A Marxist Precursor of Energy Economics: Podolinsky[1]

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This article reviews some recent work on the energy analysis of agriculture, which shows that the efficiency of 'modern' agriculture is inferior to that of 'traditional' agriculture. We consider one of the first examples of energy accounting in agriculture (published by Sergei Podolinsky one hundred years ago), and we evaluate Engels' reaction to it, in correspondence with Marx. This article is, then, an attempt to explore whether energy analysis can be fitted into the Marxist framework, and our conclusion is that Marxism would have to be much revised since there are epistemological obstacles (the use of categories from Political Economy, such as 'production', 'labour-value', 'capital') and ideological obstacles (the vision of a two-stage transition to communist abundance and equality). Although some Marxist anthropologists have used energy analysis, most Marxist economic historians and economists have not, i.e. they have not looked critically at the notion of 'development of productive forces'. We trace the origins of this divorce between Marxism and ecology.

Over the last few years, a number of studies (by non-economists, with the notable exception of Georgescu-Roegen) have implicitly questioned the meaning of 'technical progress', 'investment' (as growth of 'productive capacity'), 'development of productive forces'. Indeed, they have questioned what 'production' might mean, or at least how it should be valued.

We are not alluding to the familiar fact that in order to value heterogeneous products we need prices and that prices depend on distribution, so that production will have different values according to different distributions of income as between wages and profits. We are referring to the study of energy flows. It is the case that 'production' has grown, 'productive capacity' has increased, and 'productive forces' have developed because the capacity to destroy the stock of fossil fuels and the forces which do so have increased so much. Thus, it has been shown that the efficiency of modern agriculture is much

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less than that of traditional agriculture [*Leach, 1976*] [*Pimentel, 1979*]. Such studies do not aim, however, at providing a new criterion of economic efficiency, such as energy return to energy input, which would be substituted for the usual criterion of economic efficiency. It is a fact, for instance, that different agricultural products have use values which are not always related to their energy content, but rather to their protein or vitamin content, or simply to the pleasure to be gained by eating or drinking them. Nevertheless, such studies demonstrate that while labour productivity in agriculture has been growing considerably, on the other hand energy efficiency has decreased remarkably. The decision as to whether such a process may really be called 'technical progress' (or 'development of productive forces') has to be left to the future, which is uncertain as regards availability of energy. In other words, there is no way to decide whether overall efficiency has increased unless we have rational and agreed means of giving a value to the flows from the stock of fossils fuels, which in turn would require a decision as to how much and how far into the future we care about posterity. It would also require some hypotheses (difficult to validate) about future developments in the field of energy availability.

The main purpose of this article is not to summarise the work that has been done in energy analysis in agriculture. Neither is it to dwell upon its significance for the viability or necessity of small scale (or labour intensive) agriculture [*Buttel,* 1980], nor to contribute to the difficult question of how natural resources should be valued for an efficient allocation over time. Rather, our purpose is to consider whether energy analysis can be fitted into the Marxist framework. Our conclusion is that this would be a difficult undertaking, since Marxist economics is a closed system — with a theory of value inconsistent with energy analysis and with a vision of the relations between man and nature which is similar to that of most economists. As we shall see, the founders of Marxism themselves (or, at least, Engels) believed that economics should not be mixed up with physics.

The mechanical analogy common to mainstream economics[2] is shared by Marx, for instance in the schemes of 'simple reproduction' where there is no question that the process could be continued indefinitely. No emphasis is given to the question of where the raw materials come from, or what is the motive power of this machine. This is also the case for the Sraffian 'production of commodities by means of commodities'.[3] The Marxist vision of the capitalist machine is certainly different from that of the functionalist economists, in the sense that Marx foresaw its breakdown through the contradictions arising from the fact that, in 'expanded reproduction', one part of the machine would grow more than the other part. But, despite his occasional remarks on how capitalism misused nature, the emphasis on the ecological problem is lacking.

Since energy analysis is an instrument of great importance not only to enable us to understand the economic history of the world, but also to permit us to suggest where the world economy is going, this article will end with a plea for Marxists to discard the general notion of 'productive forces', which we find metaphysical, in favour of more precise concepts on the character of the 'material basis' of the economy.

One of the pioneers (at least in Britain) in the field of the relations between economics and energy analysis, Frederick Soddy, was of the opinion that had Marx lived after the modern doctrine on energy was established (meaning the first and second laws of thermodynamics) there is no doubt that his acute and erudite mind would have understood its significance for the social sciences [*Soddy,* 1922:13]. The fact is, however, that Marx did live after the second law of thermodynamics was established by Sadi Carnot, Clausius, William Thomson, etc., and that he took no account of it in his economic and historical doctrines. It is true that practically all economists still ignore thermodynamics one hundred years after Marx's death, and it would be invidious to single Marx out were it not that apart from being a scientist he was also the founder of a political movement based upon his doctrines. Even if we keep to science, it is a fact that Marxism still inspires a great deal of historical and social science writing.

Engels, in his reading notes of 1875 and 1876, perhaps not meant for publication but which were later included in *Dialectics of Nature,* studied Clausius' Second Law, but dismissed it in unequivocal terms as being contradictory of the First Law [*Marx-Engels,* Vol. 20, 1972:545].

Both Marx and Engels had the opportunity to study closely the work of Sergei Podolinsky, a Ukranian socialist, who seems to have been one of the first authors to draw some conclusions as to how economic analysis would have to be modified (or perhaps discarded) in order to take into account energy analysis. The present article is mainly a comment on Podolinsky's work and on Engels's reaction to it. Marx's reaction is not known, though the tone of Engels's letters to him on the subject leads one to think that he agreed with Engels and disagreed with Podolinsky.

