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The Podolinsky Myth: An Obituary Introduction to 'Human Labour and Unity of Force', by Sergei Podolinsky

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Abstract
The relationship between Marxism and ecology has been sullied by Martinez-Alier's influential interpretation of Engels's reaction to the agricultural energetics of Sergei Podolinsky. This introduction to the first English translation of Podolinsky's 1883 *Die Neue Zeit* piece evaluates Martinez-Alier's interpretation in light of the four distinct but closely related articles Podolinsky published over the years 1880–3. This evaluation also emphasises the important but previously underrated role of energy analysis in Marx's *Capital*. Engels's criticisms of Podolinsky are found to be quite justified from both political-economy and ecological perspectives. From the standpoint of Marx and Engels's metabolic and class-relational approach to production, Podolinsky's attempt to reduce use-value to energy is fraught with problems. Podolinsky's energy reductionism does not even come close to representing an alternative value analysis – let alone a groundbreaking perspective on ecological history – as was suggested by Martinez-Alier. Far from Marx and Engels's vision of communism as an ecologically sustainable and coevolutionary human development, Podolinsky's conception of human labor as an energy accumulation machine seems to uncritically mimic the standpoint of the capitalist interested in using nature only to extract as much energy throughput (work) as possible from the labour-power (potential work) of the worker.

Keywords
Marxism, ecology, thermodynamics, energy, metabolism

I. Marx and Podolinsky: the nature of the controversy

The early years of this century have seen a remarkable transformation in the understanding of classical Marxism and the environment. The first wave of ecosocialist scholarship in the 1980s and early 1990s – the work of figures

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such as André Gorz, Ted Benton, Juan Martínez-Alier, and James O'Connor – pioneered in bringing innovations in green thinking to socialism. These thinkers, however, tended to be highly critical not only of the Marxist tradition, but of Marx and Engels's position on the environment. They often pointed to the ecological potentials of Marx's early writing. But it was usually assumed that in their mature writings the founders of historical materialism had turned away from these concerns, embracing a strong 'Prometheanism'. In contrast, the second wave of ecosocialism, in which the authors of this introduction have played a central part, went back to the roots of the Marxist tradition to explore these issues more systematically, examining the ecological ideas to be found in the mature works of the founders of historical materialism. This led to the resurrection of Marx and Engels's analysis of sustainability, which was central to their understanding of capitalism's contradictions and the transition to socialism. This was evident in particular in Marx's notion of the metabolic rift. This second wave of ecosocialist research has led to the widespread acknowledgement of the ecological underpinnings of the classical-Marxist critique of capitalism.[1]

In one area, however, Marx and Engels's understanding of ecology and hence their theory of metabolic rift continues to be questioned, particularly in relation to their alleged rejection of the second law of thermodynamics and of the application of this to economic thought, preventing the emergence of a Marxist ecological economics. The key figure in advancing this critique is Juan Martínez-Alier, whose 1987 work on ecological economics is widely viewed as the preeminent history of that field. It is largely through Martínez-Alier's writings that the work of the late-nineteenth-century Ukrainian socialist, Sergei Podolinsky, has become a focal point in the debate over the potential for a Marxist ecological economics. As Martínez-Alier recently acknowledged, 'the relationship between Marxism and ecological economics' was discussed in his book 'mainly by looking at Engels's negative reaction to Podolinsky's agricultural energetics'.[2] In subsequent writings, Martínez-Alier has continued to subject Marx and Engels to critique for rejecting both Podolinsky's ideas and the economic relevance of the basic laws of thermodynamics.[3] As a result, Marx and Engels's dispute with Podolinsky has become as important to the understanding of the development of Marxist thought as earlier disputes with such figures as Proudhon and Dühring. This introduction and the following

1. See Burkett 1999, 2006; Foster 1999, 2000 and 2001; Dickens 2004; Löwy 2006; Altvater 2007.
2. Martínez-Alier 2006, p. 278.
3. For the most recent example, see Martínez-Alier 2006, pp. 275–6.

translation of Podolinsky's most frequently cited article on ecological economics comprise an attempt to bring a final accounting to this debate.

Martínez-Alier's influential history argued, more concretely, that Marx and Engels failed to incorporate energy flows and thermodynamic concerns into their historical and economic analyses.[4] His argument comprises three specific claims. The first claim is that Engels misunderstood and rejected the second law of thermodynamics. In particular, Martínez-Alier alleges that Engels saw the law of increasing entropy (the second law of thermodynamics) as contradicting the conservation of energy (the first law).[5] The second claim is that Marx's *Capital* fails to analyse the place of energy flows in capitalist industrial development; nor does it consider environmental constraints posed by conservation of energy, limited supplies of non-renewable energy sources, and the entropy law.[6]

Martínez-Alier's third, and most important claim, since it purports to provide a solid historical basis reinforcing the others, is that Marx and Engels dismissed Podolinsky's pioneering work on the energetics of agricultural labour, thereby foreclosing an important opportunity to introduce energy and thermodynamics into Marxist theory. More specifically, Podolinsky attempted to reconcile Marx's labour theory of value with the first law of thermodynamics – something Marx evidently had failed to do.[7] In addition, 'Podolinsky studied the law of entropy and the economic process, and he tried to convince Marx that this could be brought into the Marxist analysis'.[8] Unfortunately, so this influential story goes, neither Marx nor Engels appreciated these groundbreaking contributions by Podolinsky, and this may be seen as a crucial missed chance for an ecological Marxism.[9]

The first full English translation of Podolinsky's 1883 article in *Die Neue Zeit*[10] provides a good moment to reconsider Martínez-Alier's third claim,

4. Martínez-Alier 1987.

5. Martínez-Alier 1987, p. 221. See also Martínez-Alier 1995, p. 71; 2005, pp. 4–5; 2006, pp. 275–6; Martínez-Alier and Naredo 1982, p. 209.

6. Martínez-Alier 1987, pp. 218–21; 1995, pp. 71–2; 2005, p. 3; 2006, p. 275; Martínez-Alier and Naredo 1982, pp. 208–9 and 219.

7. Martínez-Alier 1987, pp. 49 and 51; Martínez-Alier and Naredo 1982, pp. 209 and 218.

8. Martínez-Alier 2006, p. 276.

9. Martínez-Alier 1987, p. xviii; 1995, p. 71. Martínez-Alier's account of the Podolinsky episode has been endorsed by many ecological Marxists, including Deléage 1994, p. 49, and O'Connor 1998, p. 3. It has also served as grist for the mills of the many non-Marxist ecological economists eager to distance themselves from Marxism. See the numerous examples cited in Foster and Burkett 2004, p. 33; Burkett and Foster 2006, pp. 146–7; Burkett 2006, p. 15, footnote 2.

10. Podolinsky 1883.

that is, his prestigious account of the 'Podolinsky business' – as Engels referred to it in his letter of 19 December 1882 to Marx, where he commented on Podolinsky's work.[11] This introduction to the translation also addresses Martínez-Alier's second claim, regarding the absence of energetics and thermodynamics in Marx's *Capital*, insofar as this is necessary to interpret Engels's critique of Podolinsky.[12] However, Martínez-Alier's first claim – Engels's purported misunderstanding of the second law – lies outside the main scope of our analysis here and hence will be dealt with only tangentially. It needs to be noted, nonetheless, that this claim also misses the mark by treating Engels's rational scepticism regarding the cosmological heat-death theory of the universe hypothesis (an extrapolation from the concept of entropy that does not have the same scientific standing as the second law of thermodynamics itself) as a blanket disavowal of the entropy law and its terrestrial-historical impact.[13]

Podolinsky's basic ideas on the energetics of human labour were published in four different versions, Russian, French, Italian, and German, over the years 1880–3.[14] In previous writings, we have subjected the French and Italian versions of Podolinsky's work to close analysis. But the German rendition (in *Die Neue Zeit*) is especially important not only because it develops Podolinsky's conception of human labour at greater length and in more detail than did the French and Italian versions, but also because it is the version that Martínez-Alier uses to analyse the implications of the Podolinsky incident for an ecological Marxism. Nevertheless, Engels's comments on Podolinsky, in the above-mentioned letter to Marx, were based on the Italian version published in 1881, not the *Die Neue Zeit* version which appeared two years later, while Marx seems to have only read (and taken extracts from) a preliminary draft of the French version which was published in 1880. It is therefore necessary and appropriate to take this opportunity to reevaluate Podolinsky's analysis, Engels's reaction to it, and Martínez-Alier's influential interpretation, in light of the differences between the *Die Neue Zeit* article and the earlier versions considered by Marx and Engels.

Our introduction here to this important manuscript begins with a brief biographical sketch of Podolinsky and a synopsis of his main arguments as

11. Marx and Engels 1975b, p. 410.

12. For a detailed discussion of the key role of energy and thermodynamics in *Capital*, see Burkett and Foster 2006, pp. 117–40.

13. The problems with Martinez-Alier's argument on Engels and the second law detailed in a separate work by the present authors, Foster and Burkett 2008.

14. Podolinsky 1880, 1881, 1883 and 1991.

they were first presented to Marx and Engels. It is then shown that, contrary to Martínez-Alier's account, Engels engaged with the 1881 (Italian) version of Podolinsky's work very seriously in the spirit of critique.[15] What Engels objected to was not so much Podolinsky's proposed energetic basis for the labour theory of value (a notion that Podolinsky himself failed to develop at all), but rather his tendency to reduce labour and production, and indeed all use-values, to pure energy terms, and his lapse into an isolated system view of human economy. Indeed, in treating human labour as a 'perfect machine' in the sense of Carnot's ideal steam engine, and championing maximum 'accumulation of energy on the earth' as the historical task of socialism, Podolinsky had in effect denied the relevance of the second law for human production.[16] Engels's criticisms of Podolinsky are informed by a metabolic and open-system conception of human labour which naturally incorporates environmental constraints on human production, including limited stocks of energy-resources as well as friction and other forms of matter-energy dissipation.

With so much as backdrop, this introduction proceeds to consider the additional insights obtainable from the 1883 German version of Podolinsky's work translated into English here. We find that the energy-reductionist notion of human labour apparent in Podolinsky's earlier articles emerges even more clearly from the more detailed discourses and applications in his final *Die Neue Zeit* article. For example, Podolinsky now defines labour more overtly as physical (muscular) activity, an activity which purposefully accumulates energy on the earth. In general, the German version translated here reduces use-value to pure energy quantities even more insistently than do the French and Italian versions, rendering more palpable the divergence of Podolinsky's approach from Marx and Engels's metabolic conception of human labour and human wealth. At the same time, the German rendition carries over the anti-ecological features that Engels found in the Italian version, namely, the calculation of energetic labour productivities without taking account of non-labour inputs (including coal), the failure to deal seriously with the role of friction and biochemical processes in human labour and production, and the closed-system interpretation of the human labourer as a 'perfect machine'.

Finally, we show below that Engels's metabolic and open-system critique of Podolinsky is fully in line with Marx's approach to production in general and

15. This portion of our analysis summarises the more extended discussion in Foster and Burkett 2004.

16. Podolinsky 2004, pp. 70–3.

to capitalist production in particular. In fact, Marx's *Capital* (the first volume of which was published fifteen years earlier) had already answered Podolinsky's question about the thermodynamic consistency of surplus labour (in its specifically capitalist form as surplus-value), and metabolic-energetic analysis was a central element of Marx's critique of capitalist exploitation. *Capital* also used thermodynamics (analysis of the conservation and transformation of material forces) to show why capitalism generates much more throughput of matter and energy than prior modes of production. More specifically, Marx showed how capitalist mechanisation of production led to a definitive breaking of the solar budget constraint – a key turning point in the history of human production according to contemporary ecological economics. *Capital*'s analysis of the metabolic rift created by capitalist production is also quite consistent thermodynamically.

