text in systems ecology, which 'created a generation of ecosystem ecologists – as distinct from plant ecologists and animal ecologists – who were prepared mentally and technically to contribute to the environmental decades' (Golley 1993, 69). What was previously a narrow, technical field was brought into the mainstream of biological analysis (Hagen 1992, 126). Central to their work was the use of the concept of metabolism to refer to all biological levels from the cell to the ecosystem (Odum 1969).[13]

In the final decades of his life, from 1983–2002, Howard Odum developed a method for measuring the total work of ecosystems embodied in commodities resulting from economic and ecosystem processes. This provided a way of calculating the extent of natural wealth (in energy terms) exchanged between countries, or the loss of a country's natural endowment through commodity trade. He called this embodied ecosystem-work – measured in terms of the energy required to produce or sustain a commodity, natural resource or entire national economic system – *emergy* (spelled with an m). Emergy thus was meant, in Odum's conception, to provide a common energetic metric for measuring real wealth/use values.

[13]As we shall see below, Howard Odum studied Marx's political economy very closely. Yet, although Odum played a critical role in introducing the concept of metabolism into ecosystem analysis and systems ecology more generally, he was not directly aware of Marx's own treatment of metabolism and his theory of metabolic rift. This was because the original translation of Marx's *Capital* into English, which Odum studied, used the words 'material exchange' in those instances where Marx had used *Stoffwechsel* (metabolism). Moreover, analysis of Marx's theory of metabolic rift emerged at the very end of the twentieth century (Foster 1999) and in sociology. Recent scholarship on Marx and thermodynamics (Burkett and Foster 2006, Wendling 2009) appeared only after Odum's death. Nevertheless, Odum and Scienceman, as indicated below, were aware of some of the thermodynamic aspects of Marx's thought and even referred to the 'metabolic rate of labor' in Marx's theory (Scienceman 1992, 33).

For Odum (2007, 276), unequal ecological exchange arose as a result of 'imperial capitalism'. Trade relations, it was shown, resulted in some countries exchanging more emergy (embodied energy) for less. Given large inequalities in ecological exchange, it was impossible for peripheral countries to foster long-term development that was both ecologically sustainable and relied on exports so long as unequal ecological trade relationships persisted. The analysis was constructed with close analytical attention to Marxian value theory and Marxian theories of unequal exchange, which were used as ways of getting at the somewhat parallel considerations of emergy analysis.

Odum made it clear, repeating this again and again (e.g. Odum and Arding 1991, 109), that he was not attempting to construct an energy theory of economic value. Rather, in a manner somewhat parallel to Marx's theory, the analysis pointed to circuits of material use value and exchange value (abstract value) that were in contradictory relation to each other (economic value moving in a circular flow, energy/emergy within a thermodynamically open system) – resulting in the robbing of the earth and the failure to provide for the replacement of lost ecological wealth in a system dominated by the accumulation of labor values.[14]

The key to Odum's theory of unequal ecological exchange was the emergy concept. The emergy nomenclature (emergy, transformity, empower, emvalue and emdollar) and the conceptual innovations accompanying it were introduced by David Scienceman in collaboration with Odum, beginning in 1983, following Scienceman's study of Odum's *Systems ecology* (1983). The original motivation for devising the new terminology was to avoid confusions that had arisen in Odum's (1983, 251–68) theory through his use of the concept of 'embodied energy' – a notion which allowed for numerous interpretations and appeared to conflict with the way the concept of energy was commonly used in science to refer to available energy or exergy (Scienceman 1995, 253). Moreover, the concept of 'embodied energy' was often confusing, since 'embodied', in the sense that Odum used it, meant something more like the effects of a jelly bean entering a body than a bullet, i.e. the energy was utilized and dissipated (253). The essential idea of Odum's 'embodied energy' was one of the past energy, no longer physically present in the same form or degree, that went into making an object or product – an approach roughly analogous to Marx's concept of value as arising from dated inputs of labor. All of this led to the introduction of the emergy category. As Odum (1995, 318) explained:

> In 1983, the term EMERGY, spelled with an 'M', was suggested by David Scienceman for our concept [of embodied energy] and emjoule or emcalorie as the unit … . EMERGY is defined as the energy of one kind required directly and indirectly to produce a service or product … For example, the production of green plants can be expressed in solar emjoules, which includes the solar energy required to make all the inputs to the plant, such as rain, wind, nutrients, cultivation efforts, seeds, and so forth.

In essence, 'EMERGY, a measure of real wealth, is the work previously required to generate a product or service' (Odum 1996, vii). The 'm' in emergy was meant to symbolize

[14]Odum's approach resembled in some ways that of the physiocrats, who, according to Marx ([1861–63] 1963b, 52, Burkett 2006, 33), 'conceived value merely as use-value, merely as material substance'. Nevertheless, Odum's analysis took on a much more critical form (influenced no doubt in part by his studies of Marx) whereby 'use value' – for Odum 'emvalue' or 'emergy' – was used as a basis for a thoroughgoing critique of capitalist commodity-exchange values, which were understood as entirely based on labor or 'human services', excluding nature from the calculations (Scienceman 1992, 33).

energy memory, or the fact that this was an accounting system aimed at total energy inputs over time (Scienceman 1987, 262).

Emergy analysis was aimed at a method that would take the various forms of energy that went into the making of a product or service and transform them into 'units of one kind'. Crucial to this was the concept of 'transformity', defined as 'the EMERGY of one type required to make a unit of energy of another type' (Odum 1991, 114; see also Odum 1996, 13, 289, Odum 1995, 317, Odum and Arding 1991, 99), usually measured in solar emjoules. 'Because EMERGY evaluation traces what was required for a product back to a common form of energy, it is a way of showing how the requirements for different products compare' (Odum and Arding 1991, 100).

Goods with higher transformity represented dated inputs of emergy (including entropy or dissipated energy) that went into their production. Higher transformity was associated with the emergence, at higher levels of production, of more useful products, i.e. in forms more accessible to human beings. One cannot eat sunlight or crude oil, but one can eat potatoes grown with the aid of such energy sources.[15] Thus 'work increases the utility of energy while degrading and dispersing part of that energy' (Odum 1995, 317).[16] For example, it is well known that it takes about 4 calories of coal to generate a calorie of electric power, giving electricity 'a higher transformity', associated with greater usefulness, and higher quality – even though available energy has been lost in the process (Odum and Odum 2001, 68, Odum 1996, 289).

Odum's emergy concept and his notion of transformity are especially indebted to Lotka's (1925) development of the maximum power principle as a law of thermodynamics. However, because Lotka did not specify systems principles based on qualities of energy, Odum modified Lotka's statement of this principle by placing 'energy of each level on a common basis using the concept "empower"' (or power as a representation of higher levels of energy transformity). 'Prevailing systems', he declared, 'are those whose designs maximize empower by reinforcing resource intake at the *optimum* efficiency' (Odum 1996, 26, italics added).[17] Systems must operate according to principles dictated by the 'universal energy hierarchy' which 'provides transformities for quantitatively relating energy on one scale to that of another' (Odum 1996, 34).

