Critical Essay

ECOLOGICAL ECONOMICS AND CLASSICAL MARXISM

The "Podolinsky Business" Reconsidered

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This introduction to "Socialism and the Unity of Physical Forces" reassesses Sergei Podolinsky's place in the history of ecological economics together with Marx and Engels's reaction to Podolinsky's work. The authors show that contrary to conventional wisdom, Podolinsky did not establish a plausible thermodynamic basis for the labor theory of value that could have been adopted by Marx and Engels. Moreover, Marx and Engels did not neglect nor abruptly reject Podolinsky's work as is commonly supposed but took it seriously enough to scrutinize it deeply in the spirit of critique. Although verifying Podolinsky's rightful place as a forerunner of ecological energetics, the authors' analysis highlights the severe limitations imposed by his energy reductionism and closed-system thinking as compared to Marx and Engels's metabolic and open-system approach.

Keywords: *energy; perfect machine; metabolism; value; use value*

Since Martinez-Alier and Naredo (1982) and Martinez-Alier (1987), Sergei Podolinsky has come to occupy a central place in the ecological literature in two respects: (a) his direct contribution to ecological economics and (b) the reception that his work received from Marx and Engels, including the role that this reception played in the subsequent relationship between Marxism and ecological economics. In relation to his direct contribution, Podolinsky is often credited with being "the first explicitly to scrutinize the economic process from a thermodynamic perspective" (Cleveland, 1999, p. 128). Martinez-Alier's (1987) influential history of ecological economics treats Podolinsky as the major 19th-century precursor and perhaps even as the founder of the discipline, arguing, for example, that he was the first to develop "the concept of energy return to energy input in different types of land use" (p. 5).

With regard to the Marx-Engels-Podolinsky relationship, the standard interpretation is based on Martinez-Alier's claim that Marx and Engels had a negative reac-

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tion to Podolinsky's work, which meant a missed chance to connect Marxian value-theoretic analysis to Podolinsky's energetics. Marx himself is faulted for his supposed silence on Podolinsky, whereas Engels is criticized for his dismissal of Podolinsky's analysis (Guha & Martinez-Alier, 1997, p. 25; Martinez-Alier, 1987, p. xviii; Martinez-Alier, 2003, p. 11). Marx's alleged "silence from 1880 to the end of his life in 1883" has been characterized by Martinez-Alier as implicit evidence that he agreed with Engels in his "negative reaction to Podolinsky's work" (Martinez-Alier, 2003, p. 11; Martinez-Alier & Naredo, 1982, p. 209). For James O'Connor, the point is summed up by saying that Marx turned a "deaf ear" to Podolinsky (O'Connor, 1998, p. 3). Martinez-Alier has further argued that Marx and Engels's negative response to Podolinsky is the root of "the Marxist neglect of ecology" (Martinez-Alier, 1995, p. 71). This too has become conventional wisdom, to the point where what are widely regarded as the ecological deficiencies of Marxism are often traced by ecological economists to the inadequate response by Marx and Engels to Podolinsky's work—the citation of Martinez-Alier's individual and coauthored writings often being deemed sufficient to establish this connection (see, e.g., Bramwell, 1989, p. 86; Cleveland, 1999, p. 128; Deléage, 1994, p. 49; Hayward, 1994, p. 226; Hornburg, 1998, p. 129; Kaufman, 1987, p. 91; Pepper, 1996, p. 230; Salleh, 1997, p. 155).

The present article advances the first thoroughgoing critique of this conventional wisdom together with a radical reassessment of Podolinsky's place in the history of ecological economics. We show that Podolinsky did not establish a plausible thermodynamic basis for the labor theory of value that could have been adopted by Marx and Engels. Moreover, Marx and Engels did not neglect nor abruptly reject Podolinsky's work as is commonly supposed but took it seriously enough to scrutinize it deeply in the spirit of critique. Although verifying Podolinsky's rightful place as a forerunner of ecological energetics, our analysis highlights the severe limitations imposed by his tendencies toward energy reductionism and closed-system thinking as compared to Marx and Engels's metabolic and open-system approach to nature and to human production.

Our analysis is informed by (a) Marx's previously undisclosed notes on Podolinsky, to appear soon in Marx and Engels, *Historisch-Kritische Gesamtausgabe* (known as MEGA); (b) the significant differences between the several (published and unpublished) versions of Podolinsky's analysis and a close investigation of the respective versions that Marx and Engels read and commented on; (c) a critical analysis of the ecological advances and shortcomings contained in Podolinsky's work in the respective forms in which it was read by Marx and Engels; (d) a detailed consideration of Marx and Engels's correspondence on Podolinsky, including the probable role that Engels's manuscript *The Mark* (1978) played in their discussions. Following our analysis, we are including an English-language translation by Angelo Di Salvo of the 1881 Italian version of Podolinsky's work (the one read and commented on by Engels), which has been carefully compared against an English-language translation by Mark Hudson of the published French version of 1880 (Podolinsky, 1880, 1881/2004). (The latter translation, though employed in a rigorous comparison with the translation from the Italian, is not reproduced here. Only the specific differences with the Italian version are noted.)

We begin with a brief sketch of Podolinsky's life and work, which serves not only to reintroduce an important socialist ecological thinker but also to establish the ways in which Podolinsky's political and intellectual milieu intersected with

and differed from that of Marx and Engels. We then locate the Italian version of Podolinsky's article in the context of the development of his work on energetics through several versions published in four different languages. This genetic textual analysis, which is also informed by a close look at two letters that Podolinsky wrote to Pyotr Lavrovich Lavrov in 1880, helps to pinpoint the specific versions of Podolinsky's piece most likely read by Marx and Engels. It also begins to establish the very limited, in fact nonexistent, extent to which Podolinsky's work addressed value-theoretic questions in a way that could have been adopted by the founders of historical materialism.

We then summarize and criticize what is actually Podolinsky's main analytical theme: his argument that human labor is uniquely gifted in its ability to accumulate energy in useful forms on the Earth and that this unique capability implies that the human being fulfills the thermodynamic requirements of a so-called perfect machine as theorized by Sadi Carnot. Here, our critique notes the practical difficulties with the kind of energy-accounting exercises that Podolinsky used to defend his energy accumulation thesis. More important, we uncover the tendency toward energy reductionism (reduction of human production and consumption, and of its historical dynamics, to pure energetics) that is implied by Podolinsky's framework. We also point out how Podolinsky's so-called perfect machine hypothesis falls prey to closed-system thinking (neglecting the resource extraction problem, as in coal, and ignoring the dissipation of energy and material waste into the environment). We argue that Podolinsky's energy reductionism and closed-system thinking greatly limit the socioecological insights obtainable from his analysis as compared to the power of Marx and Engels's metabolic open-system perspective on human production, capitalism, and the environment. As a crucial case in point, we show that Podolinsky's quantitative energetics does not provide a viable physical-scientific basis for a labor theory of value as Marx understood it, namely, as an analysis of the socioeconomic forms taken on by capitalist alienation of both nature and labor vis-à-vis the direct producers. In asserting that Podolinsky provided a potential thermodynamic basis for value analysis, the conventional interpretation implicitly adopts an energy-reductionist, crude materialist, and nondialectical approach to value that is completely alien to Marx's approach. We clarify this point with reference to the critique of naturist value thinking (ascribing value directly to nature) that was developed by Podolinsky's economic mentor, Nikolai Sieber, who was also an economic follower of Marx.

Turning to Marx and Engels's reaction to Podolinsky, we first note that Marx's detailed extracts from a draft of Podolinsky's (1880) *La Revue Socialiste* article contradict the conventional wisdom that he basically ignored or turned a deaf ear to Podolinsky's work. Moreover, from Marx's extracts, it appears that even those portions of the published versions of Podolinsky's analysis that the conventional wisdom (mistakenly) sees as adaptable to Marx's value theory were most likely absent from the manuscript read by Marx.

Finally, we investigate the two 1882 letters to Marx in which Engels comments on the Italian version of Podolinsky's work. We show that Engels's letters constitute much more than an abrupt dismissal or negative reaction. Rather, they exhibit a careful reading of Podolinsky in the spirit of critique. Moreover, Engels's criticisms focus mainly on those elements of Podolinsky's analysis that suffer the most from energy reductionism and from closed-system thinking, especially the treatment of labor as a purely thermodynamic (and not metabolic) process and the failure to account for the squandering of energy in the form of coal. In this way,

Engels's comments help clarify the metabolic and open-system character of his (and Marx's) historical materialist perspective on human production and on its development. This clarification jibes with the fact that Engels's letters on Podolinsky grew out of his discussions with Marx on *The Mark* (Engels, 1978), a work in which Engels addresses various ecological issues raised by the disintegration of communal peasant agriculture in Germany under the twin pressures of landed property and capitalist competition.

We conclude with a brief reconsideration of the relationship between ecological economics and Marx and Engels's theoretical system in light of our analysis. This reinterpretation, which is supported by notes Marx wrote about the same time he was confronted with Podolinsky's work, sheds new light on Podolinsky's real contribution and limitations. It also suggests an important avenue for expanding upon Martinez-Alier's (1987) pioneering excavation of the history of ecological economics.