We end this introduction by offering a proper and respectful burial for the Podolinsky myth as constructed by Martínez-Alier. Marx and Engels's metabolic conception of human labour has a much richer ecological content than does Podolinsky's energy-reductionist procedure. Moreover, the historical-class content of Marx and Engels's conception – its unique blending of the material and the social – enabled them to avoid the élite-engineering perspective on social reform that Podolinsky adopted under the influence of the French 'living machine' school. Ultimately, Martínez-Alier is only able to exclude classical Marxism from the history of ecological-economic analysis insofar as he reduces ecology to empirical energy accounting, that is, to 'counting calories' as Martinez-Alier himself puts it.[17]

II. Podolinsky's life and work

Sergei Podolinsky (1850–91) was a Ukrainian physician who, despite being a member of the wealthy landed gentry class, gravitated toward socialism through his involvement in the resistance to Tsarism and his concern with the agrarian or peasant question.[18] While studying the natural sciences at the University of Kiev, Podolinsky came under the sway of socialist-populist thought. It was also in Kiev that he, like many others, was exposed to Marxist political economy through the guidance of Nikolai Sieber (1844–88), the father of Marxist economics in Russia and the Ukraine. In 1872, Podolinsky

17. Martínez-Alier 1987, pp. 1–2.

18. For more detailed biographies of Podolinsky, see Serbyn 1982; Martínez-Alier 1987, pp. 53–63; Himka 1993; Foster and Burkett 2004, pp. 35–6.

took up medical studies in Paris and Zurich, but he remained active in the dissemination of Ukrainian-nationalist and socialist ideas as well as in the provision of medical help to workers and peasants.

It was no doubt while studying the sciences and medicine that Podolinsky first became interested in energy issues. One of his teachers in Zurich was the German physiologist and metabolic-energy theorist Ludimar Hermann (1838–1914). Also, while in Paris, Podolinsky could not help being exposed to the energetic-physiological analyses developed by prominent French writers such as Claude Bernard (1813–78), Gustave Hirn (1815–90), and Étienne Jules Marey (1830–1904). These theorists applied the emerging ideas of thermodynamic science, as well as Carnot's earlier work on the efficiency of steam engines, more or less directly to human labour, thus conceiving of human beings as 'living machines'.[19] Marey, for example, began his *Animal Mechanism* with the words:

> Living beings have been frequently and in every age compared to machines, but it is only in the present day that the bearing and justice of this comparison are fully comprehensible. No doubt, the physiologists of old discerned levers, pulleys, cordage, pumps, and valves in the animal organism, as in the machine. The working of all this machinery is called Animal Mechanics in a great number of standard treatises. . . . Modern engineers have created machines which are much more legitimately to be compared to animal motors; which, in fact, by means of a little combustible matter which they consume, supply the force requisite to animate a series of organs, and to make them execute the most varied operations.[20]

The treatment of animals (including human beings) as thermodynamic machines was thought to lead to easily quantifiable relations of food (combustible matter), heat and useful work. Hirn, as explained by Marey, carried out experiments in which he 'enclosed the subject in a hermetically closed chamber, and made him turn a wheel which could, at choice, revolve with or without doing work'.[21] The object was to measure the energy efficiency of human labour in ways equivalent to the measurement of the thermodynamic efficiency of a steam engine. Unfortunately, such energy-reductionist approaches were to leave a deeper imprint on Podolinsky than did the more metabolic, and less mechanical, methods of Hermann.

After receiving his medical doctorate at Breslau in 1876 and briefly returning home to Kiev in 1877 (where he married Maria Andreeva, the daughter of a

19. Carnot 1977; Gleyse 2002; Papanelopoulou 2003.
20. Marey 1874, p. 1.
21. Marey 1874, p. 18.

landowner), Podolinsky settled in Montpellier, France in early 1878. There, he practised medicine and lectured at the local medical school. The years 1878–80 were also Podolinsky's most productive as a writer. Among his major works from this period are *The Life and Health of People in the Ukraine* (1879), which utilised his practical experience as a physician, and *Crafts and Factories in the Ukraine* (1880), the first economic monograph to be written in the Ukrainian language. In addition, Podolinsky continued to make personal and financial contributions to the Ukrainian socialist and nationalist journal *Hromada* [Community], published out of Geneva, for which he co-authored an 1880 manifesto calling for Ukrainian national independence and socialism.

At the same time, Podolinsky was working on a new study of the energetics of human labour, focussing mainly on agriculture. What appears to have been the first, and by far the lengthiest, version of this new work was published in the Russian journal *Slovo* in early 1880.[22] Like the subsequent versions, it dealt with various terrestrial energetic stocks and flows (and their connections with solar energy), with the effects of plants and animals on the amount of useful energy available for human economy, and with the unique capability of human labour to purposefully accumulate energy in useful forms.[23] The last point was illustrated with some simple calculations of the energy productivity of agricultural labour in France, in which Podolinsky compared the respective caloric contents of agricultural output and (animal and human) labour input.[24]

Podolinsky then sought to spread his ideas to the Western-European context by preparing shorter versions of his work in French, Italian, and German. The French version was published in the Parisian *La Revue Socialiste* in June, 1880.[25] Prior to its publication, Podolinsky sent a draft of this version to Marx. We know this from two letters sent to Marx by Podolinsky on 30 March and 18 April 1880, and more directly from extensive excerpt-notes taken by Marx from the draft in question.[26] Unfortunately, Marx's reply to Podolinsky's

22. This first version has been reprinted in book form (in Russian) as Podolinsky 1991.
23. Podolinsky 1991, pp. 26–75.
24. Podolinsky 1991, pp. 34–5.
25. Podolinsky 1880.
26. Martínez-Alier 1987, p. 62. Marx's excerpt-notes start with a French-language title, are roughly 1,800 words in length, and focus primarily on Podolinsky's thermodynamic argument. They are to appear in Volume IV/27 of the *Historisch-Kritische Gesamtausgabe*, or *MEGA*. While contractual and copyright issues preclude us from directly quoting these excerpt-notes, we nonetheless thank the relevant *MEGA* editors (Kevin B. Anderson, David Norman Smith, Norair Ter-Akopian, Georgi Bagaturia, and Jürgen Rohan) for allowing us to see them prior to their publication.

first letter, and any comments he may have given to Podolinsky, have not survived.[27]

The *Revue Socialiste* piece is the shortest of the four versions of Podolinsky's work. The next version was published in two instalments in the Italian periodical *La Plebe* in 1881.[28] An English translation of this Italian version appeared in print only recently on the initiative of the present authors.[29] Although the *Plebe* piece contains twenty paragraphs which do not appear in the *Revue Socialiste* article, the basic argument is essentially the same in these two versions.[30] Nonetheless, the Italian rendition has an independent importance because it is the version that was read and commented upon by Engels in his letter of 19 December 1882 to Marx.[31]

The fourth and last version of Podolinsky's energy analysis appeared in two instalments in 1883, in the inaugural volume of *Die Neue Zeit* (journal of the German Social-Democratic Party).[32] This rendition exceeds the Italian version by over three thousand words (although it is still much shorter than the Russian version which appeared in *Slovo* three years earlier). The differences between the German and Italian versions are actually quite significant, especially in terms of the former's more insistent championing of a thermal-machine approach to human labour.[33]

Unfortunately, by the time the *Neue Zeit* piece appeared in print, not only was Marx dead (the second installment of Podolinsky's article was preceded by

27. We know Marx did send a reply because Podolinsky referred to it as a source of 'great joy' in his second, 8 April 1880, letter to Marx (Martinez-Alier 1987, p. 62). The loss of this letter from Marx to Podolinsky and any other correspondence that Marx and Engels may have had with him can be attributed to the fact that all of Podolinsky's private papers appear to have perished.

28. Podolinsky 1881.

29. Podolinsky 2004.

30. This statement is based on our comparison of Podolinsky 2004 with an unpublished English translation of Podolinsky 1880 by our colleague Mark Hudson.

31. Marx and Engels 1975b, p. 410. Martínez-Alier and Naredo (1982, p. 222, footnote 17) stated incorrectly that 'Engels's comments are addressed to the article published in *Die Neue Zeit*'. They said this even after noting that 'Engels refers to the Italian version of Podolinsky's article' (Martínez-Alier and Naredo 1982, p. 216). The problem is that Martínez-Alier and Naredo assumed that all four published versions of Podolinsky's work were identical, apparently without checking (see footnote 33, below).

32. Podolinsky 1883.

33. Martinez-Alier and Naredo (1982, pp. 209 and 222, Note 17) were thus doubly wrong to assert that the 1883 article published in *Die Neue Zeit* was the same one that Podolinsky had previously sent to Marx in March 1880. Also misleading is Martinez-Alier's later statement that 'Podolinsky's original article appeared in similar Russian, French, Italian and German versions between 1880 and 1883' (Martinez-Alier 1987, p. 47).

an obituary for Marx), but Podolinsky's own career as an intellectual and activist was over. In January, 1882, he suffered a mental collapse from which he never fully recovered. His parents received special permission to repatriate him to Kiev in 1885, and he remained there until his death in 1891.[34]

III. The logic of Podolinsky's analysis

As mentioned earlier, Engels's critique of Podolinsky was based on the Italian version published in *La Plebe* in 1881. However, all the passages that Engels referred to were carried over to the 1883 *Die Neue Zeit* article. For the reader's convenience, therefore, all quotations from Podolinsky's text are taken from the following German version (in English translation). For completeness, however, we paginate the more or less identical passages from the *La Plebe* version (again, in English translation) in the corresponding footnotes.[35]

Podolinsky develops his argument in six steps. First, he poses the question as to how surplus labour and surplus product are consistent with the first law of thermodynamics. Given the 'constancy of energy', labour 'consists only in a conversion of certain quantities of forces'.[36] At the same time:

> We know that human labour can accumulate greater quantities of energy in its results than was necessary to produce the labour power of the worker. Why and in what way does this accumulation of energy arise?[37]

To answer this question, it is necessary to consider how human labour converts 'natural forces' into forms appropriate to 'the satisfaction of human needs'.[38] This leads to step two in Podolinsky's argument, which is that the analysis of human labour as energy-conversion should take account of the tendency toward increasing entropy (the second law). As Podolinsky describes it, any conversion of energy 'occurs through energy losing its less enduring forms and other more immutable forms taking their place'.[39] As a result, 'further

34. Serbyn 1982, p. 8.

35. The *La Plebe* article contains no significant analytical statements that were not carried over (often in expanded form) to the version in *Die Neue Zeit*. The longest passage missing from the German rendition is a purely descriptive presentation of data on agricultural production in several European countries (Podolinsky 2004, pp. 68–9).