Odum and Marx: toward a dialectical-ecological synthesis

The significance of Odum's analysis is brought out most fully in a comparison with Marx. In a remarkable case of cross-fertilization of ideas between physical science and social science, Odum and Scienceman developed the emergy-transformity framework while

[15]However, not all goods produced in modern commodity chains are genuine use values from the standpoint of a rational production process. Odum's approach was consistent with a critical scrutiny of the 'pathological waste' (Odum and Odum 2001, 8) that was irrationally incorporated into the capitalist economy, in which the commodities sold were increasingly 'specifically capitalist use values' deriving their utility from the fact that they provided profits for the capitalist (Foster 2011).

[16]The hierarchical logic was similar to food web analysis in ecology, in which the most efficient transformers of energy, plants carrying out photosynthesis, were at the bottom of the hierarchy and carnivorous animals at the top. The loss of efficiency from the bottom of the food web to the top was associated at the same time with the development of 'dominant' species.

[17]Odum's emphasis on *optimum* efficiency was important because it suggested that in the long run it was not maximum throughput that produced the optimum outcome, but rather the optimum could actually be a steady state. This argument is perhaps mostly clearly advanced in Odum and Odum (2001).

conducting a decades-long investigation into Marxist political economy, and particularly the labor theory of value. The close connection between Odum's ecological critique and Marxian political economy is reflected in the overlapping critiques of mainstream (today neoclassical) economics with its subjective theory of value.

Odum and Scienceman viewed emergy analysis as a form of real (ecological) wealth accounting and employed the concept of 'emergy value' or 'emvalue' to distinguish this approach from the labor theory of value or 'lavalue' (which they saw as a related 'donor' or production-based theory of value connected to one energetic input – labor), as well as from other economic forms of value (Scienceman 1992). 'In the Odum terminology', Scienceman (1992, 6) wrote, 'use-value, being the bodily form of a commodity, would refer to the value (emvalue) in solar emergy content'. In other words, emergy value (or emvalue) referred to use value or 'real value' (real wealth). It was not to be confused with economic or monetary value (Scienceman 1989). Odum (2001, 40) referred to emvalue as 'a second value, the contribution of real wealth, how to use real wealth', which was distinct from 'market value' or economic value. 'Emergy', he stressed, 'measures natural value – real wealth' (Odum 2001, 112). Not only was money not a measure of real wealth, the relation was often an 'inverse' one, with prices 'being lowest when [ecological] contributions are greatest' (Odum 1991, 90). The whole analysis pointed to a notion of 'emvalue in a value added hierarchy' that resembled Marx's analysis but was oriented instead to real wealth – seen as in contradiction with the labor-value (or human-services) basis of the capitalist economy (Scienceman 1987, 269).

Odum saw great significance in Marx's linking of his approach to labor value to thermodynamics, which was being developed in his time and was integrated into his theory (Burkett and Foster 2006). Marx ([1867] 1967, 215; also Scienceman 1992, 36) himself wrote: 'Creation of value is transformation of labour-power into labour. Labour-power itself is energy transformed to a human organism by means of nourishing matter'. For Odum, Marx's theory was an attempt to explain wealth/value creation under capitalism in terms of energy transformations via abstract labor. The more physical or use-value side of Marx's analysis was viewed as having an energetic or ecological character.[18] Thus abstract labor in Marx's theory was depicted by Odum and Scienceman, following Heilbroner, as 'weighted by some as yet inadequately explained calculus', which for Odum and Scienceman clearly represented its emvalue (Scienceman 1989, 62, Odum and Sciemenan 2005, 17, Heilbroner 1988, 132). Marx's 'labor value concept', viewed from this perspective, was a 'donor' value similar to 'emergy value'. Marx saw value as 'coming from human hours contributed'; Odum saw 'emergy value [as] derived from the resource contributions' (Odum and Scienceman 2005, 23). In both cases, the focus was on production (natural and social).

Here it is crucial to interject that a certain ambiguity remained in Odum's interpretation of Marx's economic analysis in terms of physics/energetics. At times he (and Scienceman) criticized Marx's value theory for not being a kind of pure physics – as if historical economic forms could be reduced straightforwardly to energetics in the manner of Podolinsky, whom Engels had criticized (Marx and Engels 1975b, vol. 46, 410–2, Podolinsky [1883] 2008, Burkett and Foster 2008, 131–40). More often, Odum seemed to recognize that Marx's distinction between value (exchange value) and wealth (use value), and the contradiction this represented for capitalism, constituted the real strength of Marx's theory. Indeed, this

[18]Rubin's ([1928] 1972, 131–3) discussion of abstract labor, which Odum and Scienceman studied, relates the attempts of various Marxist theorists to explain this in terms of a common energetic or physiological basis – though Rubin himself argues against such an interpretation.

same contradiction was repeatedly raised in Odum's own analysis, which set real wealth against exchange value and made this the sharp edge of his critique of neoclassical economics.

As indicated above, Odum's reduction of qualitative/scale distinctions with respect to the energy hierarchy to a single common metric (emergy), while useful in the analysis of unequal exchange, also lends itself to reductionism if it leads to ignoring other dimensions of nature/reality. For life, there is no single metric. Thus Martinez-Alier (2002, 218) is quite right in cautioning that the use of a concept 'like emergy', aside from the inherent difficulties in

> calculation and application, would only account for one aspect of the link between extraction of resources and the environment. The important point is not the difficulty of calculation. The essential point, as argued above, is that incommensurability applies not only to money value but also to physical reductionism. Can 'biopiracy' be reduced to energy calculations?

It is naturally impossible to measure fully the impact in energy/emergy terms of the extinction of a single species, such as the golden toad or the Javan tiger.

Yet, with these qualifications in mind, it is nonetheless clear that the conceptual approach offered by ecological systems theory has much to offer. One must be wary of energy reductionism, but energy flows are nonetheless crucial to developing a comprehensive approach to unequal ecological exchange. Odum's systems ecology, though open to question for the reductionism it sometimes encouraged, is too revealing in scientific terms to be disregarded.

The strength of Odum's approach is revealed in his deep engagement with Marxian political economy. In a letter written to Engels on 6 July 1863, Marx provided a diagram (which he referred to as an 'Economic Table') of his reproduction schemes for capitalist production, distinguishing this from Quesnay's early 'Tableau économique' (Marx and Engels 1975a, 136). Odum and Scienceman translated this diagram of Marx's reproduction schemes into an energy-systems language diagram (Scienceman 1992, 28). They then went on to develop a deep analysis of Marx's political economy, transposing his systemic view of the capitalist economy into emergy-systems language/diagrams/equations and modeling it under different conditions (for example, steady state, expanded reproduction), running various computer simulations. This was most fully developed in their 26-page chapter 'An energy systems view of Karl Marx's concepts of production and labor value' (Odum and Scienceman 2005). In this view, 'Marx was basically trying to introduce a labor transformity scale [to explain the capitalist economy], based on an intermediate (labor energy) source rather than an original (solar energy) source' (Scienceman 1989, 64).