PODOLINSKY: LIFE AND WORK

Sergei Podolinsky (1850-1891), was a Ukrainian socialist and physician, who was an acquaintance of Marx and Engels. He was a member of the wealthy landed gentry class (Serbyn, 1982, p. 5). His father had been postmaster general of the southern provinces and later retired to his estates where he was a gentleman poet. His mother's mother had been the daughter of a French ambassador in Napolean's day. While a student of the natural sciences in Kiev, Podolinsky gravitated toward Nikolai Sieber (1844-1888), who was later the first economics teacher at a university in the Russian Empire, and probably anywhere, to be influenced by Marx.[1] Sieber was Marx's most brilliant economic follower in the 1870s and 1880s and laid the foundation for Marxist economics in Russia and in the Ukraine. In his master's dissertation, "David Ricardo's Theory of Value and Capital," published in Russian in 1871, Sieber presented Marx's work as a necessary sequel to Ricardo's (Sieber, 2001). Subsequently, Sieber was to write a series of articles explaining and defending Marx's economics.[2] Marx referred favorably to Sieber in the 1873 postface to the second edition of Volume 1 of *Capital* and again in his 1880 *Notes on Adolph Wagner* (Marx, 1975, p. 184; Marx, 1976, p. 99).[3]

In 1872, Podolinsky finished his studies in Kiev and traveled to the West, taking up medical studies in Zurich. He met Marx and Engels that summer in London through Pyotor Lavrovich Lavrov (1823-1900), a leading Russian populist-socialist thinker (Serbyn, 1982, p. 6). In September, he attended the Hague Congress of the First International. Podolinsky authored two articles on the history of the International in the first issues of the journal *Vpered!* (*Forward!*), which he, along with Lavrov, helped launch. In 1875, Podolinsky published two pamphlet-size socialist works in the Ukrainian language. One of these was "The Steam Engine," a socialist utopian story about a rural worker who is severely injured by a threshing machine while working in the fields and who dreams of a socialist future when workers will own the land and its produce and will reap the rewards (Martinez-Alier, 1987, pp. 54-56). The other was titled *On Poverty.* Podolinsky received his doctorate in medicine at Breslau in 1876 under the supervision of Rudolf Peter Heinrich Heidenhain, a physiologist. He also studied in Zurich under the physiologist Ludimar Hermann, author of the *Handbuch der Physiologie* (published in six volumes from 1879 to 1883).

In 1877, Podolinsky returned for a time to his family home in Kiev, where he married the daughter of a landowner, Maria Andreeva. They settled in exile in Montpellier, France. In 1879, Podolinsky published his long study, *The Life and Health of People in the Ukraine*, using his knowledge as a physician. Podolinsky was personally and financially involved in the Ukrainian socialist and nationalist journal *Hromada* (*Community*), then published in Geneva, for which he coauthored a manifesto on Ukrainian national independence and socialism in 1880 (Rudnytsky, 1952, pp. 206-208, 223-224). He also wrote *Crafts and Factories in Ukraine* (1880), the first economic monograph to be written in the Ukrainian language (Holubnychy, 1971, p. 684).

It should be noted that as a Ukrainian socialist political economist, Podolinsky belonged to a tradition of thought that was closer to French than to German socialism. For example, M. Drahomanov, who edited *Hromada* and with whom Podolinsky was closely associated, considered himself a follower of Proudhon (Rudnytsky, 1987, pp. 206-207, 263). Podolinsky was equally close to (and is often thought of as belonging to) the tradition known as legal Marxism, which emphasized industrial development and economic determinism rather than the class struggle. This group included Sieber and later Michael Tugan-Baranovsky. To the end of his life, Podolinsky combined a commitment to socialism with a strong devotion to the Ukrainian nation (Himka, 1993; Holubnychy, 1971; Holubnychy, 1993, p. 116; Serbyn, 1982, pp. 4, 6).

Meanwhile, by the late 1870s, Podolinsky was also working on his study of agricultural energetics, and it is this work that has drawn the most attention from modern-day ecological economists. In March 1880, Podolinsky sent to Marx his "Human Labor and the Conservation of Energy," written in French. A new version of this work was completed in May 1880 and published in late June in *La Revue Socialiste* under the title "Socialism and the Unity of Physical Forces" (a much longer version was also published around the same time in the Russian journal *Slovo* [*The Word*]).[4] In addition, in that same year—his most productive as a scholar—Podolinsky published articles in *La Revue Socialiste* on nihilism and on social Darwinism. He was on the editorial board of *La Revue Socialiste* and emerged as a well-known socialist-populist analyst.

A longer version of "Socialism and the Unity of Physical Forces" was completed around a year later and published in two installments in Italian in 1881 in the journal *La Plebe*. A still more detailed version was published under a different title, "Human Labor and the Unity of Physical Forces," in *Die Neue Zeit*, the journal of the German Social Democratic Party, in September-October 1883.[5] However, because we know from the Marx-Engels correspondence that the *La Plebe* version is the one read and commented on by Engels (Marx & Engels, 1992, p. 410), and because the *La Plebe* version subsumes the *La Revue Socialiste* article, a draft of which was likely the version read by Marx (see below), the *La Plebe* version is the one reproduced in translation following this analytical introduction. It is presented in full so that the reader can decide for herself or for himself whether Podolinsky's analysis contains ecological insights that could and should have been directly adopted by the founders of Marxism, as is so often claimed.

"SOCIALISM AND THE UNITY OF PHYSICAL FORCES"

Podolinsky's "Socialism and the Unity of Physical Forces" was a product of the revolution in the scientific understanding of energy in the early 19th century,

beginning with the discovery of the energy conservation principle in the 1840s. Between 1842 and 1847, four European scientists—J. R. Mayer, James P. Joule, L. A. Colding, and H. von Helmholtz—all introduced the hypothesis of energy conservation. An expanded list of the scientists who made this breakthrough in the period, however, would include Sadi Carnot (before 1832), Marc Séguin, Karl Holtzmann, G.A. Hirn, C.F. Mohr, William Grove, Michael Faraday, and Justus von Liebig (Kuhn, 1977, pp. 66-68). Sadi Carnot's work, in particular, was to lead to the rise of thermodynamics, especially the famous second law (the entropy law) as physicists in the 1850s and 1860s tried to determine the laws of efficient energy use based on the steam engine. Energy—a term that was only then coming into wide usage among scientists—was found to dissipate when used so that the level of entropy (the amount of energy no longer available for human purposes) increased.

Podolinsky tried to use the new thermodynamic perspective to develop an agricultural energetics, combining elements from physics, physiology, and Marxian economics. His goal was to explore the centrality of human labor to the accumulation of energy on Earth.

Development of Podolinsky's Project

From the first, Podolinsky saw his work as in a process of development. His plan, as he indicated in letters to Marx and to Lavrov in 1880 and in 1881, was to publish a set of successive versions of his original, preliminary analysis on labor and energy that would appear in various languages, with each new version extending the field of analysis over the previous ones and with each providing further illustrations. (Although he published a very extensive Russian version in 1880, he sought to spread his ideas in the western European context, and hence began publishing his work, or parts of it, in French, Italian, and German versions, presenting it in a more theoretically developed, if less extensive, form.) In his letter to Marx on March 30, 1880, he mentioned his intention to expand the work that he had sent to Marx to take account of diverse forms of production and also his intention to provide a more detailed article with further examples (see Martinez-Alier, 1987, p. 62).

Setting aside the question of the lengthy Russian version, Podolinsky did in fact extend his work published in western European languages several times. The *La Revue Socialiste* article (Podolinsky, 1880) was most likely an extension of a draft on "Human Labor and the Conservation of Energy" (also in French) that he had earlier sent to Marx. The Italian version (Podolinsky, 1881/2004), an English-language translation of which is provided here, added 20 new paragraphs not in the *La Revue Socialiste* article, a couple of sentences beyond that, and a number of footnotes. The German article published in *Die Neue Zeit* in 1883 (after Podolinsky's mental collapse and Marx's death) was the final version, and was no longer than the Italian one (Podolinsky, 1883). It appeared under a third title: "Human Work and the Unity of Physical Forces." However, because Marx read an earlier draft, out of which emerged the *La Revue Socialiste* article of June 1880, and because Engels's December 1882 letters on Podolinsky were based on the 1881 Italian article published in *La Plebe*, we have confined our analysis here to the published French and Italian versions together with Marx's notes on "Human Labor and the Conservation of Energy."

In the opening paragraphs of his article, "Socialism and the Unity of Physical Forces," Podolinsky referred to the conservation of energy and to the need to

understand how human labor should be allocated in this respect to best satisfy human needs. He then mentioned that

> according to the theory of production formulated by Marx and accepted by socialists, human labor, expressed in the language of physics, accumulates in its products a greater quantity of energy than that which was expended in the production of the labor power of the workers. Why and how is this accumulation brought about?

Although it seems to be directed at Marx's theory of surplus value and accumulation of capital, Podolinsky's question, posed in terms of physics, is really quite different: It aims at showing how human labor results in the accumulation of solar energy on Earth.

Nonetheless, due principally to this statement at the beginning of his article, in which he said that Marx's theory of production based on human labor could be "expressed in the language of physics," and because of a letter that he wrote to Marx in April 1880 that mentioned his interest in relating the physics of human labor to the concept of surplus value, Podolinsky's work has often been presented as if that was its main argument. The actual thrust of his analysis, though, was different and had little to do directly with economic value, however much that may have been his ultimate object. His argument took essentially four steps: First, he provided a competent discussion of the general problem of entropy, explaining, following Clausius, that "the entropy of the universe tends towards a maximum." Second, he proposed a definition of useful work as that which results in an accumulation of solar energy on the Earth (so that solar energy does not simply radiate back into space). In this context, he provided statistical examples drawn from agriculture to argue that human labor has the power of increasing the amount of energy generated from plants in comparison to uncultivated nature. Third, he attempted on this basis to argue that human beings (and some animals) constitute the perfect machine referred to in Sadi Carnot's and in William Thomson's thermodynamics. As a perfect machine, a human being, in Podolinsky's terms, is able to recycle work back to its own firebox. Fourth, he suggested that this perfect machine could only be properly used in a socialist system of production.