36. See also, Podolinsky 2004, p. 61.

37. Ibid.

38. Ibid.

39. See also, Podolinsky 2004, p. 62.

transformations of energy gradually become more difficult'.[40] However, having located this tendency toward increasing entropy on the level of the entire universe, Podolinsky immediately downplays its relevance for human history, due to the earth's ongoing exposure to the sun. As he says,

> we still receive on our earth enormous quantities of physical forces that are capable of experiencing the most varied transformations, as whose expression all the physical and biological phenomena appear.[41]

Hence, 'the danger of one day suffering a lack of transformable forces on the surface of the earth is still a long way off'.[42]

The issue then becomes to what extent these 'transformable forces' are suitable 'for the satisfaction of the needs of the organic world in general and of the human species in particular'.[43] In this third step, Podolinsky considers not only the energy directly contained in the sun's rays but also geothermal energy sources, coal, and the forces represented by the wind, oceanic tides, rivers, streams, and waterfalls.[44] He goes on to examine the effects of undomesticated animal and plant life on the quantity and distribution of humanly useful energy on the earth.[45] Podolinsky's main conclusion here is that 'the greater part of the physical forces on the earth's surface is far from being in the most advantageous condition for the satisfaction of human needs'.[46] He also finds that plants have a more positive effect on terrestrially available energy than do wild animals. Through the process of photosynthesis, solar energy 'can be accumulated for a longer time on the earth's surface, taking on forms that temporarily guard it against dispersion'.[47] Podolinsky points to the role of plant life in the formation of coal deposits.[48] He further refers to a report by Thomas Sterry Hunt indicating, in Podolinsky's words, that

> the free oxygen of the atmosphere… was previously combined with the carbon that now constitutes coal – and was freed from it only through the influence of the sun's rays by means of a very rich growth of plants.[49]

40. Ibid.
41. See also, Podolinsky 2004, p. 62.
42. See also, Podolinsky 2004, p. 62.
43. Ibid.
44. See also, Podolinsky 2004, pp. 63–4.
45. See also, Podolinsky 2004, pp. 63 and 66.
46. See also, Podolinsky 2004, p. 62.
47. See also, Podolinsky 2004, p. 63.
48. Ibid.
49. Ibid.

Martinez-Alier has taken this reference to Sterry Hunt here as evidence that Podolinsky recognised the effects of carbon dioxide on climate change, writing that,

> (he [Podolinsky] added in a footnote) [that] there was a theory which linked climactic changes to concentrations of carbon dioxide in the atmosphere, as Sterry Hunt had explained at a meeting of the British Society for the Advancement of Science in 1878.[50]

Yet, although it is true that Sterry Hunt is referred to in a footnote in the final German version of Podolinsky's argument, no such statement on carbon dioxide concentrations and their relation to climate change is actually to be found in Podolinsky's article (or in the earlier French and Italian versions).

By 1880, when Podolinsky first published his work, the fact that carbon dioxide and other gasses could affect global temperature was well established. The experimental laboratory basis for the notion that carbon dioxide helped regulate the climate through what is now commonly called the 'greenhouse effect' had been carried out in 1859 by the British physicist John Tyndall, who was the first to theorise this relation. Interestingly, Marx attended Tyndall's lectures and was especially intrigued by his experiments on solar radiation.

The later global warming hypothesis with regard to carbon dioxide and the tendency of global temperatures to rise secularly was not introduced until 1896 by Swedish climatologist Svante Arrhenius. Arrhenius, like other climatologists of his day, was responding to Louis Agassiz's introduction of his ice age theory in 1837, which by the mid-1860s had become part of the scientific consensus. Since he was primarily concerned about the appearance of another ice age, Arrhenius saw anthropogenic carbon dioxide emissions as having a possible beneficial effect in raising global temperature. It is quite possible that this prevailing ice-age focus may have contributed to Podolinsky's conviction, which pervades his work, that the terrestrial accumulation of solar energy and the rise in temperature that this involved was an unalloyed good.[51]

In any event, the primary function of Podolinsky's terrestrial energy survey is to set up the fourth step in his argument. Given that 'plants on the earth's

50. Martínez-Alier 2005, p. 10.

51. For all this background see Fleming 1998, pp. 65–82; Weart 2003, pp. 1–11; Imbrie and Imbrie 1979; Scheider and Londer 1984, pp. 34–6; Uranovsky 1935, p. 140.

surface are the worst enemy of the dispersion of energy into space', purposeful human labour, especially agricultural labour (including livestock raising), has a unique potential to enhance the terrestrial accumulation of energy.[52] For even though

> plants accumulate energy in the substance of their own bodies, they cannot, in the majority of cases, set such energy into movement independently; they cannot usefully employ it in the sense of a general increase of the quantity of force on the earth's surface.[53]

Only human labour, and the labour of the domesticated animals assisting human workers, can systematically and on a large scale '*increase the quantity of accumulated energy of plant life and reduce the quantity of energy dispersed by animals*'.[54] As Podolinsky indicates:

> By cultivating plants in places where they do not yet exist, or exist only in a small amount, by draining marshes, irrigating the deserts, applying perfected cultivation systems, using machines for agriculture and, finally, by protecting the cultivated plants against their natural enemies, we reach the first of the two indicated goals. Through the displacement or extermination of animals that are damaging to the plant kingdom, we work at the same time for the second goal. In both cases, we obtain as a result an absolute or relative enlargement of the solar energy retained on the earth's surface.[55]

It is in this context that Podolinsky introduces some simple estimates of the energy-productivity of French agricultural labour, focussing on hay and wheat cultivation.[56] He measures energy productivity as the energy surplus produced per hour of caloric (human and animal) labour input, with the surplus defined as the excess caloric content of agricultural output per hectare compared to that of uncultivated ('natural') pastures. Podolinsky's calculations, reproduced in Table 1, show that labour increased the energy accumulated per hectare at a rate of nearly 41 calories per hour of labour input in hay production, and by over 22 calories per hour of wheat-cultivating labour.

52. See also, Podolinsky 2004, p. 64.
53. See also, Podolinsky 2004, p. 66.
54. Emphasis in original. See also, Podolinsky 2004, p. 64.
55. See also, ibid.
56. See also, Podolinsky 2004, pp. 64–5.

Table 1

Podolinsky's Calculation of the Energy Productivity of (Animal and Human) Labour (Per Hectare, Based on Data for 1870s France)

Sector	Product (kg)	Energy-Product (kcal)[a]	Energy Surplus over Natural Pastures (kcal)	Energy Input (kcal)[b]	Hourly Energy Productivity of Labour (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

[a] Assuming 2,550 kcal/kg of hay and straw, and 3,750 kcal/kg of wheat.
[b] Assuming 645 kcal per hour of horse labour and 65 kcal per hour of human labour.
[c] Assuming 50 hours of horse labour and 80 hours of human labour per hectare.
[d] Assuming 100 hours of horse labour and 200 hours of human labour per hectare.

At this point, Podolinsky still has not answered his opening question concerning the energetics of surplus labour, that is, how human beings are able to convert their own labour and other energy inputs into need-satisfying products containing an energy surplus. All he has done is to show the empirical plausibility of this energy surplus, and how such a surplus can be translated into figures on energetic labour productivity (the shortcomings of Podolinsky's calculations are discussed in Section IV.) It is one thing to assert that 'this surplus of energy' comes '*from the labour of humans and domesticated animals*'.[57] It is quite another to explain it. And it does not help to engage in circular logic by defining labour as any activity that produces an energy surplus, as when Podolinsky tells us that:

> *Labour is such a use of the mechanical and intellectual energy accumulated in the organism, which has as a consequence an increase of the general energy budget of the earth's surface*.[58]

57. Emphasis in original. See also, Podolinsky 2004, pp. 65–6.
58. Emphasis in original. See also, Podolinsky 2004, p. 66.

It is only well into the second instalment of his article that Podolinsky attempts a thermodynamic explanation of surplus-labour and surplus-product. He does this by treating the human labourer as a thermal machine. More specifically, this fifth part of his argument begins with a discussion of experimental research by Hirn and Hermann von Helmholtz (1821–94), which established that 'the human machine' is capable of converting roughly one-fifth of the nutritional energy needed to keep it running into useful work.[59] Podolinsky then argues that this 'economic coefficient' should be adjusted downward to reflect the fact that labour's product must satisfy needs over and above 'the need for nutrition and for air to breath', including both non-nutritive material needs and 'purely intellectual needs'.[60] For illustrative purposes, he assumes a true contemporary coefficient of one-tenth. He then notices a dual contradiction: How is an economic coefficient of less than unity consistent with labour's production of an energy surplus, and with the historical growth of labour productivity? As per the second half of this contradiction, Podolinsky suggests that 'the needs of savages are much easier to satisfy than those of civilised people, and therefore its economic coefficient is significantly greater, perhaps 1/6 instead of 1/10'.[61] If this is true, then it would appear that the savages are more energy-efficient than the civilised people, even though the latter are more productive. Be that as it may, the issue remains as to how labour's production of a rising energy surplus jibes with an economic coefficient falling toward zero from a level below unity.

Podolinsky's solution to this contradiction is to assert that 'the labour of humanity' represents 'an example of what Sadi-Carnot called a perfect machine', that is, a stream engine that achieves a 'circular process of the transformation of heat into work, and work again into heat' without any loss of energy due to friction or other forms of dissipation:[62]

> When we observe the labour of humanity, however, we have before our very eyes an example of what Sadi-Carnot called a perfect machine. For from this perspective, the human organism would be a machine that not only transforms heat and other physical forces into labour, but which also brings about the operational reverse cycle, i.e. it transforms labour into heat and into the other

59. See also, Podolinsky 2004, p. 67.

60. See also, Podolinsky 2004, pp. 67–8.

61. See also, Podolinsky 2004, p. 70.

62. See also, Podolinsky 2004, pp. 69–70. Carnot's reverse-cycle uses the heat differential between the boiler and the condenser to sequentially do work (as heat moves from boiler to condenser) and maintain the heat differential (as heat moves from condenser to boiler). In its pure form, this cycle abstracts from friction and presumes that the engine constitutes an isolated system (Carnot 1977).

> physical forces which are necessary for the satisfaction of our needs, heating with its own labour converted into heat, its own steam boilers, so to speak.[63]

Podolinsky even posits that the energy productivity of human labour exceeds that of Carnot's ideal steam engine:

> A steam engine, for example, even if it could function for a longer time without the involvement of human muscular power, does not possess the ability to produce the elements necessary to undertake its own work the following year. The human machine, on the other hand, creates new harvests, raises the young generations of domesticated animals, invents and builds new machines etc. In a word: humanity regularly creates the material and the elements for the future continuation of its labour. Thus, humanity fulfills Sadi-Carnot's requirement of perfection much better than any artificial machine.[64]

Finally, the sixth part of Podolinsky's argument applies this perfect-machine perspective to human history. Here, Podolinsky compares different modes of production as alternative 'means of employing human labour to draw upon a larger fraction of natural forces for the satisfaction of human needs'.[65] His presumption is that '*the best means are those that cause the largest accumulation of energy on the earth*'.[66] By this criterion, hunting-and-gathering societies are the most backward because they are based 'merely on the use of force amassed already through earlier life processes' rather than on 'useful labour, upon an accumulation of energy'. Slavery, while 'already an advance… is still very imperfect' because it wastes too much potential energy-accumulating labour on 'perpetual wars' and on the idle classes of slave owners and overseers.[67] Feudalism increases the productivity of labour by giving the serf 'a parcel of land that he is allowed to work without being overseen by the eyes of the lord

63. See also, Podolinsky 2004, p. 70.

64. See also, Podolinsky 2004, p. 70. The notion of the human body as a 'more perfect' machine than the steam engine had been previously expounded by others. For example, nineteenth-century physicist and pioneer of thermodynamics Peter Guthrie Tait quotes James Prescott Joule (one of the discoverers of the first law of thermodynamics) as having stated that 'the animal frame, though destined to fulfill so many other ends, is, as a machine, more perfect than the best contrived steam-engine; that is, capable of more work with the same expenditure of fuel' (Tait 1864, p. 344; compare Martínez-Alier 1987, p. 51). What Podolinsky offered, however, was a much more extreme interpretation of human labour-power as a 'perfect machine' in Carnot's strict sense – indeed exceeding Carnot's own notion of what was thermodynamically possible.