Although it is clear that Odum and Scienceman cannot be characterized in any sense as Marxists in their overall world-views, their research into the Marxian system was thoroughgoing, reaching beyond Marx's *Capital* itself into the wider Marxian treatment of value theory, the transformation of values into prices of production, the reproductive schemes, unequal exchange, and the role of nature in capitalist production. In the process they scrutinized the work of such thinkers as Amin (1976), Becker (1977), Carchedi (1984, 1987, 1988), Cleaver (1979), Foley (1986), Goodwin and Punzo (1987), Heilbroner (1988), Howard and King (1976, 1985), Krause (1982), Lonergan (1988), Martinez-Alier (1987), Morishma (1973), Rubin ([1928] 1972), Samuelson (1957), Seton (1957), and Wolff (1984).[19]

[19]These references are taken from Odum and Scienceman (2005) and Scienceman (1989, 1992). The bibliography in the original conference paper of Odum and Scienceman (2005), presented in 2004 (two years after Odum's death), was marked by hand as 'incomplete'. However, its publication in the conference proceedings the following year left this note out and reproduced it as it was. The

Marx, Odum and Scienceman (2005, 31, Scienceman 1992, 36) noted, had stipulated that all production was based on nature and energy, the ultimate sources of wealth. Yet, in a capitalist economy, as depicted by Marx, the 'region' of labor values defined the realm of commodity production. Capitalism, in its value relations, thereby excluded nature (independent of labor) as a source of value (Scienceman 1989, 63). Here Odum and Scienceman appear to have accepted the labor theory of value as operative in the 'region' of capitalist economics in the manner depicted by Marx, while arguing (as Marx himself did) that the realm of real wealth was much larger, encompassing nature's work (emvalue).

For Marx, value in the system of economic accounting that characterized capitalism was the result of the addition of labor (or in Odum's system the addition of human services) to what nature has already provided *gratis*. As we have seen, Marx, like the classical economists who preceded him, referred to the production of nature itself, independent of labor, as a 'free gift' to capitalism in that it did not enter into the (economic) value-added of the system (Foster *et al*. 2010, 61–5, Odum and Scienceman 2005, 31). For Marx ([1867] 1976, 638), however, this was a contradiction of the system itself, constituting a form of robbery or overexploitation (*Raubbau*) – generating a metabolic rift.

In classical political economy, the contradiction between use value and exchange value was commonly viewed in the form of the famous Lauderdale Paradox (named after the early classical economist the Earl of Lauderdale), whereby the expansion of *private riches* was seen as based to a considerable degree on the destruction of *public wealth*. For example, the destruction of certain crops by landowners in order artificially to inflate their market prices represented the despoliation of real public wealth (use values) for purposes of enhancing private riches (exchange values). This was viewed not as a rare instance, but as an intrinsic feature of a capitalist economy (Foster *et al*. 2010, 53–72). Odum (1991, 90, Scienceman 1992, 30) followed Marx and other classical economists in incorporating the Lauderdale Paradox into his analysis, thereby pointing to a global capitalist destruction of natural wealth for private enrichment.

In general, Odum seemed to argue that Marxian theory in emphasizing labor power, rather than energetic inputs in general, had failed to develop an adequate analysis of the role of real wealth in production, requiring that this be put on a more scientific basis through emergy analysis (Odum and Arding 1991, 109, Odum and Scienceman 2005). However, in various places Odum offered a more subtle interpretation of Marx, seeming to recognize that Marx was depicting what was a real contradiction of the capitalist economy – between the accumulation system and nature – a contradiction that Odum also recognized in his own critique of neoclassical economics (Odum 1973, Scienceman 1987, 269–70). Indeed, Odum's position was in many ways more similar to that of Marx than the former realized, since Marx theorized the limitations of the law of value under capitalism, given that it didn't incorporate nature's role in the creation of wealth (Foster *et al*. 2010, 61–4, Marx [1875] 1938, 3).

bibliography referred to Amin (1976) by title and publisher, but accidentally included Becker's name as the author in that line. Clearly, this should have been two (or three) separate entries, one (or two) for Amin and one for Becker. (The manner in which the names, dates and publishers were confused suggests that the intention of the authors may have been to include Amin (1976, 1977a), and Becker (1977) in the bibliography.) Becker (1977) was clearly important to their analysis and was referred to in the text. The wider literature on unequal exchange (including Emmanuel 1972) was summarized in Lonergan (1988), which had a direct impact on Odum's analysis.

Odum and Scienceman's (2005, 41) sharpest criticism of Marx was directed at Marx's argument that since the price of labor was lower in rural, especially underdeveloped, regions, workers were highly exploited there. 'Emergy evaluation', they wrote, 'indicates a different interpretation … . Emergy values for products from rural countries in relation to price are higher than in developed countries in relation to price because more of the support of labor comes from the landscape without payment'.

In this respect, however, Odum and Scienceman underestimated Marx and Marxian theory. Marx and Engels explicitly indicated that workers could be paid less than the value of labor power for long periods of time only in those cases where the reproduction of labor was supported by marginal access to land, i.e. ecological resources. In Marxian terms, such labor under capitalism becomes the basis of superprofits arising from 'profits by deduction', i.e. deductions from the price of labor or the value of labor power (Foster 2012, 13–4, Baran and Sweezy [1964] 2012, 65, Emmanuel 1972, 110–20, 127–8). Such superprofits were made possible by the fact that wages did not cover the full cost of reproduction (the value of labor power) of the workers. What made this possible was most clearly described by Engels in the second edition of *The housing question*, where he explained that kitchen gardening and small-scale agriculture had allowed German workers to be paid extremely low wages generating exceptionally high profits, which amounted to a 'deduction from normal [i.e. required for the reproduction of workers without access to land] wages' (Engels 1979, 14–5, Foster 2012, 13–4). Hence, like Odum, Marx and Engels argued that exceptionally low wages in rural areas were due to nature's subsidies.