We will not provide a detailed exposition of Podolinsky's discussion of the problem of entropy, which was insightful for its time. In the article published in *La Revue Socialiste*, this aspect was only sketchily developed. Entropy itself was not mentioned. The introductory references to Carnot and to Thomson found in the later Italian version were not included.[6] Still, it is significant that in both versions, Podolinsky showed his close attention to scientific developments, referring, for example, to Thomas Sterry Hunt's observation that, as stated by Podolinsky, "even free oxygen in the atmosphere, according to certain geological hypotheses, originated in combination with the carbon that now constitutes coal."

Accumulation of Energy on Earth

More important to his overall argument was Podolinsky's point that useful work could be defined as work that increased the accumulation of solar energy on Earth. As he said early on in his article, "We believe . . . that to a certain extent, it is within the power of humanity to produce certain modifications in the distribution of solar energy, in such a way as render a greater portion profitable to humans." It was this

Table 1: Podolinsky's Calculation of the Energy Productivity of Animal and of Human Labor

Sector	*Product (kg)*	*Energy Product (kcal)*[a]	*Energy Surplus Over Natural Pastures (kcal)*	*Energy Input (kcal)*[b]	*Hourly Energy Productivity of Labor (kcal/hour)*
Natural pastures	2,500 (hay)	6,375,000	—	none	—
Sown pastures	3,100 (hay)	7,905,000	1,530,000	37,450[c]	40.85
Wheat cultivation	800 (wheat); 2,000 (straw)	8,100,000	1,725,000	77,500[d]	22.26

SOURCE: Martinez-Alier (1987) and authors' extensions.
NOTE: All figures are per hectare, based on data for 1870s France. kcal = kilocalories; kcal/hour = kilocalories per hour.
a. Assuming 2,550 kcal/kg of hay and of straw and 3,750 kcal/kg of wheat.
b. Assuming 645 kcal per hour of horse labor and 65 kcal per hour of human labor
c. Assuming 50 hours of horse labor and 80 hours of human labor per hectare.
d. Assuming 100 hours of horse labor and 200 hours of human labor per hectare.

accumulation of usable energy (or, as we would say today, low entropy) that Podolinsky saw as the very purpose of work and as the material-physical basis for civilization. Although human beings cannot create useful energy (because such energy all derives from the sun), they can assist in its accumulation on Earth in forms available for human purposes. They can do so directly, Podolinsky suggested, through agricultural cultivation, draining marshes, irrigation, mechanization of agriculture, protecting plants against natural enemies, and driving away and exterminating animals harmful to vegetation. Such accumulation of energy, moreover, can also occur in nonagricultural activities. The production of shoes, for example, was a way of accumulating energy usable for human purposes and thus fell under the definition of useful work.

Podolinsky used French government statistics and other sources to provide calculations on the energy productivity of (domestic animal and human) labor in agricultural production in 1870s France. He showed that the hay that was generated on a natural pasture without the contribution of human labor embodied much less energy (measured in kilocalories) than did the hay produced in sown pastures or the wheat and the straw produced in fields devoted to wheat agriculture. The energy surplus over natural pastures was accounted for by the input of human and of animal labor from which the hourly energy productivity of that labor in kilocalories per hour could be estimated. Of course, any apparent precision in such calculations hinges on specific, more or less restrictive, assumptions regarding not only crop yields and their energy content but also the quantity of (direct and indirect) energy input, including the energy equivalents of the human and the nonhuman labor applied per hectare of land (on which more presently). Podolinsky's assumptions and calculations are shown in Table 1, which is an extended version of the helpful reconstruction in Martinez-Alier (1987, p. 48).

The essential idea here was the notion that human labor had increased the throughput in energy terms over what would be found in forests or in natural pastures. This (in modern terms) energy subsidy could be expressed in amounts that were multiples of the inputs of human and of animal labor and thereby translated into figures on energetic labor productivity.

Problems with the Quantitative Energy Accumulation Approach

Even in the relatively simple context of 19th-century hay and wheat production, on which Podolinsky relied for his examples, a proper calculation of energy throughput and energy productivity of labor was far more complex than he indicated.[7] As shown in Table 1, Podolinsky did not subtract from output or include in input the energy associated with fertilizers, including manure and guano. Nor did he include the input of fossil fuels (in this case coal), though he had himself written on the role of steam engines in agriculture in the form of threshing machines in his work "The Steam Engine." Energy input was considered equivalent to work done and was not measured in terms of the total caloric consumption of humans. Energy expended through the human metabolism was therefore not included on the input side of his energy calculations. Also not included (as biologists would note) was the energy expended in the respiration of plants. Solar energy itself was not calculated as an input. (Some of these inputs were characterized by Podolinsky as "free gifts of nature.") Nor did Podolinsky consider the fact that not all energy inputs and outputs in agriculture (least of all in forests and in natural pastures) can be measured simply in terms of the energy embodied in the desired product, because natural systems, even when simplified by humans, are more complex than that. Taken together, these points raise serious obstacles to the kind of energy calculations that Podolinsky advanced. And these obstacles are even more imposing when more complex and indirect forms of production are considered.

Such energy flow calculations are, however, meaningful up to a point in that they can reveal some of the material preconditions of production, highlighting its environmental dependence. They can thus help reveal the concrete ways in which the first and the second laws of thermodynamics (conservation and dissipation of matter-energy) impose limits on human production. Energy accounting is thus likely to play an important role (together with biochemical-ecological analysis of production and consumption systems) in postcapitalist society—that is, in a socioeconomic system dedicated to a sustainable, all-round human development in coevolution with nature rather than an ecologically unsustainable process of competitive capital accumulation.

That said, any socialism worthy of the name will eschew the kind of energy reductionism arguably built into Podolinsky's analysis. Although energy flows are an important precondition and limiting factor in the production of goods and services by nature and human labor, this production also involves complex physical, chemical, and biological conditions and processes that are hardly reducible to pure energetics. This should be evident in the case considered most closely by Podolinsky, namely, the production of food. As Roy Rappaport states in his classic study of the ecological energetics of Tsembaga gardens in New Guinea, the nutritional-use value of harvested plants includes not just "a supply of calories" but also "a supply of minerals, vitamins, and proteins," so that "it should not be assumed that energy-capturing activities are the only necessary subsistence activities" (Rappaport, 1984, p. 63). Even though Podolinsky did not explicitly make the latter kind of assumption, his historical analysis, as we shall see, failed to recognize "that while the details of energy transactions may illuminate some aspects of ecological and, perhaps, economic relationships, explanations that are restricted to the consideration of energy inputs and outputs will in some cases fail" (p. 63; cf. Pimentel & Pimentel, 1996, pp. 75-76).

Podolinsky's Analysis as a Basis for Value Theory

Despite the aforementioned problems, it appears, based on the opening paragraphs of his article and on his correspondence with Marx, that Podolinsky may have been aiming at an analysis in the language of physics that would provide a firmer basis for the labor theory of value in its Marxian version. This is, at any rate, the way that his energy productivity calculations have been interpreted by many ecological critics of Marx and Engels. Thus, Martinez-Alier (1987), after going over Podolinsky's energy-accounting exercises, specifically says that Podolinsky saw this accounting as giving "a scientific basis to the labor theory of value, a point that neither Marx nor Engels appreciated" (p. 49). This criticism of Marx and Engels has become a conventional wisdom used to distance ecological economics from Marxism (see, e.g., Bramwell, 1989, pp. 85-86; Hornburg, 1998, p. 129; Kaufman, 1987, p. 91; O'Connor, 1998, p. 3). It is, however, somewhat of a stretch insofar as Podolinsky himself undertook no value analysis in "Socialism and the Unity of Physical Forces." And it becomes even more questionable when one considers the difficulty of trying directly to translate energy inputs and outputs into economic (labor) values as conceived by Marx.

For Podolinsky's work to be seen as a basis for a labor theory of value, one has to assume that (a) human labor is reducible to energy inputs that can be directly compared to the output of production as a whole and that (b) the resulting energy-flow figures can be translated directly into commodity values. But from the standpoint of Marx's theory, these assumptions run aground on the complex relations among use values (resources and produced goods and services that directly or indirectly serve human needs and human development), labor values (the abstract labor times necessary to produce commodities), and exchange values (the prices fetched by commodities in the market). In Marx's approach, abstract labor values must be objectified in vendible use values, and neither these use values nor the human labor and natural conditions that produce them can be reduced to pure energy terms. There is, moreover, no stable, one-to-one relationship between abstract, value-creating labor and concrete labor expended (even assuming that the latter can be reduced to pure energy) either intertemporally or across different firms and industries (Burkett, 1999, pp. 108-112; Saad-Filho, 2002, ch. 5). In short, although Podolinsky's attempt to measure the energy productivity of labor was revealing in many respects and was an important contribution, it was a far cry from anything that could potentially constitute an energetic basis for Marx's labor theory of value. Indeed, the attempt to directly translate energy productivities of human labor into economic value categories is extremely problematic in all respects and belongs to a long history of energy reductionism that has been opposed by some of the major figures in ecological economics (see Mirowski, 1988, pp. 822-825; Burkett, 2003, pp. 139-141, 151-153).

Stated differently, to interpret Podolinsky's work as a scientific foundation for a labor theory of value is to replace Marx's dialectical material-social analysis of value and use value with a crude materialist (specifically energy reductionist) approach. This point merits a brief historical digression.