PODOLINSKY'S ARTICLE

In September and October of 1883, Podolinsky published an article in two parts in *Die Neue Zeit* under the title 'Human labour and the unity of energy'.[4] He had sent it previously to Marx (on 30 March 1880, from Montpellier, where he lived), asking for Marx's comments and explaining that *Ihr Werk 'Das Kapital' die erste Anregung* (stimulus) *gegeben hat.* That article gives Podolinsky a fair claim to be considered one of the founders of socioenergetics. Podolinsky's objective was, in his own words, *die Mehrarbeit mit den herrschenden physikalischen Theorien in Einklang* (harmony) *zu bringen* (letter to Marx of 18 April 1880).[5]

Despite the fact that Podolinsky had been inspired by Marx's work and despite his intention of giving a foundation to the labour theory of value in the natural sciences, his efforts did not meet with the approval of Marx and Engels. Confronted with such a novel viewpoint, and with Marx near the end of his life (he died in March 1883), they failed to appreciate the significance of Podolinsky's view for the Marxist system, and particularly for a more accurate definition of the notion of 'productive forces'. Whether there were on the part of Marx and Engels ideological obstacles to the perception of this novel view — which implied that limits to growth of the economy were not to be sought only in the shackles of old relations of production but also, perhaps mainly, in the physical and biological facts of earthly life under the sun — is something to which we shall turn at the end of this article.

Let us first summarise Podolinsky's article. Despite its publication in *Die Neue Zeit*, the theoretical organ of the German Socialist Party, it seems to have had little influence on developments in Marxist thought, and indeed in the development of economic and anthropological thought. Podolinksy's ideas are no longer very new, in retrospect, but their lack of influence is a symptom of the separation that has existed between the natural sciences and the social sciences (including Marxism among the latter).

Podolinsky understood the laws of thermodynamics. He was also conscious that he was in a line of succession to the Physiocrats who had tried to analyse the economic process in material terms, though they could not have established the relations in energy terms between economic systems and natural surroundings since the theory of energy was developed only in the nineteenth century. He was worried about how the doctrine that labour was the source of value could be reconciled with the energy analysis of the economic process. He was aware of the fact that the dissipation of energy by living organisms (including man) is compatible with the continuation of life because the earth is an open thermodynamic system which gets energy from the sun. The conversion of solar energy into vegetable matter, preventing or retarding its entire dissipation as heat-energy into the atmosphere, is the key factor which has allowed animal and human life on Earth. Podolinsky placed emphasis on this basic ecological fact, which at first sight seemed to imply that since the energy used by man (as food, as clothing, as warmth, etc.) came from Nature and not from Labour, then Labour did not create Value. This was his initial standpoint.

He wrote: 'We have in front of us two parallel processes which together form the so-called circuit of life (*Kreislauf des Lebens*). Plants have the property of accumulating solar energy, but animals, when they feed on vegetable substances, transform a part of this saved energy into mechanical work and dissipate this energy into space. If the quantity of energy accumulated by plants is greater than that dispersed by animals, then stocks of energy appear, for instance in the period when mineral coal was formed, during which vegetable life obviously was preponderant over animal life. If, on the contrary, animal life were preponderant, provision of energy would be quickly dispersed and animal life would have to go back to the limits determined by vegetable wealth. So, a certain equilibrium would have to be built between the accumulation and the dissipation of energy' (p.420).

The expression *der Kreislauf des Lebens* is presumably taken from Jacob Moleschott's work with this title.[6] Moleschott influenced Marx's use of the concept of 'metabolism' between man and nature *(Stoffwechsel zwischen Mensch und Natur)* [*Schmidt,* 1978]. Moleschott already had a modern ecological vision of the 'circuit of life' even if he was bound to emphasise the laws of conservation of matter (writing in the 1840s and 1850s) and not the laws of conservation and dissipation of energy. Schmidt believes 'that Marx understood the concept of metabolism between man and nature not only metaphorically but also directly physiologically, as it emerges clearly from his critique of the abrupt separation between city and country in favour of the capitalist production of his time' [*Schmidt*, 1978:89], and Schmidt convincingly quotes the passages from *Das Kapital* (Vol. 1) where Marx commented on the fact that the cities take materials from the countryside while the dung from the cities does not return to the countryside, and he raised sound questions about land fertility in this situation. One could add passages in which both Marx and Engels commented on land erosion, on the immoderate use of coal by capitalism, etc. Nevertheless, Marxist theory does not provide and does not use the instruments for an analysis of energy flows in the economic process.[7] The consequences, for a definition of 'productive forces' and for a correct perspective on the sources and limits of economic growth, are far-reaching. To the extent that Marxist theory has preoccupied itself with natural resources, the treatment has not been an ecological one but a Ricardian one, i.e. how rent paid to the owners of natural resources would alter the patterns of distribution and saving and investment.[8] As we shall see, Marx and Engels were perplexed by Podolinsky's analysis; most contemporary Marxists, not in 1882 but in 1982, might still feel perplexed.

Podolinsky began his article by stating that since according to the First Law of Thermodynamics energy cannot be created, then it followed *daß nichts durch die Arbeit geschaffen werden kann*, that nothing can be created by work. Work was useful only insofar as it transformed some forces into other forces. What were the rules of such transformations? We must take into account, he answers, that according to Clausius' principle, i.e. the Second Law, energy is transformed in such a manner that there is a 'tendency towards a general equilibrium, which is known as the dispersion of energy, or according to Clausius' process, as entropy. This expression means the quantity of transformed energy that cannot be transformed back' (p. 414). The reference by Podolinsky is to a French edition of Clausius' work (i.e. to [*Clausius*, 1868]).