It is evident from all of this that Marx's critique and Odum's emergy analysis have a certain affinity. Both focus on the contradiction between use value and exchange value. Odum provided a concrete way of understanding the inequalities and losses in real wealth imposed by the capitalist system. As a non-historical systems theory model, however, his treatment was dependent on a somewhat artificial impetus, giving direction and purposefulness to the analysis, i.e. Lotka's maximum power, or Odum's maximum empower (see Levins 2008, 29, 37). Hence, the energetic parameters of the system were necessarily conceived in mechanical, universalist terms. As with many systems theory approaches, Odum's analysis represents

> the attempt of a reductionist scientific tradition to come to terms with complexity, non-linearity and change through sophisticated mathematical and computational techniques, a groping toward a more dialectical understanding that is held back both by its philosophical biases and the institutional and economic contexts of its development. (Levins 2008, 48)

Where its holistic/systemic outlook and attempted dialectical break with reductionism offers new critical insights, such an approach can be cautiously utilized. Where its break with a mechanistic scientific tradition remains incomplete, and where reductionism is reproduced within its analysis, it needs to be subjected to critique. In Odum's overall systems ecology, a rose, a butterfly, an ecosystem and a symphony orchestra can be evaluated in terms of the maximum empower principle and hence optimum efficiency, from an energetic standpoint. This may tell us something about each of these objects from the standpoint of physics, but the resulting information is limited by the narrowness of the measure adopted.[20] Learning from such a systems ecology approach is one thing; falling prey to

[20]The transformity of information at the top of the energy hierarachy in Odum and Odum's (2001, 69) analysis, depicted as 1×10^{11}, tells us nothing about the content of information.

the reductionism to which it can potentially lead is another. In any historical-materialist-ecological analysis, ecological materialism must take theoretical precedence over energetics, much as historical materialism in Marx's theory, as Amin (1978, 1–18) argues, takes theoretical precedence over the law of value.

Odum and the theory of unequal ecological exchange

None of these limitations of Odum's overall systems ecology, however, prevent us from drawing upon his approach to unequal ecological exchange. Although the general structure of Marx's labor-value theory of capitalist production was a source of inspiration for Odum, it was the Marxian theory of unequal economic exchange that was of most concrete interest, helping him to develop his own theory of unequal emergy exchange. While Marxian theorists used Marx's 'labor value concept' 'to show large imbalances where trade was based on market prices', Odum and Scienceman (2005, 41) suggested that systems ecology 'had shown [similar] large imbalances using emergy' analysis. A key work, comparing the two approaches to unequal exchange, influencing Odum himself, was provided by Lonergan (1988) in a review of the unequal exchange literature. Lonergan showed that in international trade, in the Marxian approach, more labor was traded for less, while in Odum's analysis more emergy value (or emvalue) was traded for less. In both cases, prices deviated from 'values' (though in Odum's case 'emvalue' or emergy was directed at real wealth or use value), creating a global value transfer to the benefit of the developed countries. Thus 'recent empirical work suggests that developed economies import more labour value than they export, and, similarly, they may also import more embodied energy than they export' (Lonergan 1988, 141–2).

Although discussing the work of Emmanuel and Amin, Lonergan highlighted the analysis of unequal economic exchange developed by Becker (1977) in his *Marxian political economy*. Becker's work emphasized the first (broader) form of unequal exchange theory within Marxism, focusing on differences between organic compositions, and how this affected exchanges between predominantly urban and predominantly rural areas – an approach that was then extended to global North-South relations. 'The law of unequal exchange', Becker (1977, 169) wrote,

> ensures that within the less developed countries most departments [of production] will experience on the average unfavorable terms in their exchanges with countries the majority of whose departments of production will experience better-than-average terms. It is not the famous – or infamous – law of comparative advantage that determines commodity flows and their relative rates of exchange. The strains of a mutual harmony of interest, sung so sweetly by economic apologists, are now and again drowned out by the noise of exchange inequalities and inequities.

It was the very rigorous argument on unequal exchange presented by Becker that seems to have had the biggest influence, within the Marxian secondary literature, on Odum's further development of his own analysis (Odum and Scienceman 2005, 41).

In order to understand Odum's theory of unequal ecological exchange, it is necessary to look more closely at his method of emergy analysis. The process for calculating emergy begins with drawing an energy system diagram for the system under study. Odum suggests that experts on a process gather round a table and list all the elements contributing to the system. For example, if you wanted to calculate the emergy of corn, you would draw an energy system diagram illustrating the inputs required to grow corn under the particular

conditions. Their relation to one another via energy pathways is also indicated via energy systems diagramming notation.

Once the system diagram is completed, each input becomes a line item in an emergy evaluation table. In this table, the raw energy data for each line item, found in already existing literature, is multiplied by its previously published or currently calculated transformity (according to the method laid out in Odum 1996), to arrive at the solar emergy of each item. In this way, the items may be summed and other indices may be calculated to look at the quantities in relation to one another and to compare systems. Calculations are included in the table according to the needs of the particular study. Emergy per dollar calculations are used to relate economic and ecological indicators. The Center for Environmental Policy (2012) has now published emergy calculations for the natural resource base of 134 national economies. Actual global maps of emergy use along various dimensions, providing comparative perspectives, are now available (Sweeney *et al*. 2007).

In emergy analysis, the dispersion and degradation of energy are taken into account in the diagrams used to delineate energy systems. Odum and Arding (1991, 97) write that

> the definition often used in elementary physics and engineering courses that energy is the ability to do work is incorrect. Degraded energy can't do any work. The work that potential energy [exergy] can do depends on its position in the energy hierarchy.
>
> (Odum and Arding 1991, 97)

Available energy or exergy is thus the 'potential energy capable of doing work and being degraded in the process' (Odum 1996, 16). Emergy sums all the previous potential energy inputs in the series of energy transformations required to produce any given output. Exergy analyses, which measure available energy, are thus not as comprehensive as emergy. However, data measuring exergy can be converted to emergy data by multiplying by the correct transformities (Odum 1996, 268).

While not proposing emergy as a price/exchange-value determinant, Odum did relate emergy to money (and thus commodity values) via several indicators that are used to assess, from a real-wealth standpoint, the long-term viability, equity and sustainability of economic processes like production, extraction and trade. Having a working knowledge of these concepts is essential to an understanding of Odum's analysis of unequal ecological exchange. Key concepts include the following:

- *The emergy investment ratio* is the 'ratio of purchased emergy to the emergy from the local free environment' (Odum and Odum 2001, 201). 'The ratio for an area is set by the state of development of the economy using non-renewable resources' (Odum and Arding 1991, 16). A competitive emergy investment ratio for a rich, developed country such as the United States is around 7 to 1, while for many peripheral economies the ratio is 1:1 or less (Odum and Odum 2001, 99, Odum and Arding 1991, 20).
- *The emergy/$* (emergy/money) *ratio* is the emergy used from all sources in an economy divided by the Gross Domestic Product (GDP) for that year. A high relative emergy/money ratio means that such countries, usually rural and undeveloped, are drawing heavily on 'direct environmental resource inputs not paid for' (Odum and Arding 1991, 18). The exports of such countries include higher levels of emergy for the international dollars received, and have lower relative ecological purchasing power (Odum 1996, 201). An emdollar 'is the emergy contribution that goes to support one dollar of gross domestic product' (Odum and Odum 2001, 94).