65. See also, Podolinsky 2004, p. 71.

66. Ibid. Emphasis in original.

67. See also, Podolinsky 2004, p. 71.

and without feeling the whip of the overseer', but it still holds back energy accumulation by forcing the serf to engage in 'compulsory labour for the lord' and his various functionaries.[68] Capitalism enhances energy accumulation through the development of division of labour and machinery; yet it 'has its dark side' of energy disaccumulation: overproduction and unemployment, which 'intensify the useless dispersion of the already available labouring powers'.[69] By comparison, socialism will achieve a much 'greater accumulation of energy on the earth's surface'.[70] It will do this by distributing food more equitably and improving public health care, thereby increasing 'the muscular and nervous force of humanity'; by implementing improved accounting systems that reduce fraud and waste; and by putting an end to overproduction crises.[71] For Podolinsky, in short, socialism is desirable because it most effectively realises the potential of human labour as a perfect energy-accumulation machine.

IV. Engels on Podolinsky

Martínez-Alier and Naredo argue that Marx and Engels 'failed to appreciate the significance of Podolinsky's view for the Marxist system', not only in terms of the energetics of labour-values but also 'for a more accurate definition of the notion of "productive forces"'.[72] According to the same authors, Engels responded to Podolinsky by asserting that 'economics should not be mixed up with physics'.[73] Engels apparently 'saw no limits to the amount of energy that could be harnessed by the work of man'.[74] The 'no limits' charge against Engels is repeated in Martínez-Alier's influential *Ecological Economics*, as is the assertion that Podolinsky's 'Energy accounting… gave a scientific basis to the labour theory of value, a point that neither Marx nor Engels appreciated'.[75] More recently, Martínez-Alier has referred somewhat obliquely to an unsuccessful attempt by Podolinsky 'to convince Marx' that the entropy law 'could be brought into the Marxist analysis'.[76]

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68. See also, Podolinsky 2004, pp. 71–2.
69. See also, Podolinsky 2004, p. 72.
70. See also, Podolinsky 2004, p. 73.
71. Ibid.
72. Martínez-Alier and Naredo 1982, p. 209.
73. Martínez-Alier and Naredo 1982, p. 208.
74. Martínez-Alier and Naredo 1982, p. 216.
75. Martínez-Alier 1987, pp. 49 and 222.
76. Martínez-Alier 2006, p. 276.

These claims seem *prima facie* extravagant insofar as they hinge on Podolinsky's analytical contribution as summarised above. Podolinsky does not provide a substantive answer to his opening question about the energetics of surplus-labour. Even if one accepts the perfect machine analogy, the whole question is how human labour is able 'to bring about the operational reverse cycle, i.e. to convert its labour into an accumulation of physical forces necessary for the satisfaction of our needs'.[77] Insofar as human beings are not literally steam engines, the analogy merely repeats the assertion that human labour accumulates energy.

The basic shortcoming of the perfect-machine analogy is its lack of any conscious connection to the relations of production. The perfect human machine is an abstract-ideal concept, that is, it is derived from completely unreal assumptions fully devoid of historical-social content.[78] This diverges from Marx, who analyses production in terms of the social relations between producers and the material conditions of production, starting with the land, and (in class societies) the corresponding relations between producers and appropriators of the surplus-product. Not surprisingly, Podolinsky's analysis of the relative efficiency of different modes of production is basically a shallow, energy-reductionist recasting of some established results from Marxist political economy and historiography. For example, Podolinsky could have drawn some of his ideas on capitalism's energetic wastefulness from Marx's *Capital*, where we read of the 'shameless squandering of human labour-power' by the suppression of wages to low levels and consequent failure to apply labour-saving technology more fully, and by the 'anarchic system of competition' with its 'vast number of functions at present indispensable, but in themselves superfluous'.[79] Long before Podolinsky, Marx emphasised the colossal waste of human energy represented by capitalism's reserve army of unemployed. Marx even expressed his 'absolute general law of capitalist accumulation' in energetic terms:

> The greater the social wealth, the functioning capital, the extent and energy of its growth, and therefore also the greater the absolute mass of the proletariat and the productivity of its labour, the greater is the industrial reserve army. The same causes which develop the expansive power of capital, also develop the labour-power at its disposal. The relative mass of the industrial reserve army thus increases

77. See also, Podolinsky 2004, p. 70.

78. Similarly, Podolinsky conceptualises the 'energy coefficient' on the asocial level of an isolated individual worker. See below for further discussion.

79. Marx 1976a, Volume I, pp. 517 and 667.

> with the potential energy of wealth. . . . *This is the absolute general law of capitalist accumulation*.[80]

By contrast with Marx's sophisticated material-social analysis of the energetics of human labour (see Section VI, below), Podolinsky's contribution reduces to the observation that labour captures and accumulates energy in humanly useful forms. As Engels generously puts it in his to Marx letter of 19 December 1882, Podolinsky's

> real discovery is 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.[81]

Before getting into Engels's criticisms, it is worth noting that none of them concern the relationship between Podolinsky's energy accounting and Marxian value analysis. But Engels's silence in this connection has nothing to do with any lack of appreciation for Podolinsky's contribution. The fact is that Podolinsky has nothing to say about value as such, unless one identifies value with the physical energy content of commodities – an approach that would be more Ricardian than Marxian.[82] Podolinsky does not connect the caloric magnitudes in his energy-productivity calculations to phenomena such as wages and market prices, for the simple reason that his energy-accounting framework does not consider the specific social forms of capitalist production, exchange, and distribution. Even Podolinsky's opening query raises the issue, not of surplus-value specific to capitalism, but rather of surplus-labour in a physical sense applying across different modes of production.[83]

Engels's critique focuses on the shortcomings of Podolinsky's energy-productivity calculations from a metabolic and open-system perspective. Engels was deeply distrustful of all efforts to reduce physical (let alone social) phenomena to purely quantitative energy terms. For systems of material forces connected with life forms, especially, he felt that a metabolic approach was required, that is, an approach focussing on biochemical exchanges and transformations of matter and energy, with due allowance for dissipative

80. Marx 1976a, p. 798 (emphasis in original).

81. Marx and Engels 1975b, p. 410.

82. For detailed discussions of this point, see Foster and Burkett 2004, pp. 41–4; Burkett 2006, pp. 18–19, 37–41.

83. See also, Podolinsky 2004, p. 61. The same goes for Podolinsky's 8 April 1880 letter to Marx, which refers to 'my attempt to bring surplus *labour* and the current physical theories into harmony'. Quoted in Martínez-Alier 1987, p. 62 (our emphasis).

processes of friction and decay.[84] Accordingly, in *The Dialectics of Nature*, Engels expressed great scepticism about efforts 'to re-import the thermodynamical category of work back into political economy'; arguing that the conception of human labour as a steam engine would lead to 'nothing but nonsense':[85]

> Let someone try to convert any SKILLED LABOUR into kilogram metres 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 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.[86]

Engels's first specific comment on Podolinsky follows directly from this metabolic critique of the labour-as-steam-engine analogy. He points out that Podolinsky's energy-productivity figures assume an equivalence between labour input and the calories consumed by (human and animal) labourers as food (see Table 1). This neglects the fact that nutritional calories 'are known in practice to lose on conversion into other forms of energy as a result of friction, etc., a portion that cannot be put to use. Significantly so in the case of the human body'.[87] Moreover, during the labour process itself, additional energy is 'lost in the increased heat given off by the body, etc., and such useful residue as remains

84. Engels 1987.

85. Engels 1987, pp. 586–7.

86. Engels 1987, p. 587 (capitalisation and emphases in original). This passage from Engels was written in 1875, well before Podolinsky published his work in ecological economics. Both Marx and Engels had studied some of the most advanced physiological treatises of their day. As a basis for his argument here Engels referred to experiments on energy and human work by the noted physiologist Adolf Fick, a friend of Clausius who integrated the second law of thermodynamics into his physiological studies. Marx left behind extensive extracts in his notebooks from Fick's work. Podolinsky himself did not cite Fick. See Martinez-Alier 1987, p. 50; Rothschuh 1973, pp. 248–9; Kolman 1971, p. 233.

87. Marx and Engels 1975b, p. 410.

lies in the fertilising property of excretions'.[88] From this angle, it appears that 'the *physical* labour performed in economic labour… is [in energy terms] invariably less' than the caloric content of food consumption.[89] In other words, Podolinsky's calculations do not allow for metabolic-entropic disjunctures between the caloric contents of produced use values and primary inputs. Here the steam engine analogy upon which such calculations were often based was misleading. As Helmholtz had pointed out as early as 1854,

> the animal body… does not differ from the steam engine, as regards the manner in which it obtains heat and force, but does differ from it in the manner in which the force gained is to be made use of [that is, in bio-chemical processes.][90]

Engels goes on to question the practicality and relevance of Podolinsky's energy-accounting exercises, especially in non-agricultural production:

> In industry all calculations come to a full stop; for the most part the labour added to a product simply 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 labouriously 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 had 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.[91]

Does this statement show that Engels felt physics was irrelevant for economics, as asserted by the conventional interpretation? Not at all. Engels is merely insisting that wealth or use-value cannot be reduced to pure energy, and that economics cannot, therefore, be reduced to an energetic exercise in counting calories. 'Matter matters, too' as the great ecological economist Nicholas Georgescu-Roegen puts it.[92] Moreover, to insist that economic conditions are social and therefore cannot be expressed in purely physical terms hardly represents a blanket denial of the usefulness of physics or of any other kind of natural science for economics. It is one thing to integrate physical laws into

88. Ibid. Engels's references to the energy lost from the body from excretions, etc. are similar to the observations in Marey 1874, pp. 16–17.
89. Marx and Engels 1975b, p. 410; emphasis in original.
90. Helmholtz 1873, p. 238.
91. Marx and Engels 1975b, p. 411.
92. Georgescu-Roegen 1979, p. 1024.

economics; it is quite another to 'confuse the physical with the economic' as Podolinsky did.[93] The problem is that Podolinsky 'sought to find in the field of natural science fresh evidence of the rightness of socialism' without taking adequate account of the social and even the material dimensions of human labour.[94] He tried to apply directly to human labour an ideal model (Carnot's reverse cycle) which abstracted from friction and other important aspects of real-world production. In doing so, Podolinsky ignored Carnot's own warning against the practical application of the concept of perfect energy efficiency even in the case of steam engines:

> We should not expect ever to utilise in practice all the motive power of combustibles. The attempts made to attain this result would be far more hurtful than useful if they caused other important considerations to be neglected. The economy of the combustible is only one of the conditions to be fulfilled in heat-engines. In many cases it is only secondary. It should often give precedence to safety, to strength, to the durability of the engine, to the small space it must occupy, to small cost of installation, etc.[95]

How much more important such material qualifications of the energetic efficiency criterion must be in the case of human labour!