Podolinsky then draws an inventory of available energy: that coming from the Sun directly and that which takes the form of running water, wind, or is geothermal. He also considers tidal energy. He gives plausible figures for coal reserves in Britain and the United States, and he mentions oil. All such forms of energy (or almost all) are transformations of solar energy.[9] The Earth receives 'incredible quantities of physical forces from the Sun which can then experience the most diverse transformations, and all physical and biological phenomena are expressions of such transformations' (p. 414). Those forms of energy are but forms of retarding the dissipation of energy coming from the Sun. His knowledge of the Sun comes from Secchi's work, much quoted by Engels in *Dialectics of Nature*. He could not know how the Sun really works (by nuclear fusion), nor does he explicitly mention photosynthesis. Our purpose, however, is not to place Podolinsky's article in the history of natural sciences (for which we are not qualified).

Impressed as Podolinsky was by the amount of energy coming daily from the Sun and by the amount of energy contained in different forms in the Earth, he was, however, quite lucid about 'the danger that we will suffer one day a scarcity of transformable forces on the surface of the earth'. This danger was still quite distant, 'but at the same time we notice after a more detailed consideration that the distribution of such forces is not always the most advantageous in order to satisfy the needs of the organic world in general and of humanity in particular' (p. 414).

Having explained how the energy input from the Sun was far greater than the transformed forms of energy on earth, and having explained also the role of vegetable life in retarding the dissipation of energy from the Sun (pointing out, too, that plants do not need to become coal in order to fulfil this role), Podolinsky goes on to make his point about how human labour may, in fact, increase the accumulation of energy. To illustrate his reasoning, he gives examples of energy accounting with reference to different ecosystems in France (using the methodology that much later was to be used by anthropologists such as Rappaport, [1968] and Lee, [1979] or by natural scientists such as Pimentel [1979] or Leach, [1976] among many others).

He considers, on the one hand, forest and natural pastures and, on the other, sown pastures and cereal agriculture. In forest, according to his source (which is *Statistique de la France* for 1874 and 1879) there is an average annual growth per hectare of nine metric quintals (900 kgs.) of dry matter. Each kilogram of dry cellulose contains 2,550 Kcal. (*Wärmeeinheiten*), and therefore the natural production of energy per hectare and per year is 2,295,000 kcal. In natural pastures average production of hay per hectare and per year is 2,500 kgs. The energy content is also 2550 kcal. per kilogramm and therefore annual production per hectare and year is 6,375,000 kcal.

He then goes on to consider two 'man-made' ecosystems. On sown pastures, discounting the seed, average production per hectare and per year is 3,100 kgs. Energy 'production' per hectare and per year is then, 3,100 x 2,550 = 7,905,000 kcal. Compared to natural pastures, sown pastures 'produce' 1,530,000 Kcal. extra per hectare and per year; this is not however a net addition, since one should substract not only the seed (which he has done already) but also the energy input from animals and men. This he proceeds to do, assuming that per hectare and per year one would need fifty horse-hours' work and eighty man-hours' work. This energy input amounts to 37,450 Kcal. (This figure is quite plausible, if we remember that 1 HP = 0,735 KW, that 1 KW = 860 Kcal., and that the mechanical work of a man working normally during one day might be equivalent to 0.5 kW, or 430 Kcal.). He then concludes that human (and animal) work contributes to a larger 'production' of energy, the ratio 37,450: 1,530,600, or 1:41. This is the energy return to the energy input from human (and animal) work.

Turning then to cereal growing, he finds in his sources that wheat average production per hectare (subtracting the seed) is 800 kgs. of wheat and 2000 kgs. of straw. (The low yield per hectare is consistent with little or no use of fertiliser from outside the farm — in any case, Podolinsky does not discount the energy input from fertiliser). Energy content per kg. of wheat he takes as 3,750 kcal. and per kg. of straw as 2,550 kcal. which means 8,100,000 kcal. per hectare. Compared to natural pastures, cereal growing 'produces' 1,725,000 kcal. extra per hectare and per year, at the cost of an energy input from approximately one hundred horse-hours or work and two hundred man-hours of work, which amount to 77,500 kcal. Therefore 'each calorie used in the form of work in wheat growing causes an accumulation of solar energy equal to 1,725,000/77,500 = 22 calories' (p. 421). The figures on the energy input from horses and men are again quite plausible. We take him to assume some twenty-five days of human work per hectare, and some twelve or fifteen days of horse work per hectare (for plowing, transport, threshing), and to assume that one hour of horse-work is indeed one H.P.-hour, and that one day of man-work approximately equals 500 kcal.

One might remark that to arrive at the ratio of caloric output/human caloric input, one would have to exclude from the output that which would go to feed the work animals, and one would have to include only human work in the input. Also, it might be pointed out that not all the straw has some use (this would depend on whether we consider purely cereal farming, or mixed farming). More important is to notice that Podolinsky's ratios agree in a general way (both as caloric output/total caloric input, and as caloric output/human caloric input) with those in modern research on traditional agriculture, which is not surprising since he used the same methodology as modern energy accounting.

There is also another point. His figures show biomass production to be greater in agriculture than in forest. He is referring to the total amount of energy fixed by plants per year less the energy spent in respiration. Gross production (in the biological sense) might be higher in forest. But, in any case, agriculture would increase the amount of energy available as food. Podolinsky's interest was in showing that controlled energy supply increases by human work, and this is why he develops the concept of the energy productivity of human work. His intention was to arrive at a definition of 'useful work' or 'productive work'. Plants, by themselves, have the quality of 'accumulating', 'keeping', 'saving', retarding the dissipation of energy, and this process is intensified by means of human work: 'Work (*die Arbeit,* which perhaps one should translate as labour)[10] is that kind of use of the mechanical and mental energy accumulated in the (human) organism which has as a consequence an increase in the general energy budget on the Earth's surface' (p. 422).[11] Labour then creates value, and this value is measured in energy terms. In other words, 'useful' or 'productive' work is work which makes a positive contribution in energy terms.