- *The emergy exchange ratio* 'is the ratio of EMERGY received for EMERGY delivered in a trade or sales transaction … The area receiving the larger EMERGY receives the larger value and has its economy stimulated more. Raw products such as minerals, rural products from agriculture, fisheries, and forestry, all tend to have high EMERGY exchange ratios when sold at market price. This is a result of money being paid for human services and not for the extensive work of nature that went into these products' (Odum and Arding 1991, 18). To assess trade between countries or local sales, 'the relative benefit is determined from the exchange ratio … A local economy is hurt when the new development takes more EMERGY than it returns in buying power. Keeping the product for home use raises the standard of those living at home' (Odum and Arding 1991, 22).

Odum utilized these ratios and indicators in developing his theory of unequal ecological exchange. 'Free trade', he wrote, is 'an ideal based on the assumption of equitable trade … But free trade made developed countries rich, with high standards of living, leaving less developed countries devastated' (Odum 2007, 273). Developed economies (and urban areas) generally have much higher emergy investment ratios than less developed countries (and rural areas). In other words, the former rely more heavily than the latter on purchased emergy (brought in from outside), and less on the work of the free environment.[21] Developed countries, where reliance on the work of the free environment is less and where emergy is largely purchased, have low emergy/money ratios. Conversely, less developed (rural) countries, in which the free environment plays a larger role in the economy, have high emergy/money ratios.[22] As a result, a developed country's currency, when converted into international dollars (foreign exchange) and used to purchase products in an underdeveloped country, has a far greater emergy-buying power per dollar than in its own domestic economy, while the inverse is true for an underdeveloped economy when purchasing the products of a developed economy – i.e. the local currency when converted into international dollars and used to purchase products in a developed economy has considerably less emergy-buying power than at home. A poor country that borrows from a rich country and has to pay back in local currency converted into international dollars loses emergy-buying power through the exchange. Thus, 'in the 1980s Brazil paid back 2.6 times more real wealth [measured in emergy terms] than it received with a foreign loan' (Odum 1996, 216).

Odum (1996, 210–11) sums this up by saying:

> When an environmental product is sold from a rural state to a more developed economy, there is a large net EMERGY benefit to the developed buyer for two reasons: (1) the EMERGY of environmental products is higher than that in the money paid for the processing services; and (2) the EMERGY/money ratio is much greater in the rural state supplying the product than in the purchasing economy.

[21]Moore (2011a, 21–2) refers to the free appropriation of the non-capitalized free environment as generating an 'ecological surplus' for capital. Although we do not use this terminology here, the overlap between his argument at this point and Odum's approach seems to us quite obvious.

[22]Not all developed countries have high emergy investment ratios and low emergy/money ratios. Some 'rich dependencies' that heavily export raw materials, such as Canada, Australia and New Zealand, depart from the developed/underdeveloped country norm because of their very high emergy per capita (Sweeney *et al*. 2007, 13).

The emergy exchange ratio is thus heavily biased against poor, rural countries. Odum (Odum and Odum 2001, 139, Odum, 1996, 210) found that in the 1980s and early 1990s the unequal exchange of real wealth (emergy received/emergy exported) in trade between nations was extraordinary. Thus, the Netherlands, West Germany and Japan all had emergy exchange ratios of 4 or above (i.e. they received four times as much emergy in exchange as they exported); the United States had an emergy exchange ratio of 2.2; India had one of 1.45 and, lower down on the scale of development, Liberia and Ecuador had emergy exchange ratios of 0.151 and 0.119, respectively.

The basis of this inequality is the fact (already emphasized by Marx) that 'no money is paid to the environment for its extensive work' (Odum and Odum 2001, 95), and this sets up the basis of a global *Raubbau* in which underdeveloped countries are systematically robbed of real wealth. As Odum (2007, 276–7) put it in his criticism of 'imperial capitalism', the entire system of 'global investing bleeds net emergy benefits from less developed areas to developed areas because of the imbalance in emergy/money ratios'.

To make matters worse, economies that specialize in the export of primary resources are specializing in those products that have high net emergy yields (defined as the emergy yield minus the emergy used to process the product). Fossil fuels are examples of commodities with high net emergy yields (Odum and Odum 2001, 98–9). In purchasing such primary products, buyer nations thus gain more in real wealth terms than seller nations. Consequently, 'developed nations receive much more real wealth [in such exchanges] than they export or pay for' (Odum 2007, 274).

From this standpoint, poor countries would be better off using their own resources to benefit the local population rather than selling them off at prices that leave nothing for ecological re-investment at home. Along with the loss to the local population, poor countries are not compensated enough under the current terms of trade to do restorative work ensuring long-term ecosystem survival in areas degraded to supply the export market (Odum and Arding 1991, 37–9).

Odum and Arding (1991) provided an intensive study into unequal emergy exchange with respect to Ecuador, allowing us to see more fully how emergy analysis can contribute to a comprehensive understanding of ecological imperialism. Although their report focused on shrimp mariculture and export from Ecuador to wealthy countries like the US, it also looked at Ecuador's overall position with respect to emergy exchange. 'The ratio of purchased EMERGY to free Environmental EMERGY [i.e. the emergy investment ratio] within Ecuador was only 0.09, much less than the values of 7 or more in developed countries' (35). The emergy buying power of a US dollar in Ecuador was found to be 3.6 times that in the United States. This meant that:

> If money is borrowed by Ecuador from the US and used to buy products in the United States and later paid back from Ecuadorian currency converted on international currency exchange, 3.6 times more buying power is paid back. This is equivalent to an interest rate of 360%. Little wonder that investments by developed countries in underdeveloped countries have caused financial depression in underdeveloped countries. (37)

All together, the emergy received/emergy exported ratio for Ecuador in the early 1990s was 0.20 as opposed to 2.2 for the United States. Thus, Ecuador sent five times as much emergy abroad as it received, reflecting net ecological losses. In terms of shrimp mariculture, the emergy of the shrimp being sent to foreign buyers was about four times what was received back in emergy buying power via international dollars (Odum and Arding 1991, 33–9).

The bulk of Ecuador's resource exports, of course, were in the form of oil, which represented seven times as much emergy exported as in the case of shrimp (Odum and Arding 1991, 24). 'Oil from the Amazon is pumped over the mountains and down to a shipping terminal on the Pacific Ocean for export' (Odum and Arding 1991, 23). This means the Ecuadorian Amazon region suffers most as a result of the export of oil.

Odum and Arding (1991) demonstrated that the natural wealth of Ecuador was drained through the mechanisms of international trade and debt to benefit the importing countries:

> Energy, minerals, and information are the real wealth. It takes energy to concentrate the minerals needed by an economy. It takes energy to maintain and process information. When resources are abundant and cheap, there can be abundant wealth and a high standard of living. If resources and basic products are imported cheaply, abundant wealth is imported … . Countries that sell their energy [fuels] give away their EMERGY 6 for 1 or worse. The benefits to countries that buy their fuels depend on the EMERGY ratio of their trade transaction. (89–90, 104)

Greenpeace used this analysis in the anti-shrimp-farming campaign of the early 1990s, when it sent a letter to the Ecuadorian president citing Odum and Arding's (1991) study of shrimp mariculture and unequal ecological exchange (Martinez-Alier 2002, 82).