Moreover, unlike Carnot's ideal heat engine, which was conceptualised as an isolated system, human labour relies on inputs of natural resources while constantly emitting matter-energy throughput into the environment. Labour's 'accumulation of energy on the earth' is not self-driven and permanent but rather externally fuelled and fully subject to entropic dissipation under the second law. In treating human labour as a perfect thermal machine and advocating socialism as a superior means of energy 'accumulation', Podolinsky neglected this crucial form-divergence between human production and Carnot's ideal reverse cycle. Podolinsky's energy-productivity calculations thus disregarded important open-system and entropic aspects of human labour. For example, as Engels pointed out, they did not track 'the *fresh* cal' that each worker 'absorbs from the radiation of the sun', without which neither human life nor human labour would be possible.[96] Perhaps more importantly, Podolinsky argued as

93. Marx and Engels 1975b, p. 412.
94. Ibid.
95. Carnot 1977, p. 59.
96. Marx and Engels 1975b, p. 411; emphasis in original. Martínez-Alier argues that Podolinsky 'did not include solar radiation in the input of energy, because he was writing as an ecological economist. Solar radiation is indeed a free gift of nature (so far without an owner, therefore without payment of rent)' (2005, p. 8). It seems that Martínez-Alier does not want to

though labour was the sole direct energy input into production, notwithstanding the fact that, as Engels objected, 'the energy value of auxiliary materials, fertilisers, etc., must also be taken into consideration':[97]

> What Podolinsky 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 [Engels tells Marx] are better informed than I am.[98]

Engels's comment actually highlights two distinct shortcomings of Podolinsky's energy-productivity calculations. First, in comparing the caloric content of agricultural output per hectare with that of uncultivated ('natural') pastures, Podolinsky implicitly presumed that the latter had not been reduced by various forms of human extractive labour such as hunting and gathering as well as forestry (not to mention disruptions from agricultural and industrial pollution). Given the negative impacts of expanding human production and population on non-domesticated plant and animal species, the treatment of uncultivated lands as simply 'natural' (in other words, exogenous) undoubtedly results in a sizeable overestimate of the relative caloric content of cultivated harvests.

Second, and more obviously, the presumption that labour is the sole input itself created an upward bias in Podolinsky's productivity estimates, corresponding to the missing inputs of fertilisers, such as manure and guano, and of fuels, especially timber and coal. Podolinsky's failure to include fertilisers in his estimates was quite extraordinary in an 1880 context, given the nature of the agricultural crisis that had swept Europe and North America in the mid-nineteenth century, which resulted in the raiding of the battlefields and catacombs of Europe for bones to fertilise the agricultural lands, the importation of guano and nitrates from Peru and Chile, and the beginnings of an industry

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mix physics with economics here, which is strange for an ecological economist. After all, as Marx argued, all natural resources are free gifts in the sense that they are not produced by human labour (Burkett 1999, Chapter 6). Martínez-Alier would evidently leave all natural resources out of economic analysis – excepting those that yield rents. In other words, if the market does not price a resource, there is no reason to include it in the analysis of production! This is a regression compared even to neoclassical theory which at least recognises the importance of 'external costs' (unpriced effects of production on natural conditions). Besides, there is nothing 'economic' about Podolinsky's energy accounting framework: it does not address the formation of values, market prices, etc. Naturally, the question remains as to how a more inclusive accounting of energy flows relates to value analysis; on which see Daly 1981; Burkett 2006, Chapter 1.

97. Marx and Engels 1975b, p. 411.

98. Ibid. (emphases in original).

for the production of fertilisers. Such issues had occupied as central a figure in the chemistry and agriculture of his time as Liebig, and had been commented on by Marx in *Capital*, which Podolinsky had presumably read.[99]

Nor is it easy to see how Podolinsky could have left coal out of his estimates. He was, of course, aware of the role of coal in both industrial and agricultural production. As we have seen, he emphasised it as one of the main forms in which plants contribute to the accumulation of useful energy on or in the earth. In addition, one of his early socialist propaganda writings, published in 1875, was *The Steam Engine* – a utopian novelette about a rural worker who is severely injured by a threshing machine while working in the fields and who dreams of a socialist future.[100] Nonetheless, Podolinsky did not include coal and other non-labour inputs in the denominators of his energy-productivity measures.[101]

Podolinsky's adoption of the perfect-machine analogy also led him to downplay the temporary nature of the energy stabilisation achieved by human labour in its output. He strongly endorsed the cosmological extrapolation of the entropy law in the form of the 'heat death of the universe' hypothesis near the beginning of his article. Yet neither his energy-accounting nor his historical discussion of energy accumulation recognise that labour, and the matter-energy throughput it initiates and oversees, are themselves subject to entropic dissipation (the second law). Engels, by contrast, emphasises that human labour is 'capable of retaining solar energy on the earth's surface', not permanently, but only 'for a longer period than would otherwise have been the case'.[102] 'In stock farming', for example, 'energy is stabilised in as much as the vegetation, that would otherwise rapidly wither, die and decompose, is systematically converted into animal protein, fat, skin, bone, etc., hence *stabilised over a longer period*'.[103] In his follow-up letter to Marx on 22 December 1882, Engels elaborates the point and extends it to livestock raising and manufacturing production, observing that the:

> storage of energy by means of labour takes place strictly speaking only in *arable farming*. In stock farming the energy stored in plants is, in general, merely

99. Foster 2000, pp. 147–63.

100. Serbyn 1982, p. 6; Martínez-Alier 1987, pp. 54–6.

101. Martínez-Alier (1987, p. 222) argues that Engels was wrong to state 'that Podolinsky had forgotten' about coal (see also Martínez-Alier and Naredo 1982, p. 217). But Engels's criticism was focussed precisely on Podolinsky's energy-accounting exercises, not on what Podolinsky may have said about coal in a broader context.

102. Marx and Engels 1975b, p. 410.

103. Marx and Engels 1975b, p. 411; emphasis added.

> transferred to the animal, hence we can only speak of storage in so far as nutritive plants are put to use which would, in the absence of stock farming, go to waste. In all branches of industry, on the other hand, energy is merely *expended*. The most one can say is that vegetable products such as wood, straw, flax, etc., and animal products in which plant energy is stored, are made available by processing, i.e. are *preserved for a longer space of time* than if they had been allowed to decay naturally.[104]

In this connection, Martínez-Alier distorts the significance of Engels's argument that the amount of energy stabilised per hour of human labour 'is dependent solely upon the level of development of the means of production'.[105] According to Martinez-Alier, this statement shows that Engels 'saw no limits to the amount of energy which could be harnessed by the work of a man'.[106] But neither in his comments on Podolinsky nor anywhere else does Engels suggest that there are no physical or energetic limits to the development of the means of production. Rather, as shown above, Engels open-system metabolic approach emphasises the constraints placed on labour's energy accumulation by finite stocks of nonrenewable resources, as well as by friction and other forms of dissipation and decay. Martínez-Alier somehow twists Engels's rational concern with the extractive and entropic matter-energy throughput of human production into an altogether different and false assertion that there are no entropic limits to this throughput! In reality, the 'no limits' perspective applies much more accurately to Podolinsky, with his notion that human labour is a more than perfect machine in the Carnotian sense, than to Engels.[107]

Another source of Podolinsky's insensitivity to open-system considerations is his initial treatment of the energy efficiency of labour in terms of the 'economic coefficient' (work divided by energy consumption) of an individual isolated human labourer. Apart from its complete lack of socio-economic content, such a perspective can easily downplay the non-labour elements of matter-energy throughput extracted and emitted by real-world systems of

104. Marx and Engels 1975b, pp. 412–13 (emphases in original).

105. Marx and Engels 1975b, p. 411.

106. Martínez-Alier 1987, p. 222.

107. Martínez-Alier (2006, p. 277) asserts incorrectly that Podolinsky's analysis of 'capitalist accumulation' took full account of energy-dissipation (for instance by the burning of coal), and that Podolinsky's notion of energy-accumulation refers only to labour's conversions of direct solar energy flows. As we have seen, both Podolinsky's agricultural energy-productivity calculations and his qualitative analyses of energy-accumulation include the full energy content of produced output, while failing to net out the energy content of non-labour inputs.

human production. Engels's open-system approach, by contrast, recognises that the true economic coefficient is the ratio of produced wealth (measured in use-values) to the total material throughput generated by an economic system.[108]

V. Elaborations in *Die Neue Zeit*

We now consider whether the German version of Podolinsky's work includes any additional analyses running counter to our own reinterpretation. Does the article in *Die Neue Zeit* contain important insights that Marx and Engels may have missed or ignored, due, perhaps, to their reliance on earlier renditions of Podolinsky's argument? Section III has already shown that the German version includes the exact same energy-productivity calculations for agricultural labour that were presented in the earlier French and Italian versions of Podolinsky's work. Furthermore, all the passages quoted in Section III in connection with the theoretical treatment of human labour as an energy-accumulation machine, including the perfect machine analogy, were from the German version (the passages in question being identical in the Italian rendition).

There are, however, five passages in the German article that do not appear in the Italian version which was evaluated by Engels. First, there is a much more extensive treatment of 'the radiating energy of the sun', and of how this energy takes on 'higher forms on the earth's surface' that are more or less employable for satisfying human needs. Here, Podolinsky provides more information on the potential usefulness, and limitations (due to problems of friction and harnessability), of such inorganic energy sources as the earth's rotation and magnetic force, tides and other water currents, winds, and geothermal heat (including hot springs) He also offers some geohistorical conjectures in support of the superior energy-accumulating capabilities of plants compared to animals. In this latter context, Podolinsky gives a somewhat clearer explanation of the process by which coal deposits were formed, as well as some additional data on coal deposits in Great Britain and North America. Nonetheless, the article in *Die Neue Zeit* does not address the squandering of coal which worried Engels; nor does it consider the role of coal and other non-labour inputs in a proper accounting of labour's energy-productivity. Hence, this central element of Engels's critique still stands.

108. Compare Georgescu-Roegen 1986; Daly 1992.

The second insertion in the German version reconsiders 'the boundaries of useful labour' from the standpoint of 'the muscular labour of animals and humans'. Here, Podolinsky argues that the food-seeking movements of a snail or a butterfly do not qualify as labour insofar as they

> do not transform the slightest quantity of solar energy into such higher forms which by their further deployment could increase the store of energy on the earth's surface.

Far from qualifying Podolinsky's mechanistic energy-reductionism, this discussion solidifies and amplifies his identification of labour (and implicitly of all use-value) with purposeful energy accumulation:

> For we should keep in mind that by the word 'labour' must be understood a 'positive act' of the organism, which has a necessary consequence an accumulation of energy. … Viewed from this perspective, we can conclude that the different movements of animals that are self-evidently goalless or have as a goal merely the seeking out of means of nutrition, etc., cannot be counted as labour, precisely because they leave behind no increase of energy accumulation.

Under this definition, any (mental or physical) activity whose goal is to reduce the energy used by each hour of human labour does not qualify as labour unless and insofar as it increases the caloric content of total output.

Third, the article in *Die Neue Zeit* has an extended discussion of the economic coefficient (ratio of work performed to energy input) of human labour. More details are provided on Hirn's 'important experiments on the conversion of the heat of the human organism into labour'. By isolating a man in a box, strictly controlling his intake of air and food, and restricting his activity to a series of calorically measurable tasks, Hirn provided the basis for Helmholtz's efforts to calibrate 'the percentage yield of the heat transformed during labour'. The German version also contains a more in-depth qualification of the figure of one fifth for the economic coefficient implied by the work of Hirn and Helmholtz. Together with the role of non-nutritional needs that was addressed in the French and Italian versions, Podolinsky now emphasises certain ways in which 'the human organism is much more complicated than any other thermal machine'. For instance, human workers are able to consciously impede the dispersal of energy from their bodies through the use of clothing, shelter, and heating devices. Compared to machines, human labour has a variety such that its 'mechanical achievements are already so rich and diverse that they are overtaken by a mechanical apparatus only with difficulty'.

None of these qualifications alter Podolinsky's basic conception of labour as conscious energy accumulation, however. He continues to insist that 'we can apply most of the laws of the steam machine or any other thermal machine (set into movement by heat) also to the labouring human'. And he still ascribes 'the increase and development of humanity', compared to other species, to humanity's superior ability, especially through agriculture, 'to employ its mechanical energy in a direction that enabled a general accumulation of energy on the earth's surface'. For Podolinsky, in short, not only human labour but human evolution can be reduced to purposeful energy accumulation. It is the imperative to accumulate energy, as a condition of human growth and development, that drives humanity's evolution toward socialism in Podolinsky's view.