Value and Nature: Marx and Sieber Versus Podolinsky

Ironically, one of the most pertinent commentaries on the difficulty of finding a scientific proof or basis of the labor theory of value in the physical world (e.g., in productive energy flows) can be gleaned from the work of Nikolai Sieber, who was

both Podolinsky's economic mentor and Marx's most formidable early economic follower. Sieber was exceptional in that, in contrast to many Marxist economists even up to the present, he understood the distinction between the quantitative value problem and the qualitative value problem that was at the heart of Marx's divergences from Ricardo (see Sieber, 2001, p. 41). In the early 1870s, Sieber began to publish a series of articles in the journal *Znanie* (*Knowledge*). In the first of these, Sieber replied to a German review of Marx's *Capital* by Karl Rössler, who had rhetorically asked why "the food in the stomach of a worker should be the source of surplus value, whereas the food eaten by a horse or an ox should not." Sieber had replied, quite inadequately from Marx's standpoint, that Marx's *Capital* was concerned with human society and not domestic animals and thus was directed only at the surplus value created by human beings. Marx commented in his published notes that

> the answer, which Sieber does not find, is that because in the one case the food produces human labour power (people), and in the other—not. The value of things is nothing other than the relation in which people are to each other, one which they have as the expression of expended human labour power. Mr. Rössler obviously thinks: if a horse works longer than is necessary for the production of its (labour power) horse power, then it creates value just as a worker who worked 12 hours instead of 6 hours. The same could be said of any machine. (Marx as quoted in White, 2001, p. 6)

If Sieber did not grasp the essential point at first, he did subsequently. In 1877, Yu. G. Zhukovskii, a follower of Ricardo, criticized Marx for arguing that only human labor created surplus value. Zhukovksii argued, as explained by James D. White, that "anything which bore fruit, be it a tree, livestock or the earth, all were capable of providing exchange value. For Zhukovskii one of the main sources of value was Nature" (White, 2001, pp. 6-7). In response, Sieber said that a good Ricardian ought to be able to grasp that human labor was the sole source of exchange value, which reflected the division of labour and the fragmentation of society. In the following year, the classical liberal political economist Boris Chicherin presented essentially the same argument as did Zhukovskii (Chicherin, 1998, p. 325). Here, Sieber's response was unequivocal, cutting into the commodity fetishism basic to the classical liberal view:

> But to people it *appears* as though things exchange themselves one for another, that things themselves have exchange value, etc. and that the labour embodied in the thing given is reflected in the thing received. Here lies the whole groundlessness of the refutations of Mr. Chicherin, and before him of Mr. Zhukovskii, that neither the one nor the other could understand…that Marx presents to the reader the whole doctrine of value and its forms…as the peculiar way people at a given stage of social development necessarily understand their mutual relations based on the social division of labour. In fact, every exchange value, every reflection or expression of it, etc. represents nothing but a myth, while what exists is only socially-divided labour, which by force of the unity of human nature, seeks for itself unification and finds it in the strange and monstrous form of commodities and money. (Sieber as quoted in White, 2001, p. 8)

Podolinsky was most likely aware of these debates on Marxian economics in Russia and in the Ukraine and of the development of Sieber's position. Yet those who see Podolinsky's energy-accounting exercises as a scientific basis for a labor

theory of value saddle him with precisely the kind of crude materialist position that Sieber came to condemn. As shown in Table 1, Podolinsky's energy-productivity calculations lump animal labor in with human labor, which, if translated directly into value terms, implies that domestic animals harnessed by human beings are, like human labor, productive of labor values. Thus, to interpret these calculations as energetic labor-value calculations is to contradict Podolinsky's otherwise strong adherence to the notion that all value derives from human labor. From this, it appears that Podolinsky's champions are extrapolating his analysis in ways that he himself might reject.

Near the beginning of his article, Podolinsky does seem to identify surplus value with physical energy, and in an April 8, 1880, letter to Marx, he did describe his work as an "attempt to bring surplus labour and the current physical theories into harmony" (quoted in Martinez-Alier, 1987, p. 62). Such statements suggest that Podolinsky's viewpoint on value was closer to Ricardo's purely quantitative approach than to Marx's quantitative and qualitative treatment, for they seem to imply that value is a thing embodied in a product that has behind it another thing—a physical reality in the form of physical force or energy (e.g., muscular labor) all of which can be quantified. It is, at any rate, easy to see how Marx and Engels's critics might interpret Podolinsky's statements in this way. Those holding such a viewpoint might genuinely think of themselves as addressing a perceived conundrum of Marx's theory—the physical basis of value.

However, in Marx's analysis value, or abstract labor time, is not a natural-physical substance but rather an alienated material-social relation behind which lies society's reproductive division of labor enmeshed with nature. For Marx, the reduction of value to abstract labor time is not because of a normative and/or empirical presumption that labor in general (let alone muscular labor in particular) is more important or primary than other production inputs. Rather, it is rooted in capitalism's social separation of the worker from necessary conditions of production (starting with the land) and their recombination only in capitalist enterprises that purchase, produce, and sell commodities for a profit. The separation of value (as abstract labor) from production's material conditions reflects workers' class-alienations from the same conditions (i.e., the conversion of labor power into a buyable commodity). Marx always insisted that as far as the production of wealth or use value is concerned, nature is just as primary as labor and that labor is itself a natural force to which supernatural productive powers should never be ascribed (Marx, 1976, pp. 133-134, 647-651). The tension between the natural requirements of human production and capitalism's reduction of value to abstract or alienated labor shows itself in the requirement that value must be objectified in use values produced by both labor and nature. But insofar as use values are produced only to make a profit, and not to promote sustainable human development in coevolution with nature, the alienated character of value reveals itself in the depletion and the degradation of both nature and the human laborers (i.e., in the alienation of use value from the requirements of sustainable all-round human development). Stated differently, the value-nature contradiction is not a contradiction of Marx's analysis as is commonly asserted; it is a contradiction of capitalism. Indeed, it is part and parcel of the contradiction between use value and exchange value, between abstract labor and concrete labor, between specifically capitalist productive conditions and the conditions required to sustain human production and development in general—the pivotal point on which Marx's critique of capitalism rests (Marx to Engels, August 24, 1867 in Marx & Engels, 1975, p. 180).

Podolinsky, as distinct from his economic mentor, Sieber, does not appear to have grasped such an intricate view of economic value. Still, the extent to which Podolinsky really thought economic values could be explained in pure energetic terms remains an open issue. The point here is that to treat his work as a potential scientific basis for a labor theory of value is implicitly to endorse energy reductionism in the realm of economics. The tremendous gulf between such energy reductionism and Marx's dialectical and material-social approach to capitalist value relations is completely fogged over when Marx and Engels are condemned for not adopting Podolinsky's purported insights.

Podolinsky's Perfect Machine Argument

The main thrust of Podolinsky's article was not directed at value theory but rather at the notion of the human being as constituting the perfect machine. More specifically, it drew from Sadi Carnot's thermodynamic notion of the perfect machine and the way that this notion had later been developed by William Thomson and by others. For Podolinsky, this thermodynamic perspective, when applied to human beings, demonstrated that although machines as such could never meet the criteria of the perfect machine, human beings could. Here, it is important to quote Podolinsky (1881/2004) at length:

> According to Sadi Carnot, in order to be able to judge the degree of perfection of a thermal machine, one needs to know not only its economic coefficient, *but also its capacity to recycle the heat spent at work*. A machine having the capacity to reheat itself, making the heat spent at work rise toward its fire-box, would be a *perfect machine*, and only such a machine could provide a true conception of the transformation of heat and *vice-versa*. Now, no machine constructed by the hands of men possesses this faculty. No machine heats its own fire-box with its own work alone, and no machine works on a *reverse cycle*, that is, the transformation of work into heat is unknown. As a consequence, the true laws of these transformations cannot be found with the aid of inanimate machines. The plant world, producing almost no effective mechanical motion, also cannot even be remotely considered as an example of a *perfect thermal machine*.
>
> But, observing the work of humans, we see in front of us just exactly what Sadi Carnot calls a *perfect machine*. From this perspective, humanity would be a machine that would not only transform heat and other physical forces in work, but that would also produce the *complete reverse cycle*, which converts its work into heat and other forces essential for the satisfaction of its needs, that is to say it would recycle to its fire-box the heat produced by its own labor. In reality, a steam engine, even admitting that it will run an entire year without the intervention of muscular human labor, could never produce all the elements necessary to sustain its work in the following year. The human machine, by contrast, will have created a new crop, will have raised young domestic animals, will have constructed new machines, and will still be able to continue with success its new work in the following year. The reason is evident: the human machine is a perfect machine, whereas an inanimate machine never achieves the conditions of perfection that Sadi Carnot requires.

Podolinsky clearly believed that he had discovered an important principle in his notion of human beings as perfect machines. Human beings, he argued, were unique in this respect. Plants, although they carried out photosynthesis, were not machines because they lacked the mechanical motion necessary for work. Animals could achieve some human-like energy accumulation on a limited instinctual basis

or if domesticated by humans. Machines themselves were dependent on human muscular labor to keep them functioning. Only the human machine was adaptable enough to carry out many different kinds of work while reheating its own firebox and thus able to carry out the reverse cycle required by Sadi Carnot's and by William Thomson's perfect thermodynamic machine.