The research on international inequalities in emergy use and emergy exchange continues to expand (Sweeney *et al*. 2007). Looking at emergy exports over time, and the inadequate compensation received for this wealth transfer, Devincenzo King (2006, 77–8) analyzed the ecological debt owed to five focal countries in the Sahelian region of Sub-Saharan Africa (Burkina Faso, Mali, Mauritania, Niger and Senegal) due to cumulative net-emergy exports that have enriched wealthier countries. According to this analysis, Sub-Saharan countries paid off all international debt in emergy terms by the early 1990s (in the cases of Mauritania, Niger and Senegal, by the 1970s) and should now be allowed to use their resources to develop internally. Indeed, in emergy terms, the Sahelian countries are shown to be net creditors, rather than debtors. Further, King (2006, 72, 86) showed that these nations experienced an emergy inequity factor (EIF, the ratio of the official exchange rate to the emergy based equitable exchange rate) in their trade with the United States that increased dramatically between 1970 and 2000, rising by the beginning of the new millennium to an EIF that gave the United States more than a 10:1 advantage in emergy (real wealth) trade with all of these countries.

To be sure, despite the attempt at comprehensiveness in accounting for all energy inputs and exchanges, emergy analysis remains a unitary indicator – one that, though particularly useful, is unable to capture all dimensions of an enormously complex and dynamic relationship of environmental exploitation, degradation and unequal exchange inflicted on the periphery by the center. It cannot by itself, for example, account for all aspects of the long-term ecological destruction of the nineteenth-century guano trade in Peru, which robbed that country of an invaluable resource with incalculable effects, and which was the basis of the social and ecological devastation and long-term underdevelopment (enforced by military conquest) of that country up to the present time (Melillo 2012, Clark and Foster 2012). Nevertheless, the analysis of unequal ecological exchange in emergy terms can be a valuable indicator – the best we have – of the vast extent of the center-periphery environmental *Raubbau.* As an analytical tool it also helps us understand the processes involved in unequal ecological exchange, and can be used in conjunction with quite different indicators, such as ecological footprint analysis, to give us a more complete picture of ecological imperialism as a major factor in the modern capitalist world-system.

The strength of Odum's analysis lies in the fact that it provides a basis for recognizing the ecological conditions and contributions of third world peoples and subsistence populations, who often are seen as 'counting for nothing' (Waring 1999, 65–74) in the ruling system of economic accounting. In emphasizing that 'developed nations receive much more real wealth than they export or pay for', Odum (2007, 274, 278) was defending the struggles of indigenous and peasant populations and rural peoples in general against the insatiable accumulation tendency of 'global capitalism', which he characterized 'as a large-scale analog of weed overgrowth'. Solutions to the global ecological dilemma, he argued, were often to be found in indigenous and peasant societies. 'Policies about population and development appropriate to low-energy restoration', Odum (2001, 87) observed, 'may be like those formerly found in low-energy cultures like the Yanomamo Indians of Venezuela'. He pointed to Kerala in India as an example of 'social progress without economic growth' (Odum and Odum 2001, 57).

Marx, Odum and the discourse of unequal ecological exchange: theoretical challenges

Our treatment of Odum's emergy theory has explored the question of a Marx-Odum dialectic in the analysis of unequal ecological exchange, building on and supplementing other analyses of this phenomenon. Both Marxian political economy and Odum's systems ecology are highly critical of neoclassical economics and the dominant doctrine of free trade. Moreover, Odum's work dramatizes a split in ecological economics between, on the one hand, a radical approach, exemplified by Odum and Marxian ecological analysis, which stress the contradiction between use value (real wealth) and exchange value (economic value), and, on the other hand, an increasingly dominant approach that seeks to find ways of internalizing the externalities, aligning ecology with price data – more in line with neoclassical environmental economics.

Indeed, the division that developed in ecological economics is best seen in regard to the distinct approaches adopted by Constanza (1980, 1981a, 1981b) and Odum. A former student of Odum at the University of Florida, Constanza was a co-founder of the International Society of Ecological Economics and was chief editor of the Society's economic journal, *Ecological Economics*, from its beginning in 1989 until 2002. Odum was a member of the board of *Ecological Economics* at its inception. In the early 1990s, however, there was a deep struggle regarding the question of emergy/real wealth versus market value. The differences that arose led Constanza to remove Odum and a number of other natural scientists from the board in 1992, and articles affirming the concept of emergy were virtually banned in the journal (Odum 2001, 37–39).[23]

The basis of this dispute preceded by a number of years the founding of *Ecological Economics* itself. Constanza (1980, 1223, 1981a, 1981b) used an embodied-energy, input-output approach employing price-based data to argue for an 'energy theory of value', which claimed that 'calculated embodied energy values … show a very good empirical relation to market-determined dollar values'. Constanza's approach was

[23]In Odum's (2001, 38) words: 'At some point, however, there was a deep struggle there [in relation to *Ecological Economics*], and one of the main issues was input-output embodied energy versus emergy. Another was market value versus other [ecological] values. So he [Constanza] took us off the board'. Just prior to the July 1992 issue Odum and six others, predominantly natural scientists, were removed from the board of *Ecological Economics*.

sharply criticized by none other than Georgescu-Roegen, the founder of ecological economics. Quoting Engels (Marx and Engels 1975b, vol. 25, 586–7) on the impossibility of an energy theory of value, Georgescu-Roegen (1986, 270–2) pointed out that Constanza relied on 'an input-output table with money values instead of real [energy] data' and left the reader 'at a loss about how' the various factors 'have been converted into energy'. Georgescu-Roegen (1981, 69–70) claimed that an 'embodied energy' theory of value as proposed by Constanza was 'a[n] … extreme falsification of actuality'.

Likewise, Daly (1981, 165–72) launched a major attack on Constanza'a (1981a) attempt to construct an energy theory of value and his attempt to demonstrate that prices were based in such energy values. According to Daly, Constanza's results in this respect were given in the assumption, built into his approach, of an energy theory of economic value and in no way proved the former. Indeed, as Constanza himself had admitted, his results were just as consistent with a labor theory of value – a possibility he dismissed, however, merely by exclaiming: 'Can any one seriously suggest that labor creates sunlight?' (Constanza 1981a, 140, Burkett 2006, 37–41).[24] In Daly's (1981, 167–8) view, Constanza's 'empirical result (or analytical imposition) that market prices closely reflect embodied energy is taken as a sanctification of the market within the framework of the energetic dogma'.[25] Finally, Daly (1981, 168) expressly objected to Constanza's argument that since energy values supposedly were good predictors of market values, in those cases where markets exist, they could then be employed 'to determine "market values" where markets do not exist, for example, in ecological systems'.[26] The weaknesses of Constanza's approach were further highlighted from a Marxist perspective by Burkett (2006, 37–41).