In a fourth addition to the German version, Podolinsky supports his application of thermal-machine analysis to the human labourer with two quotations from Carnot's work, *Reflections on the Motive Power of Fire*. In the quoted passages, Carnot suggests that the efficiency of heat-engines should first be 'considered independently of any particular agent', so as to derive principles 'applicable not only to steam-engines but to all imaginable heat-engines' regardless of how the 'difference of temperature' needed to create an 'impelling power' is generated in each particular case.[109] But the sentences quoted by Podolinsky have to do with the generality of Carnot's analysis across different kinds of mechanical heat engines, not animate ones. They are not meant to suggest that the abstract analysis of inanimate heat engines is directly applicable to human workers. There is certainly nothing in Carnot's discussion that effectively counters Engels's critique of energy-reductionism applied to human labour.

Podolinsky's fifth and final elaboration in *Die Neue Zeit* addresses the apparent contradiction between Quesnay's and Adam Smith's respective conceptions of productive labour. Quesnay, the physiocrat, held that the source of all value is the land, whereas Smith argued that only labour is productive. Podolinsky suggests that they are both right because even though 'labour… creates no material' it does add 'something to the object that was not created by labour', namely energy. His entire discussion remains on the level of use-value, unconnected to the social relations of production. As such, it has no clear implications for Marxian value analysis, according to which productive labour *under capitalism* is that which 'creates *surplus-value* directly, i.e.… is directly *consumed* in the course of production for the valorisation of capital'.[110] As Marx says, *apropos* Podolinsky:

109. Carnot 1977, pp. 6 and 8.
110. Marx 1976a, p. 1038 (emphases in original).

> Only the bourgeoisie can confuse the questions: what is productive labour? and what is a productive worker from the standpoint of capitalism? with the question: what is *productive* labour as such? And they alone would rest content with the tautological answer that all labour is productive if it produces, if it results in a product or some other use-value…[111]

Marx's critique applies doubly to Podolinsky's tautological conception of useful labour as energy accumulation.

All in all, the additions in Podolinsky's *Die Neue Zeit* article do nothing to correct the shortcomings highlighted by Engels's notes on the *Plebe* version.

VI. Thermodynamics, energy accumulation, and ecological crisis in Marx's *Capital*

In addition to the serious flaws in Podolinsky's work, another reason why Marx and Engels did not feel obligated to respond to it publicly was no doubt that Marx had already incorporated relevant thermodynamic phenomena into his own analysis of capitalist development in *Capital*. This observation runs counter to the conventional wisdom, even among so-called ecological Marxists, that Marx's mature economic work contains no significant energy analysis. James O'Connor, for example, asserts that 'Marx did *not* pay sufficient attention to energy economics', including the fact 'that capitalist production (like all production) is based on energy flows and transformations.[112]

As with the Podolinsky myth, the primary source of this standard view is the work of Martinez-Alier, who, in his influential article co-authored with José Manuel Naredo, argues that 'energy analysis… has been alien to Marxism'.[113] Martínez-Alier and Naredo assert that Marx's analysis in *Capital* is 'inconsistent with energy analysis' due to its labour theory of value and its 'metaphysical… notion of "productive forces"'.[114] These charges are repeated in Martínez-Alier's oft-cited *Ecological Economics*, which states flatly that Marx's economics 'did *not*… comprise the flow of energy'.[115]

The reality is quite different. Energy flows, and the correlation of forces, are central to *Capital*'s analyses of commodity exchange, wage-labour, exploitation, and industrial development. Although Marx does not reduce the analysis of

111. Marx 1976a, p. 1039 (emphasis in original).
112. O'Connor 1998, p. 122 (emphasis in original).
113. Martínez-Alier and Naredo 1982, p. 219.
114. Martínez-Alier and Naredo 1982, p. 208.
115. Martínez-Alier 1987, p. 221 (emphasis in original).

production to 'counting calories' (quantitative energy accounting), his socio-metabolic approach yields profound insights into the energetics of capitalist production and the roots of ecological crisis, while conforming fully to the first and second laws of thermodynamics.

For Marx, 'useful labour… mediates the metabolism between man and nature', and the human labourer 'can only proceed as nature does herself, i.e. he can only change the form of the materials'.[116] The actions of the labourer 'are not to be conceived of as acts of creation but solely as a reordering of matter', a 'work of modification' in which the labourer 'is constantly helped by natural forces'.[117] Marx's conception of labour, as 'a process between man and nature' thus incorporates exchanges and transformations of both matter and energy, fully subject to the laws of thermodynamics.[118] Far from metaphysical, labour is 'the everlasting nature-imposed condition of human existence', one that only 'develops the potentialities slumbering within nature'.[119] Indeed, when discussing the creation of a surplus-product, Marx counsels that: 'It would be absolutely mistaken to attach mystical notions to this spontaneously developed productivity of labour, as is sometimes done'.[120] As if responding to Podolinsky's fantastic notion of human labour as a more than perfect thermal machine, Marx insists that 'in no case would… surplus product arise from some innate, occult quality of human labour'.[121] Marx accordingly castigated the Gotha Programme for asserting that 'labour is the source of all wealth', because to do so was to 'fancifully' ascribe '*supernatural creative power* to labour'.[122]

Turning to capitalist economy in particular, Marx treats commodity exchange as an extension of the metabolic process of human labour, with the commodity itself as 'the economic cell-form' of this metabolism.[123] Given that the production of use-values relies on natural materials and forces (matter and energy), and that 'exchange transfers commodities from hands in which they are non-use values to hands in which they are use-values' it follows that commodity exchange 'is a process of social metabolism'.[124] As Marx says,

116. Marx 1976a, p. 133.
117. Ibid.
118. Marx 1976a, p. 283.
119. Marx 1976a, pp. 283 and 290.
120. Marx 1976a, p. 647.
121. Marx 1976a, p. 651.
122. Marx 1966, p. 3 (emphasis in original).
123. Marx 1976a, p. 90.
124. Marx 1976a, p. 198.

> the exchange of commodities breaks through all the individual and social limitations of the direct exchange of products, and develops the metabolic process of human labour.[125]

Crucially, Marx insists that use-value is a prerequisite for value (abstract labour, as represented by money), in other words, that 'nothing can be a value without being an object of utility'.[126] If a product 'is useless' (as measured by market demand), 'so is the labour contained in it; the labour does not count as labour, and therefore creates no value'.[127] 'Value is independent of the particular use-value by which it is borne, but a use-value of some kind must act as its bearer'.[128] It follows that Marx's metabolic conception of useful labour is an essential element of his value analysis.

In asserting that Marx's value theory is incompatible with energy analysis, Martínez-Alier seems to presume that Marx, like Adam Smith and David Ricardo, reduced value to labour-time based on a normative and/or empirical presumption that labour is more important or primary than other productive factors such as energy. For Marx, however, it is capitalism that reduces value to labour-time, based on workers' social separation from necessary conditions of production, starting with the land. The necessary connection between value and use-value is full of tensions precisely because of its basis in workers' alienation, an alienation which makes it appear as if value is independent of nature. For Marx, value and use-value do not comprise a dichotomy but rather a unity-in-difference or moving contradiction, as the material requirements of value accumulation constantly violate the metabolic-energetic conditions needed for a healthy and sustainable human development.[129]

Marx's metabolic-energetic approach is quite evident in his analysis of labour-power: its characteristics, its value, and its exploitation by capital. The very term labour-*power* indicates Marx's concern with energy conversions in this context. Says Marx: 'Labour-power itself is energy transferred to a human organism by means of nourishing matter'.[130] It comprises

> the aggregate of those mental and physical capabilities existing in the physical form, the living personality, of a human being, capabilities which he sets in motion whenever he produces a use-value of any kind.[131]

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125. Marx 1976a, p. 207.
126. Marx 1976a, p. 131.
127. Ibid.
128. Marx 1976a, p. 295.
129. For details on this point, see Burkett 2003.
130. Marx 1967, p. 215.
131. Marx 1976a, p. 270.

Energetic considerations are central to Marx's analysis of the value of labour power, the minimum of which is defined by the value of the commodities needed for the worker's physical subsistence. Marx notes that this subsistence component is defined by the worker's 'natural needs, such as food, clothing, fuel and housing' – needs which 'vary according to the climactic and other physical peculiarities of his country'.[132] Moreover, the value of labour-power includes the value of commodities 'necessary for the worker's replacements, i.e. his children', the reason being that 'labour-power exists only as a capacity of the living individual' and is thus by nature 'subject to wear and tear … and death'.[133]

Marx, in short, explicitly treats the role of metabolic energy conversions, including matter-energy dissipations, in the reproduction of human labouring capacity. The advantages of Marx's approach over Podolinsky's 'thermal-machine' perspective are even clearer from *Capital*'s discussion of the exploitation of labour-power. Here, the capitalist appropriates the 'use of labour-power', namely, 'labour itself', and in this process the worker 'becomes in actuality what previously he only was potentially, namely labour-power in action'.[134] Marx insists that this conversion of potential into actual work is subject to the first law (conservation of energy) whether labour is considered as production of use-values or as production of values. Even though the substance of value is abstract labour ('homogenous human labour, human labour-power expended without regard to the form of its expenditure'), the 'creation of value' still requires 'the transposition of labour-power into labour', i.e., a 'productive expenditure of human brains, muscles, nerves, hands, etc., of the labour-power possessed in the bodily organism' of the worker.[135] The creation of surplus-value likewise requires that 'fluid, value-creating labour-power … be incorporated' into means of production both materially and energetically.[136] Capitalist exploitation is not a process in which workers create something out of nothing. To emphasise this point, Marx tells us: 'What Lucretius says is self-evident: "*nil posse creari de nihilo*", out of nothing, nothing can be created'.[137] 'All the phenomena of the universe', Marx quotes the eighteenth-century Italian economist Pietro Verri as saying, 'whether produced

132. Marx 1976a, p. 275.
133. Marx 1976a, pp. 274–5. Compare Marx 1976d, pp. 39 and 57.
134. Marx 1976a, p. 283.
135. Marx 1976a, pp. 128, 134–5 and 323.
136. Marx 1976a, p. 323.
137. Ibid.

by the hand of man or indeed by the universal laws of physics, are not to be conceived of as acts of creation but solely as a reordering of matter'.[138]

That 'out of nothing, nothing can be created' is just as clear from Marx's analysis of how the capitalist's exploitation of labour-power imposes additional maintenance requirements on the worker. As a result of labour,

> a definite quantity of human muscle, nerve, brain, &c., is wasted, and these require to be restored. This increased expenditure demands a larger income.[139]

Here, Marx employs a metabolic energy income/expenditure approach strongly influenced by his study of the German physiologist Ludimar Hermann.[140] An important feature of Hermann's analysis was its sensitivity to the irreducible biochemical dimension of metabolic energy conversions, in other words, its refusal to treat labourers as equivalent to steam engines. This refusal is equally apparent in *Capital*'s treatment of the relationship between the value of labour-power and the length of the working day, where Marx notes that the worker's subsistence requirements depend on the rate of 'conversion of living substances into motion as it applies to the nature of man'.[141] Higher wages (and material consumption) may thus compensate for longer work time only 'up to a certain point', beyond which further increases in work time cause a 'deterioration' of labour-power 'in geometric progression'.[142]

Because it ignores Marx's metabolic-energy analysis of labour-power and its exploitation under capitalism, Martínez-Alier's influential critique misses the pre-emptive answer Marx gives to Podolinsky's question about the thermodynamic consistency of surplus-labour (in its specifically capitalist form, surplus-value).[143] For Marx, as we have seen, the distinction between labour-power and labour expended is a distinction between potential work and actual work.[144] The amount of productively expendable energy encapsulated in

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138. Marx 1976a, p. 133.