A key part of this argument focused on what Podolinsky referred to as the economic coefficient of human beings: the quantity of work they perform compared to the energy they consume. He argued that if one compares the quantity of oxygen inhaled during work (or the amount of food energy burned off, assuming this to be proportional to the oxygen processed by the human body) to the quantity of physical work supplied by the muscles, there is a ratio of 5:1. In this case, the economic coefficient of the human machine is 1:5, or one unit of work performed for every five units of energy consumed. Human needs in civilized society are more complex, however, so the economic coefficient should be considered nearer to 1:10 than 1:5, reflecting the growth of per capita consumption.

> This means that the satisfaction of all of our needs, presently considered as indispensable, represents a quantity of work almost ten times greater than the human muscular labor. This surplus must be accounted for by the greater productivity of human muscular labor, guided by intelligence, by the muscular power of domestic animals, or finally, by inanimate forces both natural and artificial. (Podolinsky, 1881/2004)

For Podolinsky, primitive man, who relies almost exclusively on the free gifts of nature, has a higher economic coefficient than does civilized man. The former has an economic coefficient of 1:6 mainly because of less developed needs. Nevertheless, the latter has a higher productivity and is able to accumulate solar energy on Earth in quantities that surpass "ten times the force of his muscles." Thus, despite his reliance on greater per capita energy throughput, civilized man is a more perfect machine.

It is the economic coefficient, according to Podolinsky (1881/2004), that sets the limits to human survival:

> As long as muscular labor supplied by the human machine is converted into an accumulation of energy necessary for the satisfaction of human needs, which represents a quantity in excess of the sum of the muscular work of the human machine, by as many times as the denominator of the economic coefficient exceeds the numerator—the existence and the possibility of the labor of the human machine are guaranteed.

Shortcomings of the Perfect Machine Perspective

The most problematic part of Podolinsky's analysis is his central point—the claim that the human laborer constitutes the perfect thermodynamic machine in that it is able to carry out the complete reverse cycle, in effect, reheating its own firebox. In the formulations of Sadi Carnot and of William Thomson, the perfect machine is an ideal benchmark for measurement of actual machine efficiency. As Thomson put it, "a perfect thermodynamic engine is such that, whatever amount of mechanical effect it can derive from a certain thermal agency; if an equal amount be spent in working it backwards, an equal reverse thermal effect will be produced" (as quoted in C. Smith, 1998, p. 93). In the case of a steam engine, this would mean that the work W produced by the falling of heat from boiler to condenser could be

used to raise the heat back up by an equivalent amount so that there would be no net effect.[8] A more than perfect engine, Carnot theorized, would produce work *W* with a surplus *w*—producing more than a net effect if the engine were reversed, constituting a perpetual motion machine. But this, as Sadi Carnot argued, would violate the laws of physics (C. Smith, 1998, pp. 91-93).

Yet at times Podolinsky seems to attribute even this level of perfection to human muscular labor, which is able to create work *W* with a surplus *w* that allows it to become a perpetual motion machine (C. Smith, 1998, pp. 91-93). For example, he suggests, as already quoted, that

> the human machine, by contrast [to a steam engine so efficient that it runs an entire year without the intervention of human muscle power], will have [in the same year] created a new crop, will have raised young domestic animals, will have constructed new machines, and will still be able to continue with success its new work in the following year. (Podolinsky, 1881/2004)

The extreme difficulty that Podolinsky runs into here stems from his insufficient recognition that the analysis of the steam engine carried out by physicist-engineers like Carnot, Clausius, and Thomson is constructed in terms of a closed system and an ideal, frictionless engine.[9] In contrast, the human economy (like life itself), despite the emphasis of economists on the circular flow, is not a closed system but one that continually draws on its external environment so as to accumulate energy (or low entropy) within its own (open) system while simultaneously dissipating energy and material waste back into its environment. Indeed, the capitalist economy is arguably the most extreme example possible of a system that draws on a resource tap (at ever increasing rates) and dissipates waste into the environmental sink (also at ever increasing rates), in ways that accelerate entropic degradation. The "human machine" cannot be analyzed apart from this open system.

The chief point that Podolinsky underscores—though he is not able to develop this—is that life to some extent goes against entropy (or feeds on low entropy). Here we can turn to the classic study, *What is Life?*, written in 1944 by the great Nobel prize-winning physicist and pioneer in quantum theory, Erwin Schrödinger, who wrote the following:

> How does the living organism avoid decay? The obvious answer is: by eating, drinking, breathing and (in the case of plants) assimilating. The technical term is *metabolism*. The Greek word μεταβάλλειν means change or exchange. Exchange of what? Originally the underlying idea is, no doubt, exchange of material. (E.g. the German for metabolism is *Stoffwechsel*.) That the exchange of material should be the essential thing is absurd. . . . What then is that precious something contained in our food which keeps us from death? That is easily answered. Every process, event, happening—call it what you will; in a word, everything that is going on in Nature means an increase of the entropy of the part of the world where it is going on. Thus a living organism continually increases its entropy—or, as you might say, produces positive entropy—and thus tends to approach the dangerous state of maximum entropy, which is death. It can only keep aloof from it, i.e. alive, by continually drawing from its environment negative entropy. . . . Or, to put it less paradoxically, the essential thing in metabolism is that the organism succeeds in freeing itself from all the entropy it cannot help producing while alive. . . . Thus the device by which an organism maintains itself stationary at a fairly high level of orderliness (= fairly low level of entropy) really consists in

> continually sucking orderliness from its environment. (Schrödinger, 1944, pp. 71-72, 75)

It is this that gives the appearance that the human machine is the perfect (or more than perfect) thermodynamic machine, which can endlessly carry out a reverse cycle and reheat its own firebox. But this appearance is only sustained insofar as the human sociometabolic system is not a closed, isolated system to which the entropy law then directly applies but an open, dissipative system. It continually feeds on its environment and is able to defy (or, more precisely, to give the impression of defying) the entropy law in this way. Nevertheless, human beings exist within a limited biosphere. An open, dissipative system that feeds on its environment on an exponentially rising scale through the commodification of production—demanding a continual increase in the use of energy and of materials and dumping ever more wastes into the environment—is a trait that is carried to its zenith under the profit-driven, generalized commodity economy of capitalism. Such an economy must deplete and despoil the natural conditions of human development ("simultaneously undermining the original sources of all wealth—the soil and the worker" as Marx, 1976, p. 638, puts it), especially when the scale of its biogeochemical effects begins to rival that of the biosphere itself. Increasingly, as the system's extreme exploitation of the global environment violates the limits to natural wealth of any given qualities, it produces a closing circle on human developmental possibilities within the framework of capitalist relations (Commoner, 1971).

By failing to see human life and human systems as metabolic in nature, involving an exchange with the environment (whether conceived in terms of materials and of energy or in terms of low entropy), Podolinsky gets trapped in a mechanistic and reductionist view that is unable to capture the full material and social complexity of the human relation to nature. The notion of the human being as the perfect thermal machine tends to underestimate both the real dependence of human beings on nature and the full vulnerability of the natural world to human action (i.e., the reality of coevolution). The object simply becomes the accumulation of energy stocks and flows for the benefit of the human economy while downplaying the fact that human beings produce only in conjunction with nature. The difference between Podolinsky and Marx in this respect (a subject we will take up in greater detail in the next section) could not be greater. As ecological economist Kenneth Stokes has argued, Marx and Engels's "model explicitly embodied the open-systems notion of the metabolic interaction of man and nature; the notion that the economic process is embedded in the Biosphere" (Stokes, 1992, p. 64).

Indeed, the great danger in exaggerating the role of human labor in the production of wealth, and downplaying nature's contribution, had already been stressed by Marx in 1875. As the British political economist and food activist Susan George explains,

> One day in May 1875, Karl Marx received a political platform intended to reconcile two antagonistic factions of the German Workers' Party at the upcoming Party Congress. Exasperated, he dashed off the marginal notes which came to be known as the *Critique of the Gotha Programme*—rather a grand title for a quick, irritated "will they never get it through their heads?" sort of reaction.
>
> The first sentence of the offending document declared that "Labour is the source of all wealth and all culture. . . ." Marx shot back witheringly,

> "Labor is *not the source* of all wealth. *Nature* is just as much the source of use values . . . as labour, which itself is only the manifestation of a force of nature." (George, 1998, p. ix; cf. Marx, 1966, p. 3)

Nothing could be more incongruous for Marx than the reduction of human beings to the status of machines—based on a thermodynamics of closed systems that ignored the larger part of nature's contribution to production. Nor could a theory of value (which had to encompass use values and their relation to the natural conditions of production) for Marx reduce value to a product of muscular labor. Yet Podolinsky's most explicit attempt to provide a "definition of the value of production" saw it as dependent on muscular work.

As Podolinsky indicated in his June 1880 letter to Lavrov (see Note 12), he was most uncertain about the last part of his article in which he tried to relate his theory of the perfect thermodynamic machine (at least potentially) to different land uses under different modes of production. "Primitive man," he argued in that part of his article, is simply a hunter and gatherer who does nothing to prevent the dispersion of solar energy into interstellar space. Slavery requires standing armies and continuous wars and hence is inefficient in the accumulation of energy. The feudal serf's productivity is hindered by the obligatory work on the lord's estate. Capitalism's economic crises periodically throw thousands of workers onto the streets. Only socialism, then, can allow human beings to realize their potential as perfect thermal machines able to accumulate energy on the earth.

But such arguments only showed how limited Podolinsky's analysis was in terms of human-nature interactions and how incapable the energy-accumulation model was of capturing the complexities of human land usage and their socioeconomic-ecological characteristics. Socialism became merely the universalization of a system of efficient muscular labor for the benefit of all. The inherent limitations of Podolinsky's analytical framework allowed him to go no further.

