Energy and Economic Theory

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The main part of this paper[1] criticises the onesidedness of the economist's approach to energy policy and compares it to that of the scientist (section 4 and 5); sections 1 - 3 are meant as an introduction for the non specialist reader.

I. The Flow of Energy

It is difficult to find important contributions by economists to the debate about the energy question. In fact, it is not clear at first sight why energy should be a concept used in economics at all. Before the industrial revolution and even for some time afterwards, different forms of primary energy corresponded uniquely to different forms of useful energy. Water power was used for grinding corn, the burning of wood for heating, horses for transportation, etc.... The perception of the equivalence of different forms of energy was a consequence of the invention and application of the steam engine. The technological development has now led to a situation where almost all forms of energy are converted into each other for practical purposes. As the theoretical equivalence of different forms of energy tends to become a practical reality, energy in general, and not just different forms of primary energy, becomes an object of economic consideration.

The significance of this turning point in the history of the development of the forces of production was well perceived by *Engels* who wrote in 1883[2]:

"... the event is extremely revolutionary. The steam engine taught us to transform heat in mechanical movement, but the use of electricity will enable us to transform *all* forms of energy: heat, mechanical movement, electricity, magnetism, light into each other and back, and to use them in industry. The circle has been closed.... the latest invention by Deprez according to which electrical currents of very high tension may be transmitted by means of a simple telegraph wire at relatively small

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[1] Modified and partly updated version of a paper presented to the 'Round Table' in Cambridge, February 1976.

[2] In a letter to E. Bernstein referring to an experiment shown in Munich 1882. *Marx-Engels* Werke (1967, pp. 444 - 445, my translation).

losses up to undreamed of distances ... is still in its infancy, (but it) will liberate industry for good from its local bonds, will make possible the use of even the most distant waterpower, and must of necessity, even if it will initially benefit mainly the towns, eventually become the most powerful lever for the removal of the opposition between town and country."

The flow of energy in a modern industrial society is interlocked in a complicated fashion. Different flows of energy may represent different 'energy-commodities'; the monetary costs of conversion govern the costs of production of secondary energy and represent the basis for the appraisal of efficiency from the economic point of view. But it is also possible to take on the point of view of the scientist in order to verify whether the flows of energy are converted into each other with a maximum degree of physical efficiency or whether the conversion losses, i. e. the amounts of energy which do not reach the consumer, are higher than what is inevitable according to natural law. We are, therefore, approaching a situation where the efficiency of production as an economic process can be measured against its efficiency as a technical process in so far as it involves energy, and this not only at the level of the single producing unit on the one hand or in terms of the allocation of labour in the total economy on the other, but in terms of the global allocation of a new 'factor'; the existence and homogeneity of which had hitherto been either not known or devoid of practical content[3].

Different forms of energy are not strictly equivalent because the qualitative difference between various forms of energy does not allow to transform them into each other without necessary losses in the form of energy which is of lower quality from the point of view of productive application. The best known example is that of the transformation of heat into mechanical energy. The proportion of energy generated in the form of mechanical movement as a percentage of the total amount of energy expended in the form of heat depends on the temperature of the latter and on the temperature of the environment into which the waste heat is released. Similarly the amount of energy radiated in the form of visible light as a percentage of the amount of energy radiated in the form of visible and invisible light is for an incandescent lamp by a natural law the lower the whiter the light is supposed to be.

Economic logic reflects the loss of conservation of energy when conversion losses are almost absent, for if two forms of energy can readily

[3] Compare this with the effects of the introduction of capitalism or state socialism in an underdeveloped country where people have to accept to operate like a "factor", i. e. to work for wages so that an economic equivalence is established between different occupations which may before have been separated by unsurmountable social limits (class, caste, etc.).

be converted into each other the price differential must be small (like for iron in different shapes) so that the theoretical homogeneity of energy appears in practice at once from both points of view: value in use and value in exchange. But if conversion losses are large, industrial conversion always works in one direction only. The two forms of energy are then regarded as different commodities (e. g. primary and secondary energy), and there is no economic mechanism which would differentiate the energy cost of the transformation from other monetary costs associated with it. Hence the discrepancy between economic and physical efficiency of which examples will be given below.

II. Finite Resources and the Flow of Matter

The second law of thermodynamics, the main expression of the inevitability of conversion losses looks anthropomorphic in that it is reminiscent of the human process of production which is generally conceived as impossible without efforts. But it is to be noted that whereas the local applicability of the second law of thermodynamics cannot be denied (for the universe as a whole it is still in dispute), there is — at least broadly speaking — no such thing as material losses in the circulation of matter in the biology of the earth. Even the minerals of the soil which are extracted by plants and transported to the sea by rivers, return to the soil because they are carried by the wind which picks up small drops from ocean waves. There is an increase, if anything, in the amount of matter involved in the undisturbed biological flow. By contrast the flow of energy in the biological system on earth is not circular. The energy derives from the sun, it suffers a multitude of conversions, a small part of it gets embodied in lasting form in chemical substances such as coal, but most of it is radiated back into the universe in the form of low temperature heat. The 'value judgement' implied by the distinction between 'higher' and 'lower' forms of energy has therefore a natural basis in the 'interest' of the biological life, if not of the stellar system, to survive. The analogous distinction between 'useful' forms of matter (recoverable minerals, materials capable of recycling) and 'irrecoverable wastes' has no meaning in the biological systems as a whole as long as it remains in equilibrium with anorganic matter on earth.

The suggestion that the way out of the dilemma caused by the rapid exhaustion of natural resources will have to be based on the recycling of raw materials to the extent that they do not regenerate themselves (like e. g. wood), based on an increasing use of energy from an abundant, inexhaustible source, represents objectively an attempt to integrate industrial production into the biological circular flow although the proposal is hardly ever stated in these terms which make it appear utopian because of the difference (hard to define, but easy to see) between a planned industrial process and an adaptation to an ecological system. The strategy will be difficult to realise in any case even approximately since our industrial processes frequently produce wastes in forms which make the recovery of the raw materials impossible with known technologies, and recycling will, even if feasible, clearly not be a lasting solution as long as energy is primarily produced from fossil fuels. Primary emphasis will thus have to be laid on the saving of finite resources. As long as our energy derives from them, it will be important to reach a maximum degree of efficiency in the use and transformation of energy.