139. Marx 1967, p. 171.

140. Hermann 1875; Baksi 2001, p. 378; Burkett and Foster 2006, p. 121.

141. Marx 1976a, p. 664.

142. Ibid. At this point Marx quotes Sir William Robert Grove's pioneering analysis of the convertibility of different forms of energy, *On the Correlation of Physical Forces*: 'The amount of labour which a man had undergone in the course of 24 hours might be approximately arrived at by an examination of the chemical changes which had taken place in the body, changed forms in matter indicating the anterior exercise of dynamic force' (Ibid.). For Marx's study of Grove, see Baksi 2001, pp. 385–6; Burkett and Foster 2006, p. 122.

143. Burkett and Foster 2006, pp. 125–8.

144. On the roots of *Capital*'s application of the 'potential' versus 'actual' distinction in Marx's study of thermodynamics, see the note by Engels in Marx 1976b, p. 158; Griese and Pawelzig 1995, p. 133.

labour-power is thus quite distinct from the caloric quantity of useful work needed to produce the worker's commodified means of subsistence. Indeed, it is the excess of the former over the latter that enables the capitalist to extract surplus-value from the worker. As Marx indicates: 'The fact that half a day's labour [for example] is necessary to keep the worker alive during 24 hours does not in any way prevent him form working a full day'.[145] In short, the capitalist takes advantage of the fact that 'What the free worker sells is always nothing more than a specific, particular measure of force-expenditure'; whereas 'labour capacity as a totality is greater than every particular expenditure'.[146] The result is an energy subsidy for the capitalist who appropriates and sells the commodities produced during the portion of the workday (surplus labour-time) over and above that needed to produce the means of subsistence represented by the wage ('necessary' labour-time).[147]

'For the capitalist', this surplus of energy (and of value) 'has all the charms of something created out of nothing'.[148] But it actually represents capital's appropriation of part of the potential work created by the daily metabolic-energetic regeneration of the worker's labour-power. This regeneration occurs largely during non-work time, through rest, access to fresh air, as well as through various domestic reproductive activities undertaken by the worker and/or the worker's family members. Indeed, the tendency of surplus labour-time to encroach on the free time required for these regenerative activities, and the attendant need for social restraints on capitalist exploitation, are major themes in *Capital*.

In other words, energy analysis is a crucial element in Marx's famous investigation of the struggle over the working day. Ironically, it was in this investigation that Marx revealed *capitalism's* tendency to convert workers into machines for the production of surplus-value. It is, after all, the capitalist who

> haggles over the meal-times, where possible incorporating them into the production process itself, so that food is added to the worker as to a mere means of production, as coal is supplied to the boiler…[149]

Podolinsky's conception of human labour as a steam engine thus corresponds to the exploitative, brutal, and unsustainable viewpoint of capital. By extending

145. Marx 1976a, p. 300; compare Marx 1976d, p. 41.
146. Marx 1973, p. 464.
147. Marx 1973, p. 674.
148. Marx 1976a, p. 325; compare Marx 1973, pp. 324 and 334.
149. Marx 1976a, p. 376.

and intensifying work time, capitalism 'seized the vital forces of the people at their very roots', threatening a 'degradation and final depopulation of the human race':[150]

> *Après moi le déluge!* is the watchword of every capitalist and of every capitalist nation. Capital therefore takes no account of the health and the length of life of the worker, unless society forces it to do so.[151]

This ecological perspective on capital's exploitation of society's human resources is based solidly on Marx's metabolic-energetic dissection of labour-power and surplus-value.[152]

Foreshadowing ecological economics, *Capital*'s energy analysis proceeds from the *endosomatic* level of human labour-power and its bodily organs to the *exosomatic* level of tools and machines as extended organs of human labour.[153] In considering machinery as a means of extracting more work from labour-power, Marx was forced to confront the role of extra-human energy flows and energy conversions. This is evident from Marx's opening definition of machine:

> The machine, which is the starting-point of the industrial revolution, replaces the worker, who handles a single tool, by a mechanism operating with a number of similar tools and set in motion by a single motive power, whatever the form of that power.[154]

Machines are thus means of converting both materials and (human and extra-human) energy into commodities bearing surplus-value.

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150. Marx 1976a, pp. 380–1.

151. Marx 1976a, p. 381.

152. Burkett 1999, Chapter 10.

153. See Daly (1968, pp. 396–8) on the importance of the endosomatic/exosomatic distinction in ecological economics. For details on Marx's development of this distinction, and its connections with Hegel and Darwin, see Foster and Burkett 2000; 2001. Martínez-Alier (2005, p. 3) asserts that 'Marx does not seem to have considered the metabolic energy flow, so he could not trace the distinction … between endosomatic use of energy in nutrition and the exosomatic use of energy by tools'. This has to rank as one of the most uninformed statements ever made by a scholar of Martínez-Alier's reputation. Not only did Marx make such a distinction (which went back to the ancient Greeks) but in his hands and those of Engels it became the basis for an original conception of human evolution in line with Darwin's analysis. See Foster 2000, pp. 196–207; Winder, McIntosh, and Jeffrey 2005, pp. 351, 354–5.

154. Marx 1976a, p. 497. This definition was adapted from the work of the English engineer and economist Charles Babbage [1791–1871].

Expanding upon this conception, Marx treats the industrial revolution using a model of *machinery systems* consisting of 'three essentially different parts, the motor mechanism, the transmitting mechanism and finally the tool or working machine'.[155] For Marx, mechanised production involves the transfer of force from one part of the system to another, starting from the motor which 'acts as the driving force of the mechanism as a whole', on through the transmission mechanism which 'regulates the motion, changes its form where necessary, and divides and distributes it among the working machines', and finally to the working machine which 'using this motion… seizes on the object of labour and modifies it as desired'.[156] This model was informed by Marx's extensive theoretical and practical studies of energy conversion, the mechanical theory of heat, and industrial technology.[157]

One important implication of Marx's analysis is that the industrial revolution started not with the motor mechanism and its power sources but rather with the tool or working machine. The key development, in Marx's view, was the conversion into a machine process of the portion of labour that involved working directly on the raw material(s), as a result of which the machine 'performs with its tools the same operations as the worker formerly did with similar tools'.[158] This conversion, which depended on the prior separation of the worker from control over the means of production (partly through the application of detailed divisions of labour), was the crucial prerequisite for the wider industrial application of extra-human, including inanimate, power sources. As Marx observes, 'assuming that [the worker] is acting simply as a motor, that a machine has replaced the tool he is using, it is evident that he can also be replaced as a motor by natural forces'.[159] The mechanisation of tools freed these tools from the limitations of human labour-power as the direct motive force, while the increasing scale of machine systems necessitated the application of more powerful energy sources – starting with animal, water and wind power but soon graduating to coal-driven steam (and later electrical) engines.[160]

Accordingly, when analysing the immense throughput of materials generated by mechanised capitalist production,[161] Marx emphasises the consumption of

155. Marx 1976a, p. 494.
156. Ibid.
157. Baksi 2001, pp. 385–6; Burkett and Foster 2006, pp. 130–3.
158. Marx 1976a, p. 495.
159. Marx 1976a, p. 497.
160. Marx 1976a, p. 496.
161. As Marx (1976c, p. 203) indicates, 'the increasing productivity of labour is expressed precisely… in the increasing mass of raw material that is transformed into products, worked

energetic materials serving as 'ancillaries' to production – 'coal by a steam-engine', 'materials… for heating and lighting workshops', etc.[162] He points out that: 'Even in branches of industry that do not use any specific raw material of their own, there is still raw material in the form of ancillary material', especially energy sources 'such as indigo, coal, gas, etc.'[163] True, Marx's analyses of materials-supply problems focus not on fuel crises, but rather on shortages of food and cotton in the industrial sphere and of soil nutrients in agriculture.[164] The latter were, after all, the main materials shortages occurring in Marx's time. But there is no reason why Marx's analysis cannot be extended to fossil-fuel-based crises.

At any rate, Marx's analysis of capitalist machine systems answers a crucial question in ecological energetics: how the industrial revolution definitively 'broke the budget constraint of living on solar income'.[165] And unlike ecological economics, which has tended to shun class analysis, Marx's explanation (as shown above) roots the development of fossil-fuel-driven technologies in the social relations of production.

Naturally, *Capital*'s discussion of the industrial revolution eschews the energy reductionism that afflicted Podolinsky's 'perfect machine' perspective on human labour. For example, Marx's study of science and technology made him highly cognisant of how problems of friction shaped the development of real-world machine systems, including motor mechanisms and their power sources.[166] He noted that the limitations of water power 'gave the impulse for a more accurate investigation of the laws of friction', thus creating some of the scientific basis for the development of coal-fired steam engines.[167] Marx also showed that water-power was only displaced by steam-power as the development of the entire mechanism of production (in both scale and complexity) demanded increasingly large concentrations, and more flexible, controllable, transportable, and storable forms, of energy.[168]

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up into commodities, in an hour, for example'. For details on Marx's analysis of materials throughput, see Burkett 1999, pp. 108–12.

162. Marx 1976a, p. 288.

163. Marx 1976c, p. 201.

164. For a thorough overview, see Burkett 1999, pp. 112–19.

165. Daly 1992, p. 23.

166. Marx's study of friction also enabled him to more effectively integrate the physical wear and tear of machinery into his value analysis of fixed capital. See Burkett and Foster 2006, pp. 133–4.

167. Marx 1976a, p. 498.

168. Marx 1976a, pp. 498–506; Burkett and Foster 2006, pp. 131–3.

Marx was, of course, aware that capitalism's 'development of the productive powers of labour' involved not just machine systems as transmitters of energy, but also 'the appliance of chemical and other natural agencies'.[169] In agriculture, especially, the 'conscious, technological application of science' must deal with 'the fertility of the soil' and its necessary basis in 'the metabolic interaction between man and the earth'.[170] Marx's concern with the metabolic (not simply energetic) preconditions of sustainable agriculture both spurred and was spurred on by his study of the leading agricultural chemists of his time, including Justus von Liebig and James Johnston.[171] But Marx recognised the irreducible biochemical element in any kind of production where something is 'added to the raw material to produce some physical modification of it, as chlorine is added to unbleached linen, coal to iron, dye to wool'.[172] In these cases, production consists of two periods: 'the labour process, and a second period in which [an] unfinished product is handed over to the sway of natural processes, without being involved in the labour process'.[173] Such biochemical operations obviously reduce the relevance of purely energetic analysis ('counting calories').

Building on his analysis of machinery and large-scale industry, and applying Liebig's theory of metabolic reproductive cycles, Marx shows that capitalism systematically degrades the productive powers of the earth and of labour-power both energetically and biochemically. He points out how the growing matter-energy throughput of mechanised production, the industrialisation

169. Marx 1976d, p. 34.

170. Marx 1976a, pp. 637–8.

171. Mayumi 1991, pp. 37–48; Foster 2000, pp. 149–54; Baksi 1996, pp. 272–4, and 2001, pp. 380–2. On the rather dubious basis of a reference to 'Moleschott's metabolism' in a playful love poem that Marx wrote to his wife Jenny, Alfred Schmidt claimed that the Dutch physiologist Jacob Moleschott was the main inspiration in Marx's use of the metabolism concept (Schmidt 1971, pp. 86–8). This view was later adopted by Martinez-Alier and others (Martínez-Alier 2005, p. 3, and 2006, pp. 274 and 289). It is true that Marx and Engels were both well aware of Moleschott's work. (Marx attended some of Moleschott's lectures, along with those of Liebig, Tyndall and Huxley.) But the concept of metabolism was already widespread within biology, chemistry and physiology at the time they were writing and was used by many other thinkers with whom they were familiar, including Liebig, whose influence on Marx and Engels's work was much more profound. Engels referred to Moleschott as a mechanical materialist and a proponent of the crude social-Darwinist 'struggle for existence', contrasting this to Liebig who emphasised the interdependence of nature (and of nature and society) (Marx and Engels 1975a, Volume 45, pp. 106–8). It is the latter approach that Marx focused on in his analysis of the metabolic rift (Liebknecht n.d., p. 106).