PODOLINSKY, MARX, AND ENGELS

It is crucial to understand from the outset that the ecological criticisms of Marx and Engels's responses (or lack of responses) to Podolinsky are based to a very large extent on misreadings of the available evidence and on claims that cannot be factually supported or logically justified. For example, Martinez-Alier, who has consistently faulted Marx and Engels for their alleged failure to address Podolinsky's work, recently stated that "Marx died in 1883 and apparently never commented on Podolinsky's work beyond a letter of acknowledgment in the first days of April 1880" (Martinez-Alier, 2003, p. 10). This argument, however, relies simply on the extant evidence and assumes that because we do not have certain documents (e.g., letters from Marx to Podolinsky), that they must either have said very little (in the one case that we know about) or "apparently" never existed (in all further cases). We know that in his letter to Podolinsky in early April 1880, Marx not only acknowledged receipt of the draft manuscript "Human Labor and the Conservation of Energy" but also conveyed something more, because Podolinsky indicated in a reply that the letter had given him "deep joy" (quoted in Martinez-Alier, 1987, p. 62). Yet not even this letter of Marx's to Podolinsky that we definitely know about has survived. In short, to argue based on the paucity of extant evidence that Marx "apparently never commented on Podolinsky's work" beyond a bare acknowledgment is just logically impermissible.

Marx's Notes on Podolinsky

We now know that Marx took extensive extracts from a very early version of Podolinsky's manuscript carrying the title "Le Travail humain et la Conservation de l'Energie" ("Human Labor and the Conservation of Energy"), most likely in early April, 1880.[10] The extracts were around 1,800 words long and focused primarily on Podolinsky's thermodynamic argument. Marx's notes are scheduled for publication in a few years in MEGA Volume IV/27.[11] Given the existence of these notes, it is quite plausible that Marx wrote back or otherwise passed on comments to Podolinsky. (Podolinsky's economic mentor, Nikolai Sieber, was a guest at Marx's house on a number of occasions in the years 1880 and 1881.) Perhaps Marx sent back the manuscript itself (as was customary in those days before copy machines) with marginal notes or accompanying comments. Unfortunately, the original manuscript that Marx read has not yet been found.

That Marx took the time to compile such detailed extracts—with various passages emphasized, indicating an active and engaged reading—certainly runs counter to the notion that he and Engels turned a deaf ear to Podolinsky's work. Nor can it be reasonably argued that either Marx or Engels neglected thermodynamics (much less natural science in general). Marx and Engels both filled multiple notebooks with their studies in chemistry, physics, physiology, geology, and agronomy. As Baksi (2001) tells us, Marx studied William Robert Grove's *Correlation of Physical Forces* (1846), John Tyndall's *Heat* (1870), and Adolf Fick's work on the forces of nature and on their interactions (*Die Naturkraefte in ihrer Wechselbeziehung*, 1869). In his notes and letters, Marx referred to many of the scientists who introduced the major breakthroughs with respect to the conservation of energy and the second law of thermodynamics, including Helmholtz, Mayer, Liebig, Carnot, Clausius, and Thomson. He attended lectures by Tyndall, who was the principal advocate of Mayer's views in England. He was particularly attentive to everything related to the development of electricity, which he saw as replacing steam as a motive force. The fact that the second law of thermodynamics is not addressed in Marx's economic writings is not evidence of a neglect of natural science. Clausius did not introduce the actual term *entropy* in his attempt to bring the first and second laws of thermodynamics into harmony until 1865. Tait's *Sketch of Thermodynamics*, the first widely read text referring to the new science in its title (and emphasizing both the first and second laws), did not appear until 1868—after Marx's *Capital* had been published (C. Smith, 1998, pp. 255-256; Prigogine & Stengers, 1984, p. 117).

The main charge commonly directed at Marx is that he failed to exploit Podolinsky's insights into the natural-scientific basis for the labor theory of value that was provided by the new energetics. This criticism is based on the notion that Podolinsky had developed the basic elements of such an analysis, which he made available to Marx, and that Marx could therefore have incorporated these elements into his system. As discussed above, however, Podolinsky's *La Revue Socialiste* and *La Plebe* articles did not develop even the rudiments of an analysis capable of relating energy flows to capitalist value relations as conceived by Marx, and arguments to the contrary are based on a fundamental misunderstanding of the nature and the purposes of Marx's value analysis.

Moreover, even the underlying assumption that Marx had access to the portions of Podolinsky's analysis that have been considered by some to be relevant for value theory proves to be highly questionable. Marx's notes on Podolinsky's "Human Labor and the Conservation of Energy" are missing almost all the material that in

later versions of Podolinsky's argument conceivably relates to this subject: mention of Marx's analysis, empirical estimates on the energy input of human labor in agriculture and of its effect on the output of agriculture, reference to labor values, and the discussion of land use in alternative modes of production (including socialism). If Marx's notes are an accurate reflection of Podolinsky's argument (and it is doubtful that Marx would have failed to note any of these things if presented in the manuscript), then Podolinsky's analysis in "Human Labor and the Conservation of Energy" was, as the title suggests, a straightforward treatment of thermodynamics along with its abstract application to human beings as the embodiment of Carnot's (and Thomson's) perfect machine. The other parts of the argument were therefore most likely added to the original manuscript on "Human Labor and the Conservation of Energy" between April and the completion of the final draft of "Socialism and the Unity of Physical Forces" for *La Revue Socialiste* in May, possibly as an attempt to respond to comments made by Marx. In a letter to Lavrov on June 4, 1880, (see Note 12), Podolinsky said that his work about labour would be published that month "with some, unfortunately very short, attachments about socialism" (suggesting that the final parts of the manuscript on forms of property and human energy were in fact written and attached later).[12]

Podolinsky may have believed from the start, as he wrote to Marx on April 8, 1880, that his work constituted an "attempt to bring surplus labour and the current physical theories into harmony" (as quoted in Martinez-Alier, 1987, p. 62). Nevertheless, the textual evidence from Marx's extracts strongly suggests that "Human Labor and the Conservation of Energy" was even less explicit in its argument in this respect than what was later published under the title "Socialism and the Unity of Physical Forces" in *La Revue Socialiste* 3 months later. Indeed, in terms of a contribution to bringing energetics into harmony with the labor theory of value, it appears likely that all Marx saw was Podolinsky's thesis that human beings were perfect machines able to feed their own fireboxes with their muscular labor—which, if it made sense, would only constitute an argument as to why labor was the source of all value (and one that was hardly likely to impress Marx).

Engels's Comments on Podolinsky

In December 1882, a year or so after Podolinsky's Italian article appeared, Engels wrote two letters to Marx on Podolinsky's analysis. The core of Engels's comments resides in his reactions to (a) the translation of human work into energy computations and (b) the translation of such computations into economic values. And it is these reactions that have been the focus of all the charges regarding Marx and Engels's failure to build on Podolinsky's ideas. To develop a further understanding of the Podolinsky-Marx-Engels relationship, it is therefore necessary to examine Engels's letters.

From late October 1882 until early January 1883, Marx was on the Isle of Wight, where he had gone to try to regain his health, while Engels remained in London. Engels had been working on his essay, "The Mark," which was to be published as an appendix to the German edition of *Socialism: Utopian and Scientific* (Engels, 1978, pp. 77-93). "The Mark" was about the downfall of peasant communal rights to the land and hence about the conditions of primitive accumulation in Germany. It ended with a consideration of ecological-economic factors:

1. the inability of the peasant to raise cattle without rights to common lands;

2. the obstacles to peasants continuing to farm their small plots of land without the manure provided by the cattle;
3. the growth of landed property on a large scale;
4. the threat to European agriculture then posed by United States agriculture, with its production and export of grain on a gigantic scale; and
5. the gross impoverishment of the remaining German peasants resulting from Factors 1 through 4.

On December 15, 1882, Engels sent his draft of "The Mark" to Marx asking him to return it in a few days. Three days later, Marx sent a note (the second to last item of correspondence from Marx to Engels contained in the *Collected Works*) back to Engels saying that "The Mark" was "very good" and that he was returning the manuscript. On December 19, Engels wrote that he had received Marx's note and then the manuscript. In the second paragraph of his letter, Engels then launched immediately into the "Podolinsky business" (Marx & Engels, 1992, p. 410). From this, we conclude that it is likely (but by no means certain) that Marx wrote a marginal note on Podolinsky and on the question of labor efficiency in agriculture on Engels's copy of "The Mark" or sent a note to this effect accompanying it. It was, in any case, immediately after referring to Marx's response to "The Mark" that Engels took up the Podolinsky question.

Engels wrote on December 19 that although he did not have Podolinsky's article at hand, he had read the version published in *La Plebe* (Marx & Engels, 1992, p. 410). He then proceeded to a critique of its contents. For Engels, Podolinsky's "real discovery" was "that human labour is capable of retaining solar energy on the earth's surface and harnessing it for a longer period than would otherwise have been the case" (p. 410). But this thermodynamic insight does not, Engels argued, translate directly into economics. "All the economic conclusions" that Podolinsky drew from this insight "are wrong" (p. 410). Engels then proceeded to a succinct theoretical discussion of the accounting of human energy and of its relation to work. Engels's discussion was more complete than Podolinsky's in that it accounted directly for (a) the calories human beings consumed and for (b) the fact that the economic labor performed in work in no way corresponds to the reproduction of the calories used up by human beings during the time that they are working (here Engels considers such issues as friction, the loss of calories because of increased heat, and so forth, and to human excretions).