Agriculture is certainly the activity which lends itself best to such a definition of 'useful' labour, but Podolinsky considers that the activities of a tailor, a shoemaker, a builder would also qualify as work in his sense since they afford 'protection against the dissipation of energy into space' (p. 422). He also discusses (not very convincingly) and rejects the idea that animals in nature 'work', according to his definition.

The second part of Podolinsky's article[12] considers how the human organism is capable of doing work, since 'we have not yet said anything on the origin of the capacity of the human organism to do work, without which it would be difficult to explain the accumulation of energy on the surface of the Earth under the influence of labour' (p. 449). He accurately takes the human organism to be a thermal machine, and using Helmholtz's findings he concludes that 'man has the capacity to transform one fifth of the energy gained from food into muscular work', and to this ratio (which broadly agrees with data presently used, as, for example, [*Foley*, 1976:105]) he gives the confusing name of 'economic coefficient' (p. 450) when it is in fact the energy efficiency of man as a machine which converts caloric energy into mechanical energy, i.e. work.

This so-called 'economic coefficient', or energy efficiency, is not taken as a datum by Podolinsky, on the grounds that man does not live (and work) by bread alone, i.e. that human needs also include clothes and shelter, and also that not the whole human population is able to work. Old persons and children, for instance, although they may also convert calories into mechanical work (in a purely physical sense), do not perform any work of economic value. Therefore, the 'economic coefficient' is not as favourable as the ratio 1/5 would indicate. Taking into account such factors, and also the part of total expenses which goes into non-food consumption,[13] he concludes that a good estimate for the 'economic coefficient' would be 1/10: man may convert into work one tenth of the energy consumed.

Such energy efficiency can be compared to that of other thermal machines, and Podolinsky did so, using as a term of comparison steam-engines, and quoting explicitly from the work of Sadi Carnot (of 1824) on the principles of conversion of thermal energy into mechanical energy.

He then arrives at a general theoretical principle: 'If we consider the human organism as a thermal machine with an 'economic coefficient' (meaning efficiency) of 1/10, we shall be able to determine in a more exact manner the conditions of human life on the Earth' (p. 451). We think there is an explicit desire on Podolinsky's part to use the Marxist expression 'the natural conditions of human existence'.[14]

Since human work has the capacity to increase the available flow of energy (as had been shown in his agricultural energy accounts), then:

> humanity is a machine that not only turns heat and other physical forces into work but succeeds also in carrying out the inverse cycle, that is, it turns work into heat and other physical forces which are necessary to satisfy our needs, and, so to speak, with its own work turned into heat is able to heat its own boiler. (p. 453).

In order to assure the conditions of existence, each calorie of human work must have then a productivity (this is his own term) of at least ten calories (assuming an 'economic coefficient' of 1/10). Of course, the needs, or conditions of existence, of primitive people are in a way easier to meet, since their 'economic coefficient' instead of being perhaps 1/10 is nearer, perhaps, to 1/6 — their needs are reduced to food, and with an energy productivity, or caloric return to human caloric input, of only 6:1, their existence is assured. Civilised man, with a worse 'economic coefficient' since the denominator includes not only food energy but also energy for other needs, has to have a greater energy productivity, as indeed is the case, as the figures from French agriculture show. If the necessary energy productivy of work is not achieved, then, of course 'scarcity appears and, many times, a reduction in population' (p.454).

One should remark that, since Podolinsky's days, and even in his own time, the daily 'consumption' of calories of 'civilised' people has been much greater than that of 'primitive' people, and therefore that the 'economic coefficient' or energy efficiency of 'civilised' mankind as a thermal machine is extremely low. We still convert one fifth or one sixth of our food energy intake into mechanical work (whether it is 'productive' work, or jogging, or typing in offices, is irrelevant here) but we eat a type of food which is increasingly expensive to produce in energy terms and we also expend a lot of energy for our other 'needs'. The distribution is, of course, unequal inside such countries but we could also contrast their levels of energy consumption with those of 'primitive' people, or just with poor people in the Third World, who consume much less and whose conditions of existence are therefore easier to meet, without plundering the stock of fossil fuels. For some of them, even such modest requirements are not met, and they suffer from hunger, i.e. a lack of energy supply.

Another observation is that Podolinsky, despite the fact that he was concerned about coal reserves, did not distinguish, in his discussion of the energy productivity of human work, whether the energy gained by such work would come from renewable or non-renewable sources. His examples are drawn from French agriculture, which at his time still used mainly renewable sources, and he was quite able to distinguish in principle between the energy stock in coal and the flow of energy from agricultural crops, or from forests and pastures. According to his definition, coal miners should perhaps not be classified among those who do 'useful' or 'productive' work, since their activity does not in fact increase but, on the contrary, decreases 'the accumulation of energy on the Earth'.

It must be said, in conclusion, that Podolinsky put forward in a correct way the basic proposition that human life depends on how the flow of solar energy is used. He also questioned how 'production' and 'value' should be measured. He clearly attempted to make the labour theory of value compatible with an energy theory of value, and he was quite conscious of the implications that his ecological, thermodynamic analysis had for economics. So, he also discussed some 'statements by three well-known economists'. Quesnay had said that 'labour is unproductive'; Adam Smith had said that 'only labour is productive'; and Say had said that 'labour is productive, natural forces are productive and capitals are productive' (p. 455). Although his understanding of the role of vegetable life in converting solar energy into food and other human necessities could have led him towards a reformulation of the Physiocrats' position, he thought rather that he had reconciled Quesnay and Smith (or Smith according to his interpretation, since Smith did not have only a labour theory of value [*Dobb*, 1973,]), by means of his finding that the energy productivity of nature increases through human work. His conclusion was that the energy viewpoint was compatible with the view that labour creates value. The field was left open for a study of how work increases the energy supply (and from which sources) and also for a study of how both work and the energy fruits of this work are shared among humanity. The challenge was not taken up by the Marxists (nor by other economists or social scientists), until much later, if we leave aside some isolated pioneers.[15] It is obvious that modern energy analysis has not originated among Marxist economists, but rather among biologists and ecologists.