172. Marx 1976a, p. 288.

173. Marx 1976a, p. 317; for details see Burkett 1999, pp. 41–7.

of agriculture which led to the systematic and intensive robbing of the soil, and the spatial division of labour between agriculture and manufacturing, all combine to 'simultaneously undermin[e] the original sources of all wealth, the soil and the worker'.[174] Capitalist production 'disturbs the metabolic interaction between man and the earth' insofar as it

> prevents the return to the soil of its constituent elements consumed by man in the form of food and clothing; hence it hinders the operation of the eternal natural condition for the lasting fertility of the soil.[175]

It also

> reduces the agricultural population to an ever decreasing minimum and confronts it with an ever growing industrial population crammed together in large towns; in this way it produces conditions that provoke an irreparable rift in the interdependent process of social metabolism, a metabolism prescribed by the natural laws of life itself.[176]

The systemic-energetic dimension of this metabolic rift is clear from Marx's insistence that:

> Large landed property undermines labour-power in the final sphere to which its indigenous energy flees, and where it is stored up as a reserve fund for renewing the vital power of the nation, on the land itself. Large-scale industry and industrially pursued large-scale agriculture have the same effect. If they are originally distinguished by the fact that the former lays waste and ruins labour-power and thus the natural power of man, whereas the latter does the same to the natural power of the soil, they link up in the later course of development, since the industrial system applied to agriculture also enervates the workers there, while industry and trade for their part provide agriculture with the means of exhausting the soil.[177]

Marx thus applies the metabolic energy income/expenditure approach (previously used to analyse the exploitation of labour-power alone) to the entire ecological system of land and labour power. In fact, he had sketched out this application several years earlier, in *Theories of Surplus Value*:

174. Marx 1976a, p. 638.
175. Marx 1976a, p. 637.
176. Marx 1976c, p. 949.
177. Marx 1976c, pp. 949–50.

> Anticipation of the future – real anticipation – occurs in the production of wealth in relation to the worker and to the land. The future can indeed be anticipated and ruined in both cases by premature overexertion and exhaustion, and by the disturbance of the balance between expenditure and income. In capitalist production this happens to both the worker and the land. . . . What is expended here exists as power and the life span of this power is shortened as a result of accelerated expenditure.[178]

Marx's rift analysis recognises that capitalism does not create or destroy matter-energy, but does degrade it in the sense of a reduction in the combined metabolic reproductive capabilities of land and labour-power. This degradation can be seen as a historically specific form of entropy – one produced by capitalist industrialisation based on the social separation of the producers from the land and from other necessary conditions of production.[179] And, as Peter Dickens observes, Marx's 'notion of an ecological rift, one separating humanity and nature, continues to be helpful for understanding today's social and environmental risks'.[180] The rift approach has recently been applied to the problems of global warming, depletion and degradation of oceanic ecosystems, disruptions to the global nitrogen cycle by inorganic fertilisers, and the dynamics of ecological imperialism.[181] Yet Martínez-Alier's conventional wisdom excludes Marx's analysis from ecological economics simply because it does not reduce everything to quantitative energy flows.

VII. Conclusion

Marx and Engels found Podolinsky's energy-dogmatism inadequate for the treatment of human labour as an environmentally open system structured by specific class relations. Their own approach was both historical and metabolic. While incorporating energetic factors, it also recognised the irreducibly material (including biochemical) and irreducibly social character of human production. The 'human labour as machine' analogy was neither holistic nor social-relational enough to be helpful in this context. Engels's criticisms of Podolinsky were thus more than justified. In fact, by the time Podolinsky's work was published, many leading thermodynamic theorists had, like Marx and Engels, rejected the notion that human beings and their labour could be

178. Marx 1971, pp. 309–10.
179. Mayumi 1991; Burkett 2005a.
180. Dickens 2004, p. 81.
181. Clark and York 2005; Clausen and Clark 2005; Mancus 2005; Moore 2001; Foster and Clark 2004.

viewed simply as thermal engines, and called for a more nuanced physical, biochemical, and thermodynamic analysis. The emerging anti-reductionist view – represented by such key scientists as William Robert Grove, Justus von Liebig, Ludimar Hermann, and William Thomson – understood the first and second laws of thermodynamics not just quantitatively but also qualitatively, in terms of the transformations among various co-developing material forces.[182] This implicitly dialectical current was closely studied by Marx and Engels, and, as we have seen, it greatly influenced Marx's mature analysis of capitalist exploitation and industrial accumulation at certain key points.

Unfortunately, Podolinsky chose to follow the opposing, rigidly mechanistic, current which reacted to advances in thermodynamics by seeing the work of animals and human beings in terms of the steam engine. The most direct influence in this respect was likely the French 'living machine' school represented by Bernard, Hirn, and Marey – all of whom were cited by Podolinsky. As Gleyse observes, it is difficult to ignore the capitalist functionality of this school together with its élite-engineering perspective on social efficiency and reforms:

> The idea of the rationalised energy-producing body… was perhaps not only developed in part from the technology of the steam engine, but also through the economic need for more and more efficient factory production. At least we can perceive… a metaphorical dialogue between these two types of language. But in both instances it would seem that a group of pioneers was instigating a system of control over the general population.… In the industrial universe and in the factory environment 'man' became a theoretic entity in accordance with values represented firstly by the steam engine and then by the machine.… A kind of implacable logical cycle was set up: technology gave birth to science and then science, expanding beyond its first field of application, or else being applied (or even misapplied) to other fields, led in turn to the birth of a technology, or sometimes even a technocracy. It was the human body, or more particularly in this case the physical activity associated with it, that was the subject of this technology. But this technology should not just be considered as such; above all else it was a widespread system of control that organised society, or at least a system that a few influential people wished to promote for the greater good of the masses.… Hirn consolidated this paradigm and applied it to corporal practices as a whole, going beyond the limited field of industrial production.[183]

Exemplifying such positivistic views in physiology, Bernard wrote in 1865 that:

182. Engels 1987.
183. Gleyse 2002, pp. 8–9.

> There is an absolute determinism in all of the sciences because, each phenomenon being linked necessarily to physico-chemical conditions, the scientist can modify these conditions to master the phenomenon, that is to say, to hinder or favour its manifestation. In the case of inorganic bodies, there is no debate on this subject. I would like to prove that it is the same for living bodies, and that, for them also, determinism exists.[184]

One sees in such outlooks the intellectual roots of Podolinsky's attempt to ground value-analysis in energy flows and of his vision of socialism as a tightly engineered machine dedicated to the accumulation of energy on the earth. It is interesting to note that these features of Podolinsky's thought have been rejected by some of the giants of modern ecological economics. Georgescu-Roegen, for example, referring to 'the fallacy of the energy theory of economic value', explicitly rejected what he understood to be Podolinsky's attempt 'to replace labour by energy in Marx's theory of value', supporting Engels's argument in this regard, and suggested that Engels's critique of the labour-as-steam-engine analogy 'ought to kill in the bud any temptation to replace economics by some energetics'.[185] Both Georgescu-Roegen and Daly have pointed out that the 'principle of energy maximisation', according to which the (human and other) systems that survive and grow are those that utilise the most energy reproductively, wrongly reduces use-value to pure energy.[186]

Meanwhile, the power of Marx and Engels's metabolic-energetic approach has received notice from a growing number of ecological economists. Kenneth Stokes, for example, observes that *Capital*'s 'surprisingly contemporary thermodynamic vision of the economic process is a clear departure from the circular flow concept; for it is suggestive of the modern open-systems theoretical perspective'.[187] He goes on to state that Marx and Engels's 'model explicitly embodied … the metabolic interaction of man and nature; the notion that the economic process is embedded in the biosphere', and that it treated 'social change' as 'an endogenous dialectic process in which the nature-society nexus displays reciprocal and complex interpenetrations'.[188] Georgescu-Roegen's student and leading follower, Kozo Mayumi, offers that

> Marx effectively evaluated and appreciated the development process of agriculture and the destructive aspect of modern industry in terms of the circulation of matter between nature and man.[189]

184. Bernard 2000, p. 320; compare Olmstead and Olmstead 1952, pp. 131–50.
185. Georgescu-Roegen 1986, pp. 8–9. Compare Papathanasis 1997, p. 83.
186. Georgescu-Roegen 1979; Daly 1992, pp. 215–17.
187. Stokes 1994, p. 52.
188. Stokes 1994, p. 64.
189. Mayumi 1991, p. 40. See also Mayumi 2001, p. 83.

By comparison, it is difficult to see what important insights into contemporary ecological crises can be obtained from Podolinsky's energy-reductionist approach. The only possible advantage of Podolinsky's analysis over Marx and Engels's lies in the former's effort to trace productive energy flows empirically. As shown above, however, this attempt to reduce production to pure energetics ('counting calories') may raise more questions than it answers. Certainly, it does not constitute a valid physical scientific basis for Marxist value analysis. Indeed, insofar as Podolinsky adopts a quasi-Ricardian, physicalist, notion of value as embodied energy, it draws attention away from the radical socio-ecological implications of Marx's value-form perspective. For Marx, the apparent independence of value from nature, and the anti-ecological character of the value accumulation process, are historical outgrowths of capitalism's alienation of workers from nature and from other essentially communal conditions of production. One of the most severe collateral damages of the Podolinsky myth has been its reinforcement of the serious misunderstandings among ecological economists (and even among many so-called ecosocialists) about the real ecological significance of Marx's value-analysis.[190]

Marx and Engels's socio-metabolic approach to human labour offers a more pro-ecological and humanly liberating vision of socialism than does Podolinsky's mechanical-engineering perspective. Instead of treating socialism as an energy-accumulation machine, Marx and Engels see it as a system of sustainable human development that maximises the self-management capabilities of workers and communities.[191] As Marx indicates:

> Freedom, in this sphere, can consist only in this, that socialised man, the associated producers, govern the human metabolism with nature in a rational way, bringing it under their collective control instead of being dominated by it as a blind power; accomplishing it with the least expenditure of energy and in conditions most worthy and appropriate for their human nature.[192]

Among socialism's first tasks, in Marx's view, is the healing of the rift between people and nature through a 'systematic restoration' of society's reproductive metabolism with the land 'as a regulative law of social production, and in a form adequate to the full development of the human race'.[193] This restoration will once and for all relegate Podolinsky's work, and all other energetic myths, to their rightful place in the pre-history of materialist ecology and of human

190. Burkett 1999, Chapters 5–8; 2003, and 2006, Chapter 1.
191. Burkett 1999, Chapter 14; 2005b; 2006, Chapter 10.
192. Marx 1976c, p. 959.
193. Marx 1976a, p. 638.

development. If Podolinsky remains important to Marxist theory (and to ecological economics) and well worth close study today, this has less to do with what he offers directly than with the new insights into Marx and Engels's much more formidable economic-ecological synthesis that a critical scrutiny of his work provides. In this sense, we can certainly say of Podolinsky, R.I.P.

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