In Engels's view, the energetic significance of the labor conducted during a day in which a certain number of calories are consumed—Engels provides for illustration a hypothetical figure of 10,000 calories—"consists rather in the stabilisation over a longer or shorter period of the *fresh* cal," (calories) that workers absorb

> from the radiation of the sun, and this is the only connection that the latter have, so far as labour is concerned, with the first 10,000 cal. Now whether the *fresh* cal stabilised by the expenditure of 10,000 cal of daily nourishment amount to 5,000, 10,000, 20,000 or a million is dependent solely upon the level of development of the means of production (Marx & Engels, 1992, pp. 410-411)

that is, human productive powers and human needs (the historically determined level of subsistence) developed at any given stage of production. Engels clearly felt that the daily expenditure of human energy in economic work is not easily related to the daily amount of energy physically consumed because human beings (a) draw on other sources besides their own production for energy, (b) consume energy in

ways that are related to their basic metabolic processes and not simply in relation to the work they do, and (c) have needs and productive capacities that are a product of the historical development of society and production.

Engels was well aware that Podolinsky's energy calculations had not included fertilizers, and he pointed to the fact that their inclusion was not only necessary but made the quantification of energy input much more complicated. Equally important, he insisted, was the role of coal, which showed how human beings draw on their environment to exploit solar energy from the past. This was something that had not entered directly into Podolinsky's calculations despite his knowledge of the role that the steam engine played in agriculture, particularly in threshing.[13] As Engels wrote to Marx,

> What Podolinski has completely forgotten is that the working individual is not only a stabiliser of *present* but also, and to a far greater extent, a squanderer of *past*, solar heat. As to what we have done in the way of squandering our reserves of energy, our coal, ore, forests, etc., you are better informed than I am. From this point of view, hunting and fishing may be seen not as stabilisers of fresh solar heat but as exhausters and even incipient squanderers of the solar energy that has accumulated from the past. (Marx & Engels, 1992, p. 411)

The difficulty of analyzing human production as a whole in terms of energy emanating from human labor presented problems so formidable that Engels contended that they were virtually insurmountable. This was particularly the case in industry. As he further explained in the same letter,

> In industry all calculations come to a full stop; for the most part the labour added to a product does not permit of being expressed in terms of cal. This might be done at a pinch in the case of a pound of yarn by laboriously reproducing its durability and tensile strength in yet another mechanical formula, but even then it would smack of quite useless pedantry and, in the case of a piece of grey cloth, let alone one that has been bleached, dyed or printed, would actually become absurd. The energy value conforming to the production costs of a hammer, a screw, a sewing needle, is an impossible quantity. . . . To express economic conditions in terms of physical measures is, in my view, a sheer impossibility. (Marx & Engels, 1992, p. 411)

Engels's argument here is one that he had developed earlier, in a notebook entry written in 1875 (later published as part of his *Dialectics of Nature*), in which he commented on attempts by scientists to explore the relation between human physiology, energy, and work. In a manner closely resembling what had happened with the Darwinian theory (specifically the competitive struggle for existence), Engels contended, the concept of work had been transferred from political economy to natural science and was in the process of being transferred back from natural science to political economy with absurd results. "Let someone try to convert any *skilled labor*," he wrote,

> into kilogram-metres [after the physiological experiments of Fick and Wislicenus] and then to determine wages on this basis! Physiologically considered, the human body contains organs which in their totality, *from one aspect*, can be regarded as a thermodynamical machine, where heat is supplied and converted into motion. But even if one presupposes constant conditions as regards the other bodily organs, it is questionable whether physiological work done, even lifting,

> can be at once fully expressed in kilogram-metres, since within the body *internal* work is performed at the same time which does not appear in the result. For the body is not a steam-engine, which only undergoes friction and wear and tear. Physiological work is only possible with continued chemical changes in the body itself, depending also on the process of respiration and the work of the heart. Along with every muscular contraction or relaxation, chemical changes occur in the nerves and the muscles, and these changes cannot be treated as parallel to those of coal in a steam-engine. One can, of course, compare two instances of physiological work that have taken place under otherwise identical conditions, but one cannot measure the physical work of a man according to the work of a steam-engine, etc; their external results, yes, but not the processes themselves without considerable reservations. (Marx & Engels, 1987, pp. 586-587)

This rejection of attempts to reduce human work to the thermodynamic logic of a steam engine reads like a critique, well before the fact, of Podolinsky's treatment of the human being as the perfect machine based on Carnot. It is worth recalling here that Carnot's notion of a perfect machine (and Clausius' thermodynamics) did not address everyday engineering concepts, such as the loss of heat through friction, because Carnot and Clausius were looking at ideal, completely reversible engines, in which all of this was abstracted from. Likewise Podolinsky, in the examples he uses to illustrate his interpretation of human beings as perfect machines, able to reheat their own fireboxes, abstracts from all the ways in which energy is dissipated through the normal workings of the human metabolism as well as from the important path dependencies involved in metabolic processes of human consumption and work. The importance of these factors is clarified by the analysis of so-called energy income (consumption of energy sources convertible into work) and so-called energy expenditure (work), as developed by one of Podolinsky's teachers, the great physiologist Ludimar Hermann.

As Hermann emphasized in his *Elements of Human Physiology*, an adequate analysis of energy flows in human labor must recognize that the biochemical compositions of energy income and of expenditure, and their compatibility (or lack thereof) with nutritional and with other metabolic functions, helps determine the sustainability of any particular labor process—that is, its consistency with the healthy reproduction of the laborer (Hermann, 1875, pp. 199-200, 215-225). Different kinds of labor require different biochemical forms of energy income, not just different amounts of caloric input. Moreover, according to Hermann, the biochemical constituents of the energy flows associated with labor operate interactively with the effects of immediately previous activity (e.g., in terms of whether the laborer is properly warmed up or, at the other extreme, not already exhausted by prior labor) to complexly determine the amount of energy expenditure and effective work performance achievable from any given caloric income (pp. 240-241). In short, although path-dependency effects certainly apply to both inanimate and animate (including human) machines (cf. Mirowski, 1988, p. 819), the complications they pose for the calculation of energy productivities are clearly compounded by the metabolic nature of animate (including human) labor. It is ironic that Engels shows greater sensitivity to this crucial metabolic dimension than does Hermann's one-time pupil, Podolinsky.

Accordingly, Engels resists too sharp a distinction between the forms of life—both between plants and animals, and between human beings and other animate species. For example, he argues that one should not treat human beings as accumu-

lators of energy while downplaying the role of other life forms. Thus, Engels writes in his December 19, 1882 letter to Marx,

> Man, by his labour, does deliberately what plants do unconsciously. Plants—and there is nothing new in this of course—are the great absorbers and repositories of solar heat in modified form. Thus man, by his labour, in so far as it stabilises solar energy (which in industry and elsewhere is by no means always the case), succeeds in combining the natural functions of the energy-consuming animal with those of the energy-gathering plant. (Marx & Engels, 1992, p. 412)

If human beings are able, like plants, to accumulate solar power on Earth, they are also squanderers of energy like animals (and, as Engels had already indicated, on a vast scale). By emphasizing the human squandering of energy, Engels raised ecological questions that were much deeper than Podolinsky, with his steam engine analogy, was able to grasp. Although emphasizing that Podolinsky had made "a very valuable discovery" in his treatment of human beings as accumulators of solar energy, Engels insisted that Podolinsky's conflation of physics with economics had driven him to false conclusions that oversimplified some of the fundamental problems of human existence (Marx & Engels, 1992, p. 412). At the same time, Podolinsky's recognition of the dependence of industry ultimately on agriculture, although not new, was, Engels reiterated in his letter of December 22 to Marx, a crucial element (a "time-honoured economic fact") in a materialist perspective, even though Engels did not find its translation "into physical terms . . . particularly rewarding" in terms of the furtherance of economic analysis (Marx & Engels, 1992, p. 413).

Given Engels's careful critique of Podolinsky, it would be a mistake to argue, as some have done, that he simply ignored or carelessly rejected Podolinsky's ideas. Furthermore, it is significant that in all of this, Engels never directly addresses value questions, reflecting the fact that although Podolinsky raised that issue, he had nothing to say about it directly. For this reason, it is a misnomer to say that "Engels was uninterested in Podolinsky's attempts to redefine the labour theory of value" (Martinez-Alier & Naredo, 1982, p. 218). Rather, Engels approached Podolinsky from his strong point by addressing the latter's attempts to present basic economic conditions in physical terms. But even then, Podolinsky's argument was found wanting.

Marx never answered Engels's letters on Podolinsky. Perhaps they needed no answer. But also, Marx was scarcely in a position to do so because he was extremely ill. A few weeks later, on January 10, 1883, Marx wrote his last letter to Engels. On January 11, Marx's daughter, Jenny, died, and he left for London immediately. On January 13, Marx contracted bronchitis and an inflammation of the throat and was unable to swallow. In February 1883, he developed a lung tumor, and on March 14, he died.