ENGELS' COMMENTS ON PODOLINSKY

Let us now see Engels' reaction to Podolinsky's paper, which ends with a short section interestingly entitled *Einheit der Kraft und Volkswirtschaft,* which could be translated as 'The Unity of Energetics and Economics'; but which contains a not very illuminating excursus where Podolinsky tried to correlate modes of production (slavery, serfdom, capitalism) and the 'accumulation' of energy through work, the main point being how the proportion of productive workers (in his definition) in such systems is quite different. When he deals with capitalism he deviates from his consistent energetic viewpoint, and he says: 'Instead of increasing the accumulation of energy on Earth, machines often intensify the already existing useless dispersion of the labour force, since a part of the proletariat is taken off production because of overproduction' (p. 457).

Engels did not pay much attention to this last section, and went straight into the heart of the article.[16] It was not the first time he had read about the Second Law and the concept of 'entropy'. He did not refer to such basic principles in his letters to Marx. What he did was to summarise Podolinsky's energy accounts for Marx, and then went on to deny that one could draw any interesting economic conclusions from energy accounting. He thought, moreover, that an industrial economy could not be analysed in energy terms. He was uninterested in Podolinsky's attempts to redefine the labour theory of value, and he did not perceive that Podolinsky was in fact very near providing a physical, empirically based definition of 'productive forces'.

In his letters to Marx (of 19 and 22 December 1882, over two-and-a-half years after Podolinsky had written to Marx), Engels refers to the Italian version of Podolinsky's article.[17] At the beginning of his first letter, Engels asserts that Podolinsky's true finding is that human work is able to keep solar energy longer on earth than would be the case without it, but that all the economic conclusions derived by Podolinsky from this fact are wrong. He then repeats Podolinsky's argument, that the daily food energy consumed by a man, which Engels sets, as an example, at 10,000 *Wärmeeinheiten*,[18] transforms itself into physical work, but much energy is lost on the way: physical work is not equivalent to the food energy intake, it is much less. This physical work will become economic work if it achieves an additional fixation of solar energy. Engels understood quite well both of Podolinsky's concepts, i.e. the 'economic coefficient' (the efficiency of man as a thermal engine) and the 'energy productivity' of human work. Engels then proceeded to show his conception of economic growth, shared by most economists of Marxist and non-Marxist persuasion, for he wrote: 'Whether the new kilocalories *(Wärmeeinheinten)* fixed by the expenditure of the 10,000 kcal. *(Wärmeeinheiten)* of the daily food, will amount to 5,000, 10,000, 20,000 or one million, this depends only on the degree of development of the means of production'. Such figures were, of course, not given by Engels as reasoned estimates. But we think it would be fair to infer that (given adequate relations of production) he saw no limits to the amount of energy that could be harnessed by the work of man.

Perhaps it is of interest to consider that the figure of one million kcal. is roughly equivalent to the annual food intake of one person, and therefore Engels was saying that with one day's work one could get one year's food, if the means of production were developed enough. This is indeed, coincidentally, the kind of result that 'modern' agriculture achieves [*Pimentel,* 1979] [*Leach,* 1976] [*Naredo,* 1980] with ratios of energy output/human energy input in the region of 2,000 to 3,000. This can be compared to the ratios in traditional agriculture ([*Rappaport,* 1968], [*Thomas,* 1976], [*Naredo,* 1980] and also the studies on Mexico and China cited by Pimentel and Leach) of about 10 to 60. If we take again Podolinsky's figures for wheat growing in France, with an output of 800 kgs/ha. and some 25 days of work per hectare (and assuming horses to feed on straw and pastures on unused land, and not giving straw any other value), the ratio of caloric output to human caloric input is about 250.[19] In these examples — except in 'modern' agriculture — human caloric input is the only input that counts, since draft animals (where they exist) feed on waste or on fallow land, and we can take fertiliser to be recycled organic fertiliser. In 'modern' agriculture, with many inputs from outside the farm, though the ratio of caloric output to human caloric input is very high, the ratio of caloric output to total caloric input is much lower than in traditional agriculture. A North-American diet, taking into account fertiliser, oil for enginers, pesticides, etc. and also the energy costs of distribution through supermarkets to homes requires ten calories for each calorie delivered at table. The optimistic picture drawn by Engels lacks substance for the world in general though it would be appropriate enough for the countries able to draw upon an energy subsidy from oil. But as Pimentel and Leach have shown, the agricultural methods and the diets (based largely on meat) of North Atlantic countries cannot be extended to the world at large.

Of course, oil workers, or workers at nuclear power stations (also, workers at hydroelectric works) would show ratios of energy output to direct human energy input which are extremely high[20]. Such types of work did not exist in Engels' time, but coal mining certainly did, and he refers to it: 'Podolinsky has completely forgotten that a man who works does not only incorporate *actual* solar heat, he is rather a great squanderer of *past* solar heat. How we squander energy reserves, coal, minerals, forests and so on, you know better than I do'. It is not true that Podolinsky had forgotten about this — but this does not matter. What really matters is that Engels believed, at the same time, that the 'development of the means of production' would be the cause of (unlimited?) increase in energy supply.

Are we then to measure the 'development of the means of production' by the ratios energy output/human energy input achieved? This was indeed implicit in Podolinsky's approach, but Engels refused to take this line, for he went on to deny that energy analysis was applicable to an industrial economy.