Criticizing Constanza's embodied energy theory of value from a physical science rather than an economic standpoint, Odum insisted that the focus of ecological economics should be on real-wealth accounting, which could not be derived from money-based categories. Nor was it legitimate to add energy of different forms and qualities without converting to emergy of one kind first (Odum 2001, 37–9). All of this demanded an emergy approach directed at use values, with such real-wealth flows constituting a contradictory 'countercurrent' to monetary flows. Crucial to Odum's analysis, as we have seen, was the recognition that 'much of the contribution of environment to society has no corresponding circulation of money' (Odum 2007, 260–8).

This split in ecological economics over such issues as (1) the emergy concept vs. Constanza's embodied energy approach and (2) real wealth/use value versus market/exchange

[24]Constanza (1981a, 140) insisted that his embodied energy theory of value in no way challenged neoclassical economics. 'The results', he wrote, 'indicate there is no inherent conflict between an embodied energy (or energy cost) theory of value and value theories based on utility'.

[25]The term 'energetic [or energy] dogma' was introduced by Georgescu-Roegen (1981, 53) to refer to views that reduced questions of economic value and all ecological/entropic issues to mere energy. Georgescu-Roegen also used the notion of 'energetic dogma' in a narrower sense to refer to those who, in defiance of thermodynamics, believed that recycling could occur at a level of 100% (Mayumi 2001, 60).

[26]Daly (1981, 167) indicated that he thought that Odum and his associates were also gravitating toward an energy theory of economic value, though differently from Constanza. But while Daly indicated that Odum probably fell under the same stricture, and that Constanza 'is representative of the Odum school' he was uncertain due to the quite different nature of Odum's argument. This was before the introduction of the emergy nomenclature two years later, which clarified the nature of Odum's theory in this respect and the differences between it and Constanza. Daly (1981, 168) has argued for a retention of subjective value analysis in the broad neoclassical tradition – although he often draws on economic/ecological critiques from outside that tradition.

value was carried over into the analysis of unequal exchange. Alf Hornborg, a cultural anthropologist, who has played a leading and generally positive role in the discussion of unequal ecological exchange, launched an attack in *Ecological Economics* (under Constanza's editorship) on Odum's approach. Hornborg (1998, 130) asserted that 'emergy' was a 'metaphysical' concept like the labor theory of value. Hornborg went on to disparage the labor theory of value for its failure to demonstrate the correspondence of values and market prices – not understanding that such a correspondence was contrary to Marx's own analysis[27] – and as a 'normative' theory of value (also a misconception) (Hornborg 2003, 5). Instead, value, Hornborg (1998, 130) declared, was 'subjective, cultural, and contextual'. The chief object of Hornborg's attack, however, was not Marx, but rather Odum, who was criticized for providing in his emergy analysis a 'normative' view in the form of 'an energy theory of [economic] value' that 'echoes Marx' (Hornborg 1998, 130–2, 2001, 40–3, 2003, 5–6, 2011, 17, 104).[28] Moreover, Odum was characterized as offering an approach similar to the early-twentieth-century Technocrat movement in the United States, which had proposed an energy theory of value (Hornborg 2011, 104).

In our view, these criticisms of Odum by Hornborg completely missed the mark. Central to Odum's analysis was the stipulation, as we have seen, that 'market values are inverse to real-wealth contributions from the environment', since no monetary payments are given for nature's work. Indeed, this constituted the very core of his theory of unequal exchange (Odum 1996, 60, Cleveland 1987, 59, Brolin 2006, 262). But by accepting at face value Constanza's claim that there was a rough correlation between embodied energy and price, and attributing this view – wrongly – to Odum, Hornborg erroneously arrived at the opposite conclusion: that emergy analysis blocked an understanding of the inverse relation between energy flows and price (Hornborg 2011, 104). Confusing Odum with Constanza and targeting the former rather than the latter in this respect, Hornborg characterized Odum's analysis as 'nothing less than a way to legitimate, by and large, world market prices as they are' (Hornborg 2001, 40–2).[29]

All of this ignored Odum's repeated insistence that his concern was not with market value but real wealth, picturing these as separate, contradictory circuits in ways analogous to Marx' argument. Thus, in the very work on which Hornborg (1998) concentrated his fire, Odum and Arding had stated in no uncertain terms: 'EMERGY value [emvalue] is not meant to be used for market value'. They added: 'Some confuse EMERGY concepts with the technocrat movement of the 1930s, which used energy as the basis of value and proposed to pay people with energy certificates in place of money … Technocrats wanted to substitute energy value for money, whereas EMERGY value is not meant to be used for market value, but for larger scale [ecological] evaluation of the economy' and planning (Odum and Arding 1991, 109, Brolin 2006, 245–6). Odum's position here

[27]This relates to the whole transformation process/problem in Marx's analysis, in which prices of production are transformed values. For a general discussion see Hunt and Lautzenheiser (2011, 227–31, 518–24). It is noteworthy that it is precisely this deviation of prices of production from values that became the basis of the Marxian theory of unequal exchange.

[28]The same basic criticisms were repeated (though with some reservations) by Joan Martínez-Alier (2002, 217–8), who accepted Hornborg's basic definition of the problem with respect to Odum's work, and the case to be made for exergy.

[29]Hornborg was not the only theorist in this area to confuse Odum with Constanza. Stokes (1992, 147–54) also interpreted the former in terms of the latter, and was not aware of their divergent courses. Stokes was, however, interpreting Odum only up to 1983, so his work missed the entire emergy stage of Odum's analysis.

was related, as we have seen throughout this contribution, to the distinction that Marx had made between wealth and value in his critique of the capitalist economy (Foster, Clark, and York 2010, 61–4). In Odum's case, the analysis is so removed from a theory of economic exchange value that, as Brolin (2006, 264) notes, there is no discussion of the formation of market prices to be found anywhere in his work. Odum and Scienceman's analysis thus was, as we have noted, formally consistent with the classical labor theory of value, and was concerned with drawing out the more radical implications of this for the theory of real wealth.

In opposing Odum's concept of emergy as the basis of unequal exchange analysis, Hornborg proposed to substitute the concept of exergy, or available energy, as the basis for such a theory. He insisted that exergy was superior to emergy in the analysis of unequal ecological exchange since it was clear that the more money attached to a product the less available energy was associated with it (Hornborg 1998, 131–2). Yet there was a fundamental flaw in this argument. Since all production and all exchanges involving physical elements in all places and all times involve losses of available energy – given that this is a fundamental law of physics – this represents a universal problem. The mere inverse relation between flows of money and exergy can hardly constitute a meaningful theory of unequal ecological exchange from a social standpoint, since it follows inexorably from the entropic condition governing all production and thus applies invariably where production and exchange, involving monetary transactions, occur. The problem is somewhat analogous to that of the broader unequal economic exchange theory based on inequalities in organic composition – but on a wider scale. This is so much a part of any system of production and exchange that 'unequal exchange' in these terms loses its significance. To make unequal ecological exchange a meaningful concept, it has to be based in social-economic power differentials.