In response to growing social awareness of the potentially disastrous consequences of an exhaustion of vital resources, much has been written by economists to prove that the market can cope with the problem by directing processes of substitution. But in my view it would be better to admit that the logic of capitalism does neither take account of the problems of finite resources, nor that it maximizes the degree of efficiency in the conversion of energy. The classical economists visualized the progress of production in a capitalist society as a circular flow of commodities on an expanding scale where the net product may in part be productively consumed by the workers, in part it appears as a surplus. It was expected that not the productivity of 'capital', let alone energy, but of labour, would grow restlessly. To *A. Smith* and *D. Ricardo* it appeared permissible to sacrifice social justice, artistic or natural beauty to a considerable extent to increase the production of wealth per capita.

This view which had its first theoretical expression in the labour theory of value contrasts with the famous 'one-way avenue' of the neoclassicals leading from primary resources to consumption in a not necessarily growing economy with 'fair' distribution. If we look at the human process of production from a technological point of view, the neoclassicals seem to be right. Primary resources are extracted, their derivatives are ultimately consumed, but in capitalist production most of the matter consumed does not reappear in production, it is obnoxious waste. The classical view therefore represents correctly what capitalism does only as far as the subject matter of economics, i. e. commodity production, is concerned; capitalism works economically as a system reproducing itself on an expanding scale without limit, but the reproduction of materials is taken for granted without being guaranteed in reality. In this, the image of the one-way avenue is unfortunately correct, although it does not yield an adequate analysis of the capitalist process as far as the theory of reproducible capital goods is concerned. The Cambridge critique[4] of neoclassical economics has revived the classical representation

[4] The essence of the "Cambridge"-critique of neoclassical economics consists precisely in the objection that neoclassical economics cannot recon-

of production as a circular flow of commodities in *P. Sraffa*'s theory of prices. It is ironic that so many neoclassicals now hasten to affirm that the task of regulating recycling and substitution can be left entirely to the market although their theory does in spite (or perhaps because) of its inability to explain prices of produced means of production consistently at least allow to state the question in dramatic form of what happens when the exhaustion of the supply of a 'factor' without an economically recoverable substitute appears to be imminent.

According to classical theory there is normally no difference from the point of view of capitalist production between a process transforming raw materials and one extracting them. In the former case differential rent has to be paid for the location of the factory, in the latter for the location and the cost-advantage of the mine. A difference comes in, however, when the exhaustion of a resource is seen to be imminent. In *Ricardo*'s case corn is invariably still grown on the more fertile land when the less fertile has been brought into cultivation. With exhaustible resources by contrast, those with lower costs of production are sometimes exhausted before one moves to the others causing higher costs, provided the technically feasible rate of extraction is sufficiently high for the cheaper mine to allow it. If the extraction of the cheaper mine is retarded *artificially* in order to obtain the rent corresponding to the price deriving from the one which is more expensive, this must be due to a monopoly which, unlike the Ricardian landlords, must control the entire supply of the resource at low cost. The price may be driven up to any extent, if the monopolist controls the total supply of an absolutely indispensable resource[5]. It is much more likely, however, that a substitute

cile the notion of capital as a factor of production, i. e. as one of the entrances of the one-way avenue, supplied by the owners who demand a supply price for their abstinence, and the fact that capital-goods are, as commodities, reproducible and have a cost price such that the rate of profit is uniform in all industries.

[5] Recent work on the theory of exhaustible resources has emphasised the power of the owners of an exhaustible resource in a *competitive* market to let the difference between the price of an exhaustible resource and its cost of production rise at the same rate at which any other asset appreciates by retarding the supply of the commodity correspondingly, i. e. by supplying it so slowly that the capital value of the last unit delivered will exceed its cost of production by an amount corresponding at the same time to the appreciation due to "waiting" and the then ruling supply price of the cheapest substitute. The price $p(t)$ of the commodity at time t equals its given cost of production $c(t)$ plus a rising rental $r(t)$. The present value $k(o)$ of each rental $r(t)$ must be the same for all t from now (time zero) to T (the time when the resource has been exhausted and its price has risen to $p(T)$, the price of the substitute). Hence, the rate of appreciation of $r(t)$ is the rate of interest: $p(t) = c(t) + r(t)$; $r(t) = k(o)\ (1 + i)^t$. T is such that $\sum_{t=0}^{T} q(t) = Q$, the total amount of the resource in question, where $q(t)$ is the amount that can be sold in period t, given the demand conditions then ruling. The difficulty is to determine T simultaneously with the other

exists or that the monopolist controls only part of the resource, i. e. the cheap mines. By artificially retarding their exploitation he enforces the simultaneous use of more expensive mines so that the price is driven up accordingly. The rent is therefore, for the neoclassical paradoxically, defined as differential rent but due to monopolistic power.

Competitive capitalism works therefore (if the classics were right) simply by ignoring that resources are finite, and monopolistic capitalism proceeds arbitrarily (OPEC prices are not totally arbitrary since the costs of potential substitutes act as upper bounds; OPEC countries obtain the differential rent). It follows that control of the use of finite resources will have to be accepted even by those who are otherwise believers in the potentialities of unfettered capitalism. Our raw materials are only to a diminishing extent derived from biological materials capable of self reproduction. Recycling is feasilble in some cases and will be undertaken even under capitalism provided appropriate prices are imposed. But it does not seem to be feasible for a very long time in those cases where the raw material ends up minutely dissipated over the environment like the lead contained in petrol. Processes leading to such "dissipative" squandering of finite resources will have to be replaced in order to approach recycling. Such replacement requires intervention, be it in the form of direct prohibition or of market disincentives.

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magnitudes, but if T is known we have $p(t) = c(t) + [p(T) - c(T)]\,(1 + i)^{t-T}$. An optimum allocation of resources will ensue if the rate of interest prevailing in the asset market corresponds to the social rate of time preference. It is comfortable that we are not asked actually to believe in this price mechanism, since the same authors rush to admit that the social rate of time preference may diverge from the rate of interest, that the relevant forward and contingent commodity markets are missing almost everywhere, and that the price movement of the exhaustible commodity will depend on expectations which are in this case bound to be highly unstable.

Be it because of uncertainty, because the forward markets for unborn generations are difficult to conceive, or even because of fear of expropriation: the facts are that there is no major example of a multitude of owners of an exhaustible resource in near perfect competition who did not rush, like the gold-diggers of California, to mine their commodity as quickly as possible. A speculative holding of stocks which are not too expensive to carry is conceivable but mining will be done at once in order to remove at least the uncertainty about the amount owned, and fast selling is likely in view of the uncertainty about the amount the market will bear in the future and about the possibilities of technical progress in the production of substitutes. It is therefore safe to assume that in the overwhelming majority of cases an exhaustible resource will under competitive conditions be sold at prices close to costs of production (including the profit characteristic for the industry) so that the assertion made above, namely that only a monopolist will be able to retard the extraction of an exhaustible resource significantly, is, although not the only one logically conceivable, the only one reasonably realistic both in view of the facts and of the instability of price expectations. (See *Solow* 1974, pp. 1 - 14 and the book edited by *Pearce* [1975], in particular the contribution by *G. Heal*, p. 118).

A basic point to be noted here, however, is simply that all such new technologies are susceptible of increasing our use of energy. There is no recycling in the case of consumed energy in principle, moreover, there is no consolation in the substitution of technologies employing finite resources[6] if the substitution is based on an increased use of energy derived from exhaustible fossil fuels — and this all the more so since the amount of energy required for the extraction of fossil fuels is increasing as the most easily accessible fields are exhausted and as the extraction of shale-oil etc. is taken up.

If the interpretation above is correct, recycling represents an attempt to retreat towards the biological equilibrium characterized by the transient flow of energy and the circular flow of matter in the biosphere[7].

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[6] It is not worth quoting the widely differing figures about the number of years that various fuels, metals etc. will last, until 'ultimately recoverable reserves' are used up if the rates of growth of consumption are not discussed. If high rates of growth of consumption are assumed many materials will be exhausted very soon, and a little more or less of the resource does not change much the outcome. If one reckons in terms of years of current consumption (as e. g. *Nordhaus* does 1974, pp. 22 - 26) the estimate is relevant only if one assumes some kind of a stationary state, and therefore the end of the industrial system as we now know it (the problem is not confined to capitalism).

The notion of ultimate recoverability is treacherous, but nevertheless important. It cannot be discussed by considering the mining of one commodity in isolation, since the question is how many resources we can devote to it, and what alternatives there are to mining. In theory we can synthesize almost all materials from chemical elements (and nuclear physics even allow to transform different elements into each other), but the cost of such conversions in terms of energy and other materials may be prohibitive in the sense that the economy, considered as an input-output system, may be incapable of reproducing itself with a surplus. From the economic point of view there is no difference between the rise of the physical cost (energy and other inputs) in producing a given commodity by extracting it from poorer and poorer ores, and increased costs from direct recycling, from indirect recycling by recollectin it in the environment where the resource has been dissipated, or from synthesising it on an evermore artificial basis. With sufficient energy, materials, and labour we can grow trees in the desert and recover almost any material from the ocean. It follows that the 'ultimate recoverability' of one commodity from mines depends on the 'ultimate recoverability' of all the others. Ultimate recoverability depends in particular on the amount of energy available — the most basic of all commodities. To consider the recoverability of different resources separately corresponds from a more rigorous point of view to the neoclassical fallacy of the 'one way avenue'.

[7] The chief merit of the works sponsored by the Club of Rome derives from their emphasis on the *interdependence* of the problems of energy, finite resources, pollution and population. Even *Nordhaus* (1974, p. 26) admits that waste heat may endanger the climatic balance of the earth in seventy years or so (run-away melting of the polar ice-caps), and he knows about the greenhouse effect of CO_2, but the climate of tropical regions has already been badly affected by the cutting of the jungles (Brasil and Central Afrika in particular), with reductions of rain and the consequent spreading of the desert (see *Lévi-Strauss* 1975, p. 103 for an account of the early beginnings of this process, and *Dorst* 1970). The critique of *Nordhaus* (1973) and others,

But usually recycling is not meant as an adaptation to the functioning of the ecosystem, but rather technocratically as an addition of some new processes for the recovery of wastes to a given system of industrial production. The ecologists who propagate the use of more labour intensive 'intermediate' technologies mean something else when they claim that no less than a different attitude of man to nature is required (decentralization, use of organic processes where feasible instead of anorganic ones, etc.). As fare as energy is concerned, this would suggest a *decentralized* use of solar sower. But the leading forces in industrialized nations appear to be determined either to go the rather dangerous road of using atomic power which, like the sun, transforms matter into energy, or to use the sun in a very technocratic fashion by building enormous centralized sun power plants.

III. Atomic Power Stations

Any introduction to problems of energy analysis would be incomplete without at least a brief special summary of the by now well known difficulties of assessing the economic and environmental impact of the gigantic plan to solve the energy problem (and indirectly also that of substituting exhaustible resources) by replacing all fossil fuels by nu-

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although justified in most details, fails by returning to the old habit of extrapolating too much from partial considerations (industry but not economy, economy but not society, society but not biology) to appreciate the importance of studying global interdependence. If we find, by considering the sole effect of energy on global temperature, that the climatic limit will be reached in 160 years — a number suggested by *Nordhaus* — chances are that local perturbations such as the extension of the desert may link up with the developing greenhouse effect to create climatic changes for better or for worse much earlier.

[Further research into the CO_2 problem has been made since this was written. It turns out that the climatic effects of cutting the jungle and of increasing the CO_2 content of the atmosphere are also linked directly through the release of CO_2 by burning the jungle. Reafforestation could help to mitigate the impact of the CO_2 problem, but a destroyed tropical jungle recovers fully only in a geological time span. A strategy of probably deceptive simplicity to deal with the CO_2 problem has recently been proposed at a conference (see *Stumm*, 1977, in print) and has been discussed by myself (*Schefold* 1977).

The proposal states very briefly that the CO_2 content of the atmosphere could be kept down to tolerable limits if all oil and natural gas recoverable by conventional means was burnt and supplied most of the world's primary energy within the next fifty years, to be gradually phased out and replaced by a substitute other than coal (nuclear, preferably solar) thereafter. Assuming considerable but not unreasonable savings of energy, the present standard of living of Western Europe should then be on average within reach of the world population to be expected a hundred years from now if demographic trends continue. It was argued at the said conference that this scenario was modest, realistic, and did not require too much social change but each of these assertions is subject to dispute.]

clear energy, which must in the long run mean by means of liquid metal fast breeder reactors (LMFBRs), if fusion does not work.

Atomic power stations raise a number of intricate economic and environmental problems. Cost benefit analyses are dubious concepts but really comprehensive ones have hardly been attempted in this case. Atomic power stations are being introduced at present under the pretext that their low running costs more than compensate for the higher fixed costs of their installation. It is being claimed that atomic power stations are therefore susceptible of becoming cheaper than conventional sources of electricity[8] but it is very questionable whether this is true. It is an indisputable fact that the monetary costs of electricity produced in fossil fuel, hydroelectric, and nuclear power stations is at present in OECD countries of the same order of magnitude, and an alleged trend of nuclear energy to gain a decisive price advantage follows from pessimistic predictions about the cost of fossil fuels and optimistic predictions about the supply of uranium and the development of construction costs. But considering the amount of state interventions in all aspects of energy production one may well ask whether it is not the other way round and whether costs of production have not been adapted so as to make the prices of nuclear and conventional electricity generation comparable through direct subsidies, through socializing of costs (including feeble safety regulations), tolerance of the OPEC price rise, etc. The statement about the cost advantage of nuclear energy is correct, if at all, only if it is based on the prices paid today to the big companies which deliver the station under contracts which usually involve also the delivery of enriched uranium and the collection of the waste products for a specified period, say ten years, at specified prices. But the "true" cost of atomic power stations is not reflected in the payments made between electricity generating boards and the producing firms[9].

First of all the cost of development of power stations cannot be separated from that of military research which made atomic power stations possible. Moreover, atomic power stations have been able to show a book-

[8] On page 190 of the OECD-Report (1974) is a diagram showing that a unit of electricity costs (within the range given by the uncertainty about fuel costs) roughly the same for nuclear reactors and thermal reactors fired by gas, coal, or oil in 1972, while nuclear power is expected to show a neat advantage by 1980.

[9] The payments themselves differ widely. In the report: US Atomic Energy Commission (1974, p. 3) it is shown that nuclear plant cost estimates for plants of 1000-MWe have risen from 140 to 700 millions of dollars in seven years. Only a part of this staggering rise is to be explained by inflation and rises of interest rates, a little is due to changed safety prescriptions, the greater part to unforeseen factors such as the lengthening of the time of construction which is a strange phenomenon, since increasing experience ought to have the contrary effect.

keeping profit for a long time only because they sold plutonium generated in the station for military use to the government[10].

Secondly, there are numerous environmental side effects especially if the cheapest method for cooling is employed, i. e. cooling by means of river water. The warming up of the river deteriorates the quality of biological life in the river[11]. This has to be compensated through better cleaning the polluted waters discharged into the river by cities and industry (which is of course a good thing anyway). Wet cooling towers impair agriculture. The best solution would be to use the waste heat from atomic power stations to heat houses. But this implies a reduction in the efficiency of electricity generation since the waste heat has to be released at higher temperatures than otherwise. It would be a nice exercise to discuss the difference between the "value" of the heat so generated to society and its "cost of production" to the power station. The latter is basically defined as the cost of the electricity not produced because of the higher temperature of the cooling water. Characteristically, only this latter calculation is used in discussions, the former being more complicated since it would have to treat the price of electricity as an unknown. There are plans in mid-European countries to build a centralized system for heating by means of atomic power stations[12]. The execution of these plans would make a significant contribution to the energy problem since space heating takes roughly half the energy consumed, e. g. in Switzerland, but the build-up of the corresponding infrastructure would cause considerable social and political problems because of the congestion of the cities and because the workers would presumably have to be imported.

Thirdly, it is true that the dangers arising from the running of an atomic power station do not appear to be great as far as technical failures or natural hazards are concerned, but the picture alters drastically, if we take into account that civil wars do not seem to be rare these days[13]. Hazards of accidents and nuclear proliferation are further

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[10] This was pointed out already in the book 'Zur Ökonomik und Technik der Atomzeit', ed. by *E. Salin* (1957, p. 35). Anyone who is still apt to believe engineers too easily when they promise that such and such problem will be solved 'soon' is recommended to study this book where, twenty years ago, most of the problems we now have were promised to be solved 'quite soon' and where *W. Heisenberg* cheerfully declared (p. 5) that radioactive waste disposal is no problem at all, since all wastes can be deposited on the ocean floor.

[11] One sets artificial limits for the maximum permissible rise of temperature in relation to the level of pollution of the river.

[12] If the number of houses served by a centralized heating system is sufficiently large, waste heat from an atomic power station can compete with other heating systems, even if the station is 50 km away. See *Sulzer AG* (1975).

[13] Nuclear power stations raise the difficulty of containing local conflicts and keeping them conventional.

increased dramatically when nuclear power stations are delivered to underdeveloped countries with an unreliable, not sufficiently skilled workforce, and with unstable governments.

Fourthly, the question of the disposal of radioactive wastes has not been solved. The present fashion is to advocate deposits in ancient salt mines. But it is not known what will happen in the long run when the tanks containing the wastes will have been destroyed through corrosion. Many accidents are possible before the place for eventual storage has been reached. The extent to which the costs of reprocessing and of final disposal have been socialized is not known[14].

Fifthly, enrichment of the uranium is also beset with difficult problems. It consumes huge amounts of energy and it is an extremely intricate and dangerous process[15]. The extent to which the costs of enrichment (which are very considerable) have been socialized is not known either because of the link with military production.

Finally, it should be stressed that light water reactors work with a relatively well-known degree of reliability (it is not as high as propaganda would have it). But both the known and the estimated reserves of uranium at lower or even at some higher ranges of costs of extraction are limited and will run out soon, if the future energy production is mainly to be based on light water reactors[16]. The use of LMFBRs would economize on the use of natural uranium to such an extent that the problem of exhaustion of reserves could be disregarded. But commercially viable breeders do not exist yet, for the dangers they imply far exceed those of light water reactors[17].

The self assurance with which radical representatives of the atomic lobby sometimes pretend to be able to solve the energy problem is somewhat ironical, for if they mean the problem of exhaustible resources, light water reactors are a less durable solution than coal, and

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[14] Present arrangements are relatively cheap for the producers (see OECD 1972), but costs of waste disposal could rise to any extent, if more perfect waste disposal and more security were to be demanded. (Absolute perfection is impossible.)

[15] The main problems arise in reprocessing of partially used uranium since the fission products comprise several hundred radioactive substances.

[16] 'Reasonably assured resources' *plus* 'estimated additional resources' in the lower price range are estimated to last until 1990 in the OECD Report (1974, p. 193). An estimate for the next higher price range of uranium is given in 'Atomwirtschaft' (Dec. 1973, p. 598) where more optimistic conclusions are drawn on the basis of essentially the same figures.

[17] Since this was written, the French have decided to build the first big breeder 'Superphenix' (more than 1000 MWe). Whether it will be safe and commercially viable remains to be seen. It is revealing that this step has been taken so late considering the fairly large number of experimental breeders that have been built around the world since the second world war.

if they talk about future technologies such as breeders or fusion, one may just as well mention solar power[18]. I do not wish to doubt the integrity of many eminent energy analysts, of other experts and politicians, but there appears to be a lack of sincerity in many *public* discussions. It may partly be due to the fact that the market for atomic power stations is dominated by a few giant firms who must rely on methods characteristic for imperfect competition in order to sell their product. If they are asked e. g. to supply a system for the surveillance of the safety of reactors to a developing country it is natural for them to give away one cheap if it admits as 'safest' the particular type of station which the seller manufactures. It is but normal if they similarly advertise their product in their own country by stressing the long run necessity of nuclear power in general and the merits of their plants in particular. The representatives of the firms are therefore no more to be blamed as individuals than public employees, since both fulfill the role institutionally assigned to them. Our problem is precisely that we are here dealing with questions transcending the responsibility of each of our established institutions for reasons which we shall examine below from a theoretical point of view.

Lest it be thought that I simply dismiss the potential of nuclear power I should like to stress that the growth of the world population coupled with the limitation imposed on an expanded use of fossil fuels by the CO_2 problem and the still utopian character of a vast application of solar power or fusion gives weighty arguments to those who maintain that we should 'keep the nuclear option open'. It is mainly the irreversibility implied in the creation of huge amounts of radioactive waste and the dangers of nuclear proliferation which suggest on the other hand that we should also as long as possible keep open the option of *not* going nuclear on any significant scale. There are profound reasons why no clear cut solution can be found in the traditional political framework to the dilemma thus created.

IV. Some Theoretical Puzzles

Even ten years ago different kinds of useful energy were still produced by means of different sources of primary energy in countries such as Switzerland where fossil fuels for heating and road traffic came from outside and where all electricity was produced by means of hydro power stations. Switzerland has since become the country where the proportion of electricity generated by means of atomic power stations is the highest in the world, but there are still no important thermal power sta-

[18] For a description of some projects see Scientific American, Sept. 1971.

tions which are responsible elsewhere for the interlocked character of the energy sector. In countries such as Great Britain there are hydro power stations, nuclear power stations, and thermal power stations fired with coal, oil, or natural gas. The electricity so produced competes in the most important market for energy — which is heating — with a direct application of fossil fuels for heating purposes and potentially also with waste heat from nuclear power stations.

The interlocked character of the energy generating system leads to numerous quarrels between various government agencies concerned with the production of energy in the United Kingdom and elsewhere, but economists are not of great help, accustomed as they are, to an analysis of the development of an industry in terms of one or several *separate* markets. Here we come to the theoretical questions which are best attacked by considering an example of orthodox analysis.

In his book on "Fuel Policy" *Posner* constructs a marginal cost curve[19] for energy by measuring primary energy (oil, coal, gas, nuclear) in terms of tons of coal equivalent. The oil price is considered as given and oil is in unlimited supply, other resources are to be used to the extent that their marginal cost is inferior to the oil price. This works very well for coal where a nice marginal cost curve can be constructed, but all recoverable North Sea gas appears to be cheaper than oil; its supply is limited by production so that the marginal cost curve is inelastic on the right. Similarly for nuclear power which is subject to increasing returns[20]; its expansion is said to be limited by the capacity of the grid, and very artificial conventions are required to express an additional unit of nuclear electricity in terms of coal equivalents and to calculate its "marginal cost". All these assumptions are necessary in order to incorporate the discussion of the energy supply system in the analysis of one market, held together by electricity generation through which marginal costs of different fuels are supposed to get equalized.

The interesting fact is that every interesting bit of information is outside the diagram of the cost curves which disregards the character of fossil fuels as exhaustible resources. No serious attempt is made to incorporate the social costs of atomic power stations. (There is some discussion of shadow exchange-rates and shadow wages for miners in order to represent specifically British problems, but these special considerations are not related to the subject of this paper.) In particular, no account is being taken of the fact that there is not only the possibility of substitution of different forms of primary energy as inputs to the

[19] *Posner* (1973) p. 329.

[20] US Atomic Energy Commission (1974, p. 53) gives an estimate of the returns to scale involved.

production of electricity but also between different forms of energy for the consumer. We are thus presented with one aggregate supply curve for energy, to be matched by an aggregate demand curve which implies that questions concerning the efficiency of conversion between different flows of energy and alternative ways of supplying energy for the same use to the consumer are not considered.

There are good reasons for this in the history of economic thought. The neoclassical who wants to analyse demand and supply of energy in terms of several Marshallian curves encounters *Sraffa*'s dilemma[21] of 1925. If energy is considered as one factor and is being used for many purposes, one use of energy can be analysed by disregarding the others, but then we have constant costs in that particular energy-using industry. Or energy is used only in a few industries. Then changes of demand in one industry will have repercussions on the costs of energy in others since the scarcity of the factor will then affect each of the uses, and costs in each industry cannot be determined independently of the determination of the share which each industry has in the factor.

Sraffa did not turn to Walrasian economics in order to overcome his famous dilemma since Marshallian economics seemed to be richer in empirical content[22]. But neither is of much help for a critical analysis of an actual situation when there is not only the possibility to use the same "factor energy" for different end uses but when the "factor energy" is itself derived from different resources each of which may be used in different ways.

Consider the following simple example for the interlocked character of the energy producing industries. Houses can efficiently and conveniently be heated by means of gas. It is further possible to produce electricity by means of gas in order to generate light. This is also an efficient use of gas from the point of view of the production of light, but if the electricity so generated is used to produce heat for a house, there is a loss of efficiency because the degree of efficiency for the conversion of gas into electricity is low (40 %, steam engine). The effect will be economically possible only because of price discrimination with electricity for heating being delivered at night at a price corresponding roughly to direct costs and with daily production having to pay for all the overheads[23]. These prices do not express the fact that gas is an exhaustible, particularly precious resource nor do they reflect the loss of efficiency due to the fact that gas is not used for direct heating but by the round-

[21] This is discussed in *Schefold* (1976 a), p. 146.
[22] See *Schefold* (1976 a), p. 148.
[23] A recent discussion of this kind of pricing policy is to be found in *Crew* and *Kleindorfer* (1975) where the welfare theoretical aspect is treated in a sophisticated manner, and where the efficiency aspect is ignored.

about way using electricity as a carrier. The inefficiency exists independently of the price system and is relevant independently of the fact that gas is exhaustible (although the latter consideration lends importance to the former)[24].

The materials employed in atomic power stations are susceptible of early failure because of radiation. For this decisive reason (and also because atomic power stations have relatively low running costs), atomic power stations should, if possible, run continuously at near maximum capacity and whith very little variation of output. Supply may respond to fluctuations in demand by means of special hydrostations which pump water to high reservoirs at periods of low demand and which generate electricity with water flowing down at periods of high demand (such devices operate with a degree of efficiency of about 70 %). Taking this into account we can enlarge our former example:

$$
\begin{array}{lll}
G & \longrightarrow & ED, EN \\
N & \longrightarrow & ED, EN \\
EN & \longrightarrow & ED \\
G & \longrightarrow & H \\
EN & \longrightarrow & H
\end{array}
$$

The letter G denotes gas, ED electricity produced during the day, EN electricity produced during the night, N nuclear fuel, H the heating of an average house at average temperatures. The first arrow denotes the process of electricity production by means of a gas fired power station, the second that by means of a nuclear power station, the third the transformation of electricity produced during the night into electricity produced during the day by means of a hydro station, the fourth the heating of a house by means of gas, the fifth the heating of a house by means of electric storage heaters.

If we assume the prices of gas, nuclear fuel, and of all other inputs to these processes as given, we have five equations for the determination of three prices, i. e. of ED, EN, and H. The system is therefore overdetermined if we assume given profit margins (mark-ups), and underdetermined if the margins are flexible in these five activities which are of course not all commercial in the same sense.

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[24] The overall loss of efficiency because of an important increase in the number of houses equipped with electrical heating is considerable. It has been quantified by *Chapman* (1975, p. 129) where it is shown that the total amount of heat delivered to households in the form of fuel or electricity for heating has risen very little in GB from 1950 - 1975 while the amount of primary fuel (fuel delivered *plus* fuel to produce electricity for heating) has risen by 40 %. (This figure is a little misleading, however, in so far as heating with home-burnt fuels is less efficient than heating with electricity because of ventilation etc. Energy delivered has been better used.)

Let us assume for the sake of argument that the profit margins in the different lines of activity are somehow given. The resulting over-determination of the system disappears, if the inputs and outputs of the system are considered as variables. (The proportion of electricity produced during the day or the night may change. Or it is conceivable that the price of gas depends on the amount demanded.) However, nothing will be gained in this way if constant returns prevail, and it is doubtful in any case whether prices can continue to be compatible with the given mark-ups even if they once had, after some change in the pattern of demand has taken place.

It seems more appropriate to consider the constellation as a disequilibrium where new processes "try to establish themselves" while old prices are still ruling. The atomic power stations may represent the new technology; an adaptation of production to fluctuations of demand between day and night is facilitated by introducing the new type of hydro station (pumping plant). An equalisation of "marginal costs" will then not necessarily take place, since there is no equilibrium.

As we know, economists analyse the profitability of an actual system accepting the data from reality and conclude that the cheapest method is best because that is what welfare economics prescribe on the assumption that there is an equilibrium using the optimum technique. But the actual situation is a disequilibrium characterized by a competition between techniques which does not necessarily show the "optimum" technique, if exhaustible resources are treated like any other commodities, if imperfect competition allows to "manipulate" techniques, and if the presence of joint products renders proper accounting difficult. (Product differentiation and manipulation of what is to be regarded as "cost of production" is a more important feature of imperfect competition than the arbitrariness of administered prices. It is worth noting, nevertheless, that if there is imperfect competition, the arbitrary setting of prices in the presence of joint production will depend on bookkeeping conventions and on what the market will bear, and will not be corrected through competition "behind the backs of the producers".) There is, therefore, taking all in all, no reason to expect that the economic system will maximize the global degree of efficiency of energy conversion in the aggregate. (But there will not be any reason to expect such an efficiency of energy conversion in the economy as a whole even from the neoclassical point of view under the assumption of perfect competition, since competition minimizes monetary costs, not energy used.)

The classical economists did not rashly conclude that competition would lead to the choice of an 'optimum' technique. *Marx* started instead from the assumption of given 'socially necessary techniques' and a given structure of inputs and outputs which would allow to calculate values and prices of production. The concept of 'socially necessary techniques' does not exclude the possibility that the choice of methods of production is modified by imperfect competition and influenced by political and other extra economic forces. OPEC countries have managed to make substitute processes such as the liquefaction of coal 'socially necessary' so that they obtain a differential rent.

The present example shows that even the cautious Marxian procedure runs into difficulties as long as it is not clear which technique (here for the production of energy) is 'socially necessary', let alone which is 'optimal'. It is an open question whether atomic power will make it, and if it does, this will not be due simply to its efficiency in terms of costs. The laws of competitive markets cannot function, since there is a coexistence of techniques which implies a disequilibrium but which cannot simply be reduced to either an effect of substitution or of technical progress. It does not follow that rational planning would be easy, given the complexity of the state of the productive forces. It is, in fact, more difficult to say what 'rational' planning should be than to predict what the actual market is likely to do.

V. Energy Analysis

I have several friends who are scientists and work in the field of energy production. None of them seems very interested in what economists have to say about the subject, and this cannot be much of a surprise if the foregoing analysis is correct. Among scientists and environmentalists a new way of approaching energy problems is rapidly establishing itself. They focus on technical rates of conversion of energy, they consider the flow of energy through an economy as a whole, without respecting the border lines given by the division into different enterprises, and they discuss the environmental impact of various strategies.

A first example of such an approach concerns an analysis of the potential for the saving of energy. By means of methods reminiscent of the labour theory of value they calculate the direct and indirect energy content of various commodities taking into account also the energy which the remains of a consumed commodity are still capable of delivering (e. g. a plastic bottle which can be burned after having been used. A commodity yielding more energy than is used or 'embodied' in its production is a net source of energy and is analogous to labour power.)[25]

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[25] The analogy with the labour-theory of value is invoked in order to warn the reader that energy accounting is not strictly an engineering procedure in that the energy 'prices' are coefficients which show how much energy content is to be *imputed* to each commodity after it has been decided that the energy

They conclude that the saving of energy is no easy task at all, for if people are forced to use e. g. the bicycle instead of the car, they may spend the income saved in making the transition on such items as beer in bottles which contain a great deal of energy because the production of aluminium is very energy-intensive[26].

Energy is thus viewed as the most basic of all commodities. The school of thought may be called "energocracy", because their exaggerations are analogous to those of the physiocrats. Their use of input-output tables for the analysis of energy contents of various commodities has, after aggregation of the entire energy sector by means of measuring energy contents, naturally led them to consider the coefficient showing the amount of energy required as input to produce a unit of energy as output. It appears that this coefficient is bound to rise dramatically for the following reasons: Firstly, the amount of energy consumed in order to obtain a given amount of fossil fuels is — barring unexpected discoveries — bound to increase. Secondly, the build-up of atomic power stations is extremely energy-intensive, not only because they are "big", but also because the enrichment of uranium consumes a great deal of energy, and because reserves of uranium recoverable at little energy cost are dwindling rapidly. Thirdly, a policy very actively pursued in various European countries and in the United States consists in advocating atomic power, not only for the supply required to satisfy the expected increase in demand for electricity, or for the gradual substitution of thermal power stations, but even for the substitution of all other forms of primary energy except hydro-electricity. Light water reactors and soon fast breeder reactors are supposed to produce hydrogen by means of electrolysis at night during periods of low electricity demand, and later also during the day, until all consumption of fossil fuels, except for chemical purposes, is substituted[27]. This project, if undertaken in earnest, might raise the amount of energy required per unit of useful energy for consumption to an intolerable extent. Over-

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contents of the total outputs of commodities in an industry shall be equal to the energy content of the commodities (and labour) used up in the industry *plus* the amount of direct energy consumed. This is not the law of the preservation of energy, since only commodities (not all goods, wastes, etc.) are taken into account; the natural laws come into play only when different forms of direct energy inputs are converted into each other, and when the energy which is potentially contained in a commodity is ascertained. More or less arbitrary definitions have to be adopted when energy contents are to be imputed to joint products and even when rules for conversion are established; the amount of energy which the plastic bottle yields depends on the method of burning it. Energy analysts are therefore less 'emancipated' from economics than some of them think.

[26] See *Mannon* (1975).

[27] *Neuve-Eglise* (1974), pp. 605 - 607; *Michaelis* (1973), p. 458; *Mandel* (1973), p. 19.

production due to an ordinary accelerator effect would be likely. Analytically the situation is in some way analogous to a rise in the organic composition of capital[28], but the economic consequences would probably first show in distribution, and in political haggling about the supply of enriched uranium. The consequence for society would be a constant scarcity of useful energy relative to demand while at the same time there would be a steady increase of waste heat due to the energy used up in building stations, enrichment, beginning conversion of nuclear energy to hydrogen etc. The paradox is summarized in an aphorism due to *Chapman*[29]: "too much energy, but not enough fuel". The waste heat would cause local, if not global, climatic changes such as are already visible near big towns, while the constraints on delivered energy would encourage further expansion.

The enormous difficulties involved in making a transition from one kind of energy production to another have been described, with their social and environmental implication, by *Lovins*[30] who has stressed that the problem of the exhaustion of the fossil fuels now supplying most of our energy appear to the planner not as the lack of energy as such (there is plenty of it available) but as the problem of how to achieve an adequate rate of growth of a new power system which is as dangerous and takes as long a time to be built up as nuclear energy.

The outlook resulting from most projections looks bleak and implies an urgent necessity to change the course of action taken. It must be said, however, that there are also those who predict that a saturation level in energy consumption will automatically be reached soon in advanced countries[31].

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[28] When he realised that capital saving technical progress might halt and reverse the rise of the organic composition of capital which he correctly observed in the 19th century, *K. Marx* resorted in 'Theories of Surplus Value' to the Ricardian argument that 'the insipid law of rent' and the 'inadequate command of man over organic nature' (as opposed to his remarkable command over anorganic nature) would cause the value of raw materials to rise, thus causing the ultimate fall of the general rate of profit. See *Schefold* (1976 b), pp. 806 - 819.

[29] *Chapman's* book (1975) forms a most remarkable antidote to *Posner's*, for while the latter argues exclusively in economic terms without direct reference to physical constraints, *Chapman* is able to show that a continuation of present growth policies (no attempt to reduce demand) defines an almost unique strategy of expansion of the energy sector for GB leaving almost no option for choices between different supply systems, because the *physical* constraints due to the limited availability of primary fuels, the maximum attainable growth rates of the nuclear programme etc. are so important. (The only relevant economic constraint entering into the consideration is the balance-of-payments argument.) Options arise when energy saving is allowed for. *Chapman* very carefully works out two 'scenarios', one moderate and one not so moderate, for the saving of energy by influencing demand through economic incentives and direct interference.

[30] *Lovins* (1974), pp. 14 - 50.

VI. Economic and Political Conclusions

We have seen that there is a slow historical tendency for energy to become a "homogeneous" commodity due to the discovery and the increasing efficiency of transforming various forms of energy into each other. The economic system treats the fossil fuels which supply primary energy as if these resources were not exhaustible. The collective response to the fact that they are has not been an attempt to introduce technologies which reintegrate human production into the biological system. In fact, the consequences of such an attempt do not seem to be compatible with capitalist production or with socialism as we now know it. The technocratic approach has at this time of the day, perhaps inevitably, led to the adoption of nuclear power as the main new source of energy for the coming decades[32]. It is advocated as being cheaper than conventional sources of power and solar power, but both arguments are open to doubt, if social costs are taken into account. An analysis of the complexities of the energy supply system reveals that economic theory, let alone welfare economics, has no say in the matter since the assumptions of conventional economic theory are not fulfilled. Energy planners rely in consequence mainly on arguments derived from scientific analysis. The exclusiveness of their point of view is also open to criticism but it is an urgent task for economists to get acquainted with it, because economists will willy-nilly be drawn into advising about an increasing number of allocative decisions where simple market criteria fail without any clear cut basis for rational planning becoming apparent as a substitute. In this situation the planning process cannot be left to the engineers, because the carrying out of overall planning involves markets and prices; the market must act as an instrument of planning, even where

[31] E. g. *Elbek* and *Korsbech* (1975).

[32] Present policies are perhaps summarized best in the figures of R & D for the production of energy in the U. S. (Fiscal Year 1974, total 853 Mill. $), in percents:

Fossil Fuels	22	Oil	10
		Coal	90
			100
Nuclear	74	Fast Breeders	57
		Fusion	16
		Safety	8
		Radioactive Wastes	1
		Enrichment, other	18
			100
Other Sources of Energy	4	Solar	38
		Geothermal	30
		Other	32
	100		100

From OECD (1975, pp. 104 - 107). Research expenditure for solar energy is currently being increased.

it does not suffice to guide the decisions of allocation. Nor can planning be abandoned, and allocation be left to the market, as pure economists would have it. The complexity of the structure of production leads to a contradictory situation where market and planning must coexist and where there is no rationale for arguing that one should dominate the other.

We are here faced (to use a suggestive Marxian term) with a new kind of 'contradiction between the development of the forces of production and existing social productive relations' which appears, perhaps in different degrees, in all industrial societies also in other economic spheres such as public transportation, urban renewal, social services etc. where it is equally difficult to leave the definition about efficient methods of production, just prices and fair distribution either to the market or to define a plan on the basis of existing simple, rational criteria. This ambiguity is politically dangerous because it undermines public trust in political and economic institutions, which are intrinsically not adapted to the problems they are supposed to solve. It is no wonder that various movements have begun to ask for more direct participation in decision taking or seek to obtain moral and financial support for ventures in areas such as health service or agricultural production which are commercially not viable but which are valuable on different social or environmental criteria. Such movements should in principle be welcomed, although they are at present of no great importance in relation to the magnitude of the problems to whose solution they wish to contribute. A comprehensive and more fundamental new departure is required. It will not get under way as long as it is not recognized that qualitatively new solutions are necessary because we are confronted with new types of problems.

Summary

The efficiency of conversion of different forms of energy into each other and the alternatives of energy policy may be considered from an economic, but also from a technical point of view, and the latter will gain in importance to the extent that the market does not furnish any reliable indicators for the allocation of resources in view of imperfect competition and environmental limitations. The analysis of the energy content of commodities allows to predict the consequences of various strategies to conserve energy and an increase of the amount of primary energy required to produce secondary energy. The contradiction between alternative appraisals are likely to overtax political authorities.

Zusammenfassung

Die Effizienz der Umwandlung verschiedener Energieformen ineinander und damit die Alternativen der Energiepolitik können sowohl unter ökonomischen als auch technischen Gesichtspunkten beurteilt werden, und

der letztere Gesichtspunkt gewinnt in dem Maße an Bedeutung, als der Markt infolge unvollkommener Konkurrenz und angesichts der Umweltproblematik keine zuverlässigen Indikatoren für die Allokation der Ressourcen mehr liefert. Die Analyse des Energiegehalts der Waren gestattet Prognosen über den wahrscheinlichen Erfolg verschiedener Energieerhaltungsstrategien und über ein zu befürchtendes Ansteigen der zur Produktion der Sekundärenergie erforderlichen Primärenergiemenge. Die Widersprüche, die sich nach verschiedenen Einschätzungskriterien ergeben, drohen die politischen Entscheidungsinstanzen zu überfordern.

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