The calculus of energy ratios and energy costs was only possible in the most primitive sectors of production, he wrote, such as hunting, fishing, stock-farming, and agriculture. In agriculture such calculus was already very difficult because one should include in it the energy value of fertilisers and other auxiliary means — this was a very perceptive comment. And if one considered industry, all such calculus had to stop.[21]

Value was given by labour, and Engels thought that in industry there was no way of translating such economic categories into physical quantities. Engels wrote: 'The energy value, according to their cost of production, of a hammer, a screw, a needle, is a quantity which cannot be calculated'[22]. Whatever the practical difficulties of such a calculus, this is what is done in energy accounting. Not only the energy analysis of industrial processes, but also that of 'modern' agriculture would be impossible if the energy worth of machines, pesticides, fertilisers, etc. could not be calculated.[23] But Engels had a prejudice against this: 'In my view,' he wrote, 'the wish to express economic relations in physical measures is quite impossible'. All that Podolinsky had shown was the old story that all industrial producers have to live from the products of agriculture, stock-farming, hunting and fishing — this well known fact 'could, if one so liked, be translated into the language of physics, but little would be gained from this'. This is how he ends his second letter to Marx, and perhaps many economists would have agreed with him until recently. Agriculture feeds the towns, and greater agricultural productivity (because of 'technical progress', 'growth of productive capacity', 'development of means of production', expansion of 'productive forces', and so on, including 'mechanisation', and 'chemicalisation') will allow greater industrial expansion, and greater incomes for those peasants or land workers still left behind. Each land worker would be able to feed ten, twenty, fifty, one hundred town dwellers. This was taught by economics (with the sociological corollary that small scale or, rather, labour intensive agriculture, was a left-over from the past). But when the facts are translated into the language of physics *(ins Physikalische übersetzen,* as Engels wrote), what in economic language is called 'greater productivity' should clearly be called 'smaller productivity'. An understanding of the real sources of growth, and also, perhaps, of the limits to growth, is gained by this. The same applies to industry. Greater 'productivity' in economics is greater 'destructivity' of the stock of fossil fuels, in energy analysis.

CONCLUSION

Podolinsky was well intentioned but wrong, according to Engels, because he had mixed physics and economics. Engels meant, we think, that Marxism already had a theory of value which did not need any support from physics, as Podolinsky had sought to provide. Things had value because they were created by labour, and this value was greater than the labour cost, since labour was sold at its reproduction cost. The things that composed production, though they were heterogeneous, could be summed up by using their values — and not, certainly, by using their energy costs, or energy content. And 'production' would increase according to the development of 'productive forces', which capitalism would in due course be unable to increase further, but that socialism would increase in such a way that at the end distribution according to need would be possible, after a period of distribution according to the quantity and quality of work. There is no need to quote the lyrical passage from Marx in 1875, in the *Critique of the Gotha Programme*, about the growth in *Produktivkräfte*. A rigorous materialist analysis (in energy terms, and also in terms of material resources) was then lacking, and has been lacking since.[24]

The alternative is not to adopt an energy theory of value (although some people have proposed this). Nor is it to fall back on a theory of values = prices, since prices do not reflect energy costs now, nor can they reflect energy availability in time since this is not known.[25] Besides, prices do reflect a very unequal distribution of income and therefore to guide production by prices means to accept this unequal distribution. The alternative is, perhaps, to do without a general theory of value. This might not allow the world economy to be run in such a way that it produces the use values that people need, while at the same time destroying little non-renewable energy and sharing more equitably the burden of work. But at least it might permit people to think along such lines without feelings of guilt about their lack of economic (or chrematistic) rationality.

Marxism, by refusing to tackle energy problems, has been able to keep alive a vision of future unlimited abundance. In the meantime, in the so-called socialist countries, distribution was to be according to the so-called *Leistungsprinzip* (for which one would need a theory, which does not exist, of why some types of work are more valuable in quantity and quality than other types of work). We have little to add to the recent discussions on such questions (by Harich and others) except perhaps to recall the remark by Kropotkin (already in 1889, in *The Wage System*) that, while inequality in capitalism lacked legitimacy, some Marxists seemed bent upon giving a positive sanction to inequality after the revolution in the name of revolutionary principles. Marxists have found it difficult to discard this vision of abundance. Even Havemann [*Morgen*, 1980] does so — though that Marxists should write Utopias is a welcome development in the direction of a more scientific socialism.

Energy analysis and, in general, ecological analysis, has been alien to Marxism, and this paper has been an attempt to trace the origins of this divorce. One could perhaps say optimistically that Engels understood the principles of energy accounting in agriculture, though not in industry, that he also clearly understood the difference between spending the energy stock in coal and using the flow of solar energy, and that he was far in advance of many later economists, sociologists and historians in his knowledge and interest in science. But it must be said that Marx and Engels had the opportunity of reading one of the first efforts at ecological Marxism, and that they did not use it profitably. It was of course very late in their lives (Engels died in 1895). It should have been left to later Marxists to modify Marxism in the light of energy analysis, but there have been epistemological obstacles (the use of categories from Political Economy) and ideological obstacles (the vision of a two-stage transition to communist equality) to such an undertaking.

As a final footnote, we would remark on how the memory of Podolinsky's contribution was lost.[26] Thus, the anthroplogist Leslie White, who combined a Marxist and an energy approach to the study of the evolution of culture, took his clues not from Podolinsky but from the later German chemist and philosopher, a Nobel Prize winner, Wilhelm Ostwald. Ostwald himself was unaware of Podolinsky's article, and apparently uninterested in Marxism — he was a member of the Monistenbund, founded by Haeckel, a convinced 'materialist' (or, rather, 'energeticist').[27] We have already cited Frederick Soddy, also a Nobel Prize winner, who, we think, drew upon Ostwald, and who was indeed interested in Marxism — but he was also unaware of Podolinsky. His main contribution was the idea that 'capital' meant in one sense accumulation of means of production, and in another sense debt to the holders of shares and bonds; since in the first, 'real' sense, capital was in fact not an accumulation of means of production but rather the result of energy already spent, the world was increasing its debt towards the owners of a stock of energy which no longer existed. The debt would eventually be defaulted. He was hopeful, however, about radioactive energy, which was his field of study as a natural scientist.[28] Marxists who have recently noticed Engels' position on the Second Law of Thermodynamics do not refer to Podolinsky or to Engels' comments on him.[29] Equally, recent Marxist writing on the controversy on limits to growth keeps silent on Podolinsky and Engels, obviously not on purpose but because the memory of this early debate had been lost.[30] Not is there a mention of Podolinsky's article and Engels' reaction to it in Alfred Schmidt.[31]