In our view, the theory of unequal economic exchange developed on the basis of classical economics, and later expanded by Marxian and world-system theory to take into account unequal ecological exchange as well, sets the stage for the development of a wider dialectical synthesis between ecological science, Marxian political economy and environmental social science. Specifically, we need a Marxian/world-system analysis that draws critically on Odum's systems approach to unequal ecological (emergy) exchange and the destruction of real wealth by capitalist production. It is possible, we believe, to link this up with theories based on Marx's metabolic rift analysis (Foster 1999, Foster, Clark, and York 2010, Schnedier and McMichael 2010, Moore 2011a).

Such an approach, we are convinced, would allow for a theoretical and empirical deepening of the analysis of unequal ecological exchange already approached in various ways in the work of such important thinkers as Amin, Bunker, Clark, Hornborg, Jorgenson, Lawrence and Rice. Odum's method of analysis gives us a powerful way of analyzing unequal ecological exchange and ecological debt that complements and supplements ecological footprint analysis, and for which there is now extensive data for 134 countries (Sweeney *et al*. 2007, Center for Environmental Policy 2012).

The strength of Odum's analysis, as we have seen, was rooted in the recognition of what Sweezy (1942, 23–40) called the 'qualitative value problem', i.e. the role of use value and the contradiction between use value and exchange value within capitalist production. By criticizing the capitalist economy from the standpoint of use value (via emergy analysis), Odum pointed to the need for an external ecological assessment of production, as a means for social and ecological planning – one not subordinated to market pricing.

'In ecology', Murray Bookchin (1980, 88) observed, 'the Newton of … thermodynamics, or more properly, energetics, is Howard Odum'. Odum was also a major critic of

capitalism, neoclassical economics and ecological imperialism. His critique benefitted from a deep and extended inquiry into Marx's environmental analysis. He was clear that the capitalist system of accumulation must in our age give way to what he called 'a prosperous way down' in which the economy would need to be redirected to sustainable production, environmental (and energy) justice and social equality (Odum and Odum 2001). Historical conditions, Odum (1973, 222) argued, pointed to the need for a stationary state (or steady-state) economy more conducive to the implementation of 'socialistic ideals about distribution' on a world scale. It is here, therefore, that we find one of the most important points of convergence between ecological science and environmental social science. Most crucially, however, from a world-system approach to ecology, is the opportunity that this provides to clarify the historical conditions of ecological as well as economic inequities between center and periphery. It is here, as we have seen, that Odum's analysis helps us understand some of the key dimensions of the problem, as orders of magnitude. In order to move toward the kind of contraction and convergence that is needed worldwide today in areas such as climate change, it is important to recognize the centuries of unequal exchange and the enormous ecological debt owed to the periphery – both of which are highlighted by Odum's analysis.

Odum's systems-ecology critique of imperial capitalism provides the necessary means for the synthesis of the metabolic-rift and unequal-ecological-exchange literatures. As Clark and Foster (2009, 313) argue, unequal ecological exchange – defined as 'the disproportionate and undercompensated transfer of matter and energy from the periphery to the core, and the exploitation of environmental space within the periphery for intensive production and waste disposal' – is dialectically connected to Marx's concept of metabolic rift. In Odum's view, Marx's theory pointed in the right direction by emphasizing the 'metabolic rate of labour', and thus a larger human-nature metabolism (Scienceman 1992, 33, Odum and Scienceman 2005). Recent work on Marx's concept of metabolic rift (Foster 1999, Foster *et al*. 2010, Schneider and McMichael 2010, Moore 2011a) has demonstrated the larger ecological implications of Marx's metabolic critique – in relation to which Odum's work (and particularly his approach to unequal ecological exchange) can be viewed as a partial complement. With the resulting Marx-Odum dialectic of unequal exchange as its basis, it is possible to envision a more critical global agroecology, supporting the international peasant mobilization over land resources (Schneider and McMichael 2010, 461), and converging with the incipient rise of what has been called a nascent 'environmental proletariat' (Foster *et al*. 2010, 439–40).

It is important, however, to insert a word of caution. It is a dialectical analysis that must be the final object of any critique of the capitalist order and its ruling ecological regime. Odum's emergy approach, evolving out of systems ecology and physics, provides us with a powerful critical tool. But neither ecology nor society, as we have seen, can be reduced to a single measure (whether labor values or emergy).

The danger of reification is an inherent product of capitalism. If we are compelled to search for means of commensurability in the analysis of use values or real wealth, it is only to highlight the narrowness of capitalist value analysis, its overexploitation of nature and the unequal impact on the world's population – and for the purpose of helping to form a new historical system in which the associated producers are able to 'govern the human metabolism with nature in a rational way' (Marx [1863–65] 1981, 959). There is no single, universal metric that holds the key to the human relation to nature. It is a complex, contingent and coevolutionary relation that we nonetheless have the power to affect.

What we have referred to as the Marx-Odum dialectic with respect to unequal ecological exchange attains its ultimate significance in enabling us to comprehend the means of

socially transcending the metabolic rift, i.e. the rift in nature and society that finds its highest expression in capitalism itself. For Marx ([1857–58] 1973, 489),

> It is not the *unity* of living and active humanity with the natural, inorganic conditions of their metabolic exchange with nature, and hence their appropriation of nature, which requires explanation or is the result of a historic process, but rather the *separation* between these [natural,] inorganic conditions of human existence and this active existence, a separation which is completely posited only in the relation of wage labor and capital. [Italics in original].

The rift in 'the metabolic exchange with nature', together with the dialectical movement through which the elemental unity is 'restored', represents, then, for Marx nothing other than the capitalist alienation of nature together with its eventual transcendence. As Moore (2011b, 136–9) has insisted, nature and society is not a 'binary' relationship – outside of the existence of alienated historical conditions – but a unified one. Humanity is itself a part of nature. However, under capitalism, this relationship becomes a one-sided expropriation and alienation of all nature outside of humanity in the name of capital accumulation. It is for this reason that recent attempts to reconceive the world capitalist system as a world ecology (and not just as a world economy) are so important as critical developments in our time, allowing us to perceive a large dialectical unity (see especially Wallerstein 2004b, Moore 2011a, 2011c). The analysis of unequal ecological exchange has a vital role to play in this respect.

'The justice of nature', Epicurus (341–271 BC) wrote, 'is a pledge of reciprocal usefulness, neither to harm one another nor be harmed'. Today this principle must be applied to all of our social relations and (to the degree to which is rational) to all of our ecological relations as well (Epicurus 1994, 35).

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