CONCLUSION

In the same year (1880) that Podolinsky sent his first small work on labor and energy to Marx, the latter wrote his *Notes on Adolph Wagner.* In these notes, Marx reiterated his conception of value accumulation as necessarily accompanied by real material exchanges—involving the human metabolism with nature—that limit and constrain it. It is this understanding of capitalist society as alienated against

itself and against nature that constitutes the heart of Marx's critique and the core of his ecological vision. Referring to the method used in his political-economic works, Marx wrote, "I have employed the word [*Stoffwechsel*] for the 'natural' process of production as the material exchange . . . between man and nature" (Marx, 1975, p. 209). *Stoffwechsel* translates as *metabolism*, and it was essential to Marx's conception of human labor as a metabolic relation between human beings and nature occurring in and through society, i.e., as a material-social metabolism (Marx, 1976, pp. 207, 283). In this conception, the relation between human beings and nature could not be reduced to the closed thermodynamic model of 19th-century physics but had to be seen in terms of an open, dissipative system in which the human metabolic relation fed upon nature—and not simply in terms of quantifiable energy but also more qualitative elements, such as specific soil nutrients. Rather than a perfect (or more than perfect) machine that accumulated energy (if used fully), Marx's analysis highlighted the emergence of a metabolic rift as human beings robbed the environment that constituted the basis for human production, undermining the conditions of sustainability (Foster, 2000, pp. 141-177). The analysis of living systems, including human society, as metabolic systems was to be the key to the development later on of ecosystem ecology, which was never reducible to pure energetics.

Marx's view, which refused to conflate physics with value, is entirely compatible with ecological economics as long as this does not take the form of energy reductionism. As Martinez-Alier has pointed out, Nicholas Georgescu-Roegen (1906-2004)—unquestionably the greatest of modern ecological economists—"knew [Engels's] *Dialectics of Nature* to the core" and liked "to highlight Engels's anticipation of arguments against an absurd theory of energy-value when he [Engels] wrote in 1875 that 'no-one could convert specialized work into kilogrametres and determine salary differences based on that criteria'" (Martinez-Alier, 1997, p. 231). Obviously, Georgescu-Roegen, though he did not know Podolinsky's work specifically, nonetheless shared some of the same criticisms as did Engels of attempts to reduce economic values to physical energy.

The important thing, as Georgescu-Roegen would have said, is not that the human economy can be reduced to energy (or to low entropy) but rather that it feeds on it and must attempt to conserve it (Georgescu-Roegen, 1971, p. 277). Looked at from this perspective, Podolinsky, inspired by Marx, presented what Engels called "a valuable discovery" in laying out some of the physical (and ecological) conditions of human production—a discovery that helped open the way to a more developed critical analysis and to a more complete ecological view.

Our analysis has contested the conventional wisdom that finds in the "Podolinsky business" evidence that Marx and Engels were indifferent or even hostile to ecological concerns. At the same time, we do not mean to reject in toto Martinez-Alier's (1987) valuable account of a number of provocative and sophisticated precursors of an ecological political economy—precursors whose work has been largely ignored by the discipline of economics as a whole. Rather, our critique of the energy-reductionist and closed-system elements of Podolinsky's thought, and our demonstration that Marx and Engels's reaction manifested and clarified their own metabolic and open-system concerns, suggest that Martinez-Alier's pioneering survey should be built upon in a way that incorporates important socioecological thinkers (including Marxists) whose work was less strictly centered on energy issues (cf. Foster, 2000, pp. 226-256). Such an extension would merely be following Martinez-Alier's (1987) own recognition that "to seek out the

writers who have counted calories" is "a somewhat one-sided" approach to the history of ecological economics (pp. 1-2).[14]

NOTES

1. We use the Russian-German form of Nikolai Sieber's name here because this was the form used by Marx and is the one most familiar in the Marxist literature. In most bibliographies and discussions of Ukrainian intellectuals, however, the Ukrainian spelling of his name is used: Mykola Ziber.

2. A revised and expanded edition of *David Ricardo's Theory of Value and Capital*, incorporating later work by Sieber on Marx, was published in 1885 under the new title *David Ricardo and Karl Marx in their Socio-Economic Investigations* (White, 2001, p. 6).

3. Sieber met Marx and Engels for the first time in 1880 (the year that Podolinsky sent his manuscript to Marx), when Sieber was a frequent guest at Marx's house. For detailed discussions of Sieber's economics and relation to Marx, see White (1996, pp. 229-238); White (2001); D. N. Smith (2001); Koropeckyj (1984, pp. 203-214); and Koropeckyj (1990, pp. 194-203).

4. Marx's extracts from Podolinsky's "Human Labor and the Conservation of Energy" are predominantly in French and correspond word for word with much of the 1880 French version of Podolinsky's manuscript published in *La Revue Socialiste*. As discussed later, however, the limited coverage of Marx's extracts compared to the published text, and their different titles, strongly suggest that Marx was reading an earlier and shorter version of the *La Revue Socialiste* article.

The 1880 Russian article in *Slovo* was titled "Human Labor and its Relation to the Distribution of Energy." It was very extensive—70 pages long in small type, with 12 chapters. It has been reprinted (Moscow: Noosfera, 1991) in book form, with an introduction by P. G. Kuznetsov. Its chapter headings (translated into English by Leontina Hormel) are as follows:

1. "What is Energy? Its Conservation and Distribution";
2. "Converting Energy on Earth";
3. "Economy of Energy";
4. "The Appearance of Organisms. The Meaning of Plants in the Distribution of Energy";
5. "The Meaning of Animals and Man in the Distribution of Energy. The Concept of Labor";
6. "The Origin of the Capacity Toward Work in the Constitution/Organism of Man";
7. "Man as Thermal Machine";
8. "Labor as the Means for the Satisfaction of Needs";
9. "Various Forms of Labor and Their Relation to the Distribution of Energy";
10. "Labor, the Tendency Toward the Production of Mechanical Work";
11. "The Plunder and Accumulation of Energy"; and
12. "General Conclusions."

5. In January 1882, Podolinsky had suffered a mental collapse from which he never fully recovered. In 1885, his parents obtained special permission to repatriate him, and he returned to Kiev, where he remained until his death in 1891.

6. Although the paragraphs at the beginning of the 1881 Italian version that referred to Carnot and to Thomson were not included in the *La Revue Socialiste* article of June 1880, Marx's notes show that they were included in the work on "Human Labor and the Conservation of Energy" that Podolinsky had sent to him in March 1880. These paragraphs were probably dropped in the June 1880 version simply because of lack of space.

7. Many of the problems we raise here are recognized by Martinez-Alier, but he gives them a different emphasis by stressing the common elements between Podolinsky's energy calculations and more recent agricultural energy-flow analyses, especially their recognition

of the role of human activity in imparting an energy subsidy to agricultural production (see Martinez-Alier, 1987, pp. 48-50).

8. Carnot's ideal engine (known as the Carnot engine), if run backward, would consume "as much motive power as it produced running forward. . . . Joined together but operating in opposite directions two engines [combined into one larger engine] would, therefore, produce no net effect" (Challey, 1971, p. 81).

9. "Clausius was no more concerned than Carnot with the losses whereby all real engines have an efficiency lower than the ideal value predicted by the theory. His description, like that of Carnot, corresponds to an idealization. It leads to the definition of the limit nature imposes on the yield of thermal engines" (Prigogine & Stengers, 1984, p. 114).

10. This is the title given on Marx's notes themselves and is also the title provided by the editors of the journal *Russian Contemporaries* in a footnote they attached to Podolinsky's March 24, 1880, letter to Lavrov. The March 24, 1880, letter from Podolinsky to Lavrov is reproduced in Sapir (1974, p. 67). Translated into English by Mikhail Balaev (from the Department of Sociology at University of Oregon in fall 2003), it reads as follows (copied from the journal *Russian Contemporaries*):

> Montpellier, 24 March 1880
>
> I sent to you, Petr Lavrovich, my work 'about labour' ["Le travail humain et la conservation de l'energie" (footnote by the editors of the journal *Russian Contemporaries*)] that I have just received. Please, be so kind as to send the address of Marx to me: I want to send it to him as well as the thing is directly related to him and was inspired in my mind by the theory of added labour . . .
>
> I shake your hand.
> S. Podolinskii

11. We are grateful to Kevin B. Anderson, David Norman Smith, Norair Ter-Akopian, Georgi Bagaturia, and Jürgen Rohan, the editors of the MEGA volume in which Marx's notes on Podolinsky will appear, for allowing us access to these notes for our research. Although contractual and copyright issues prevent us from directly quoting Marx's notes, it is still possible to give a fairly clear idea of what they tell us about both Marx's engagement with Podolinsky's analysis and the respective versions read by Marx and Engels.

12. Podolinsky's June 4, 1880, letter to Lavrov (Sapir, 1974, p. 68), translated into English by Mikhail Balaev (from the Department of Sociology at the University of Oregon in fall 2003), reads as follows:

> Montpellier, 4, June 1880
> Quartier Mont Maur
>
> Dear Petr Lavrovich!
>
> Please be so kind as, if possible, to send me a copy of "Intricate Mechanics" [a brochure by Varzar] in Russian. Malone is asking me for it in French, but I have only my Ukrainian version that I consider myself as having no rights to translate in the author's name. I also could not get a Russian original from Geneva.
>
> On 20 June my work about labour ["Le Socialisme et l'Unite des Forces physiques"] will be published in *Revue Socialiste* with some, unfortunately very short, attachments about socialism. Besides that, "Steam Engine" with attachments and "Wealth and Poverty" will be published as fiction.
>
> Will you be in Switzerland this summer? We are planning to go there for some three months.
>
> Shaking your hand firmly,
> S. Pod.

13. From his letter to Lavrov in June 1880 (see Note 12), it would appear that Podolinsky's story "The Steam Engine" was being reprinted in the same June 1882 issue of *La Revue Socialiste* in which his article on "Socialism and the Unity of Physical Forces" appeared. On the introduction of steam engines for threshing into Russian agriculture, see Hume, 1914, pp. 67-75.

14. We must, however, reject Martinez-Alier's (1987) accompanying assertion that "not much is lost analytically by focusing on the use of energy as the central point in ecological economics" (p. 2). This assertion seems to us to represent an unjustified narrowing of the discipline's subject matter.

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