Apart from Leslie White [1943], other ecological anthroplogists who have considered themselves to be Marxists (as indeed Podolinsky himself did), for instance Richard Lee [1979], have not been aware of this early contribution. It is remarkable that Marx and Engels knew that one could study the energy flows in foraging and agricultural societies (though they did not think this would be very useful) nearly one hundred years before Lee's book.

NOTES

1. This is a new version of the second part of an article published in Spanish in 1979 [*Martinez-Alier and Naredo*, 1979] and in Catalan in 1980 [*Martinez-Alier and Naredo*, 1980]. We first became aware of Engels' letters to Marx on Podolinsky in Marx and Engels, *Lettres sur les sciences de la nature*, Editions sociales, Paris, 1973. We thank Verena Stolcke and Jordi Brandts for their help with the German language and Nicholas Georgescu-Roegen and Klaus Schlüpmann for comments.

2. As Georgescu-Roegen has often said, one finds in introductory economics textbooks a diagram depicting the economy in which the flows going from production to consumption and from consumers to production (as the services of productive factors) go round as a free pendulum.

3. In heterodox economics textbooks (such as Joan Robinson and John Eatwell, *An Introduction to Modern Economics*) the diagram referred to above, is lacking, but they do not always show an awareness of the physical facts of life.

4. *Menschliche Arbeit und Einheit der Kraft*, but he used *Kraft* (force) interchangeably with *Energie*, as Meyer, Helmholts had done. The article appeared in Vol. I of *Die Neue Zeit*, pp. 413-24 and 449-57. We have checked in the following volumes of *Die Neue Zeit* whether there was a reaction to Podolinsky's article. There was none.

5. These two short letters, rather formal and uninformative, are at the Institute of Social History, Amsterdam. We are grateful to Rudolf de Jong and to the Institute for photocopies of them (though we are not allowed to publish them in full). There are no letters from Marx to Podolinsky in the published correspondence (in MEW) or in Amsterdam. Marx certainly replied to Podolinsky's first letter but, from Podolinsky's answer, Marx's letter appears to have been a kind acknowledgement that he had received the paper (he also showed interest in Podolinsky's health, which was bad).

6. Mainz, 1857 (many editions). Moleschott had already published *Lehre der Nahrungsmittel* (on nutrition), in 1850. He was born in 1822 in the Netherlands, and died in Rome in 1893, was a university professor, and a militant 'materialist'.

7. Nor of material flows, since 'matter also matters', as Georgescu-Roegen has recently pointed out. For instance, soil lost through erosion and which is now at the bottom of the Oceans could be perhaps, recycled. However, the cost in energy and other materials, and the time necessary for complete recycling would be virtually infinite.

8. For this kind of approach, which is of great interest but which is alien to the energy analysis of the economy, see for instance Mohssen Massarrat, ' "Energiekrise" oder die Krise des Kapitalismus', *Probleme des Klassenkampfes* (Prokla), n°11/12, Berlin, 1974, or in English his article 'The Energy Crisis: The Struggle for the Redistribution of Surplus Profit from Oil', in P. Nore and T. Turner, *Oil and Class Struggle*, Zed Press, London, 1980. See also Massarrat, *Weltenergieproduktion und die Neuordnung der kapitalistischen Weltwirtschaft*, Campus Verlag, 1980.

9. Among such transformations Podolinsky included the work of engines moved directly by solar energy, 'such as the solar machine of M. Mouchot, now widely known'. He does not footnote this comment, but A. Mouchot wrote a book, *La chaleur solaire et ses aplications industriels*, Gauthier-Villars, Paris, 1869.

10. Engels wrote that in English there was a difference between 'work' (as used in physics) and 'labour' (as used in economics), that in German the word *Arbeit* had both meanings, and that the German word *Werk* could be used (MEW, Vol. 20, p. 383).

11. We shall leave aside Podolinsky's comments on 'mental' energy, which are in the nature of a digression and which did not (quite rightly, we think) merit Engels' attention.

12. In the following issue of *Die Neue Zeit*, which happened to carry Marx's obituary as well.

13. He here uses money values, leaving aside his *energetische Weltanschauung* (not our own term, but the title of a book by W. Schnenen, of 1908, which is a comment on W. Ostwald's doctrines).

14. In German, *die Bedingungen des menschlichen Lebens*, and *(die) ewige Naturbedingung des menschlichen Lebens (Kapital*, Vol. I, MEW, Vol. 23, p. 1980). Marx also used *die Naturbedingung der menschlichen Existenz*, in *Zur Kritik der politischen Okonomie*, cit. by Schmidt, op. cit., p. 92 (also in the *Grundrisse*, Schmidt, p. 80). Schmidt concludes that this general problem was not a Marxist problem, in the sense that Marx wanted to show rather how the conditions of existence adopted different forms in history; for instance, direct appropriation from Nature *(produktive Konsumption*, Schmidt, p. 69) in primitive society, consumption of commodities bought with wages earned by selling labour force, in capitalism. But to determine the conditions of human existence, which in Podolinsky's view meant to determine which energy flows were available to man and how they were used and modified by man, is a problem which ought to be connected to the Marxist concept of 'productive forces', even though *Produktivkräfte* is often used by Marxists with no reference to the meaning of *Kraft* as force or energy, in the physical sense.

