THE WASTE-MINIMISING ECONOMY: A CONSIDERATION OF SET-UP PROBLEMS ON THE PRODUCTION SIDE

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The last eight years have witnessed a steadily growing body of literature concerning a particular branch of welfare economics which emphasises the material and energy balance aspect of the production-consumption cycle.[1]

As long as it was possible to ignore the class of externalities associated with resource depletion and residuals disposal from production and consumption processes, the economic system could well do without this extra complication.

It is now quite evident, however, that increasing economic development with rising industrial and population concentrations is causing certain threshold values of environmental acceptance of man's activities to be surpassed.

As far as production and consumption are concerned the environment has two basic attributes: the ability to supply the resources and the ability to absorb the residuals. The philosophy behind a mass and energy balance approach is the reduction of the production and consumption waste flows of Figure 1a to the

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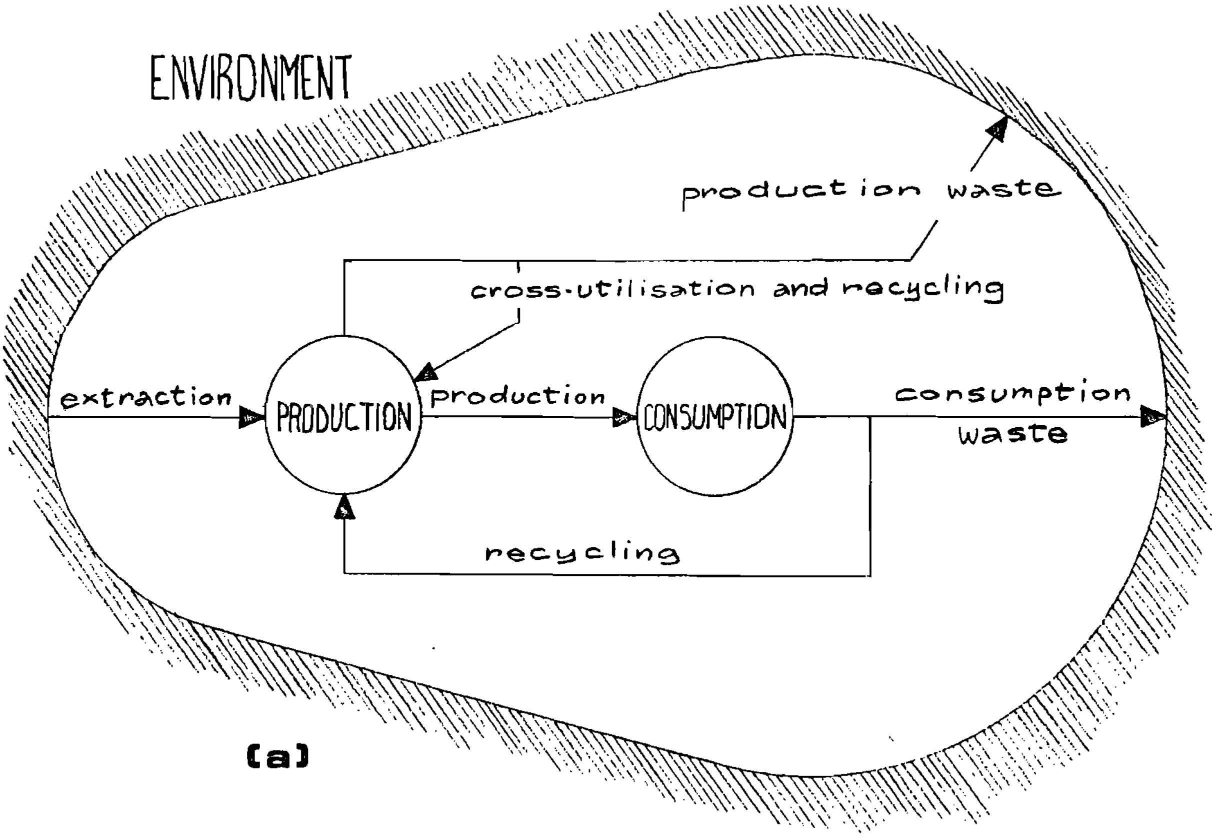