15. Mainly some physicists and chemists, and later some ecological anthropologists, and, even later, a very few economic historians of a decidedly non-Marxist bent, such as Carlo Cipolla, in his *Economic History of World Population*.

16. In letters to Marx published in MEW, Dietz Verlag, Berlin, Vol. 35, 1967.

17. Which appeared in *La Plebe*, in 1881 and which is substantially the same one as that *in Die Neue Zeit*. We do not know either in which language Podolinsky first wrote his article. It was probably in German or in French. In his letters to Marx he refers to work he is writing for the *Revue socialiste*, but we have not checked whether this was published. Perhaps Marx still had around the paper that Podolinsky had sent to him in 1880. In any case, it is clear from Engels' letters that Marx had asked him for his views on Podolinsky, and it is obvious that Engels' comments are addressed to the article published in *Die Neue Zeit*, which is most probably the same one that Podolinsky sent to Marx in 1880. *Die Neue Zeit* was edited by Karl Kautsky, the author of *Die Agrarfrage*.

18. Which we take to be kcal., and which would be too large a quantity, but this is a minor point.

19. There is a wide range of variation in the ratios of energy output/human energy input reported for traditional agriculture. Some of the lowest we have seen are those in [*Thomas*, 1976] for tubers in the Andes, under 10. The ratio of 250 for French wheat growing, according to Podolinsky, is in fact reduced to around 50, if human caloric input is measured as it is usually done. There are in principle three ways of measuring human caloric input. Let us assume a man 1) eats 3,000 kcal. a day 2) works eight hours, during which he spends 2,000 kcal. (he spends the other 1,000 kcal. while sleeping and resting) 3) the work done during the eight hours is, in energy terms, equivalent to, say, 400 kcal. Podolinsky measured human energy input as 3), while Rappaport, Thomas, etc. measure it as 2). To measure it as 1) would, on the other hand, be appropriate for oxen or horses (though Podolinsky did not use this measure — he also used the energy equivalent of work done), since it could be argued that the only purpose of draft animals in life is work. For tractors, 1) and 2) would be the same ('food' would be the energy in oil), and 3) would be a fraction, which would depend on the efficiency of the tractor.

20. The question of the ratio of energy output to total energy input in nuclear power stations, if one includes in the input all that should be included, is altogether a different matter. Besides, the military implications (to put it mildly), the psychological repercussions of living under fear near a nuclear station, etc. are not amenable to energy analysis.

21. *Bei der Industrie hört vollends alle Berechnung auf: die dem Produkt hinzugefügte Arbeit läßt sich meist gar nicht in WE ausdrücken.*

22. *Der Energiewert, den Produktionskosten nach, eines Hammers, einer Schraube, einer Nähnadel ist eine unmögliche Größe.*

23. See Leach or Pimentel for references.

24. Despite the fact that Marx had also written in the *Critique of the Gotha Programme* that it was not only Labour that was a source of use values, but also Nature, and that Labour itself was a manifestation of a natural force.

25. Nor do they reflect material 'entropy', to use again Georgescu-Roegen's idea.

26. Podolinsky seems to have died in the early 1890s. The editors of *Die Neue Zeit* explained in a footnote to his article that because of a nervous illness Podolinsky could not write further on the subject, as he had planned to do. In MEW (Vol. 35, p. 577), the date of his death is given as 1891. That he was ill and could no longer work is confirmed in the remarks of Lisa Podolinsky, Podolinsky's son's second wife, in a book by Podolinsky's son (also Sergej), edited by Arnold Harttung, *Russland vor der Revolution* (Berlin Verlag, Berlin, 1971), a book of memoirs on the peasantry and Stolypin's reforms. Stolypin was a cousin of the author, and so a nephew of Podolinsky Sr. According to Lisa Podolinsky, Sergei Podolinsky was in 1879 a young teacher in the Faculty of Medicine in Montpellier. He came from a family of landowners and high civil servants in Russia. His mother's maiden name was Choiseul-Gouffier. His wife (Marie Andrejew, daughter of the grandmarshall Poltawa) was involved in the assassination of Alexander II, and their son Sergej was brought up in humble surroundings in London, after being kidnapped from Montpellier. Such tragic events apparently broke Podolinsky's spirit. He went back to Russia. Lisa Podolinsky does not refer to Podolinsky's article in *La Plebe* and in *Die Neue Zeit* nor to his contact with Marx — her husband, Podolinsky's son, was born in 1879, and obviously there was no reason why he should have known.

27. He was the author of *Energetische Grundlagen der Kulturwissenschaft* (1909), *Der energetische Imperative* (1912), *Die Philosophie der Werte* (1913). Ostwald explained his views for the first time in 1895, as he himself says in the preface to *Der energetische Imperativ.* He refers to Georg Helm and to Ernest Solvay as cofounders of sociological energetics. We do not know what Solvay, the industrialist, wrote, while Helm had written books on energy in 1887 and 1898. Ostwald's 'energetic imperative', which in his view was a moral imperative, he formulated thus: *Vergeude keine Energie, verwerte sie!* — do not waste any energy, use it profitably!

28. *Cartesian economics* (1922) were originally lectures to Birkbeck College and LSE students, in London. Soddy did not, therefore, make the distinction between natural resources and (reproducible) capital, common to conventional and Marxist economics.

29. See for instance the curious remarks by the editors of *Dialectics of Nature* (MEW, Vol. 20, Dietz Verlag, Berlin, 1972, pp. xx and xxi) or the more intelligent comment of Robert Havemann, in *Dialektik ohne Dogma*, on Engels and the Second Law.

30. See for instance, W. Harich, *Kommunismus ohne Wachstum.*

31. The 3rd. edition of *Der Begriff der Natur in der Lehre von Marx* with a new postscript, is of 1978. Nor is Podolinsky mentioned in Howard L. Parsons [1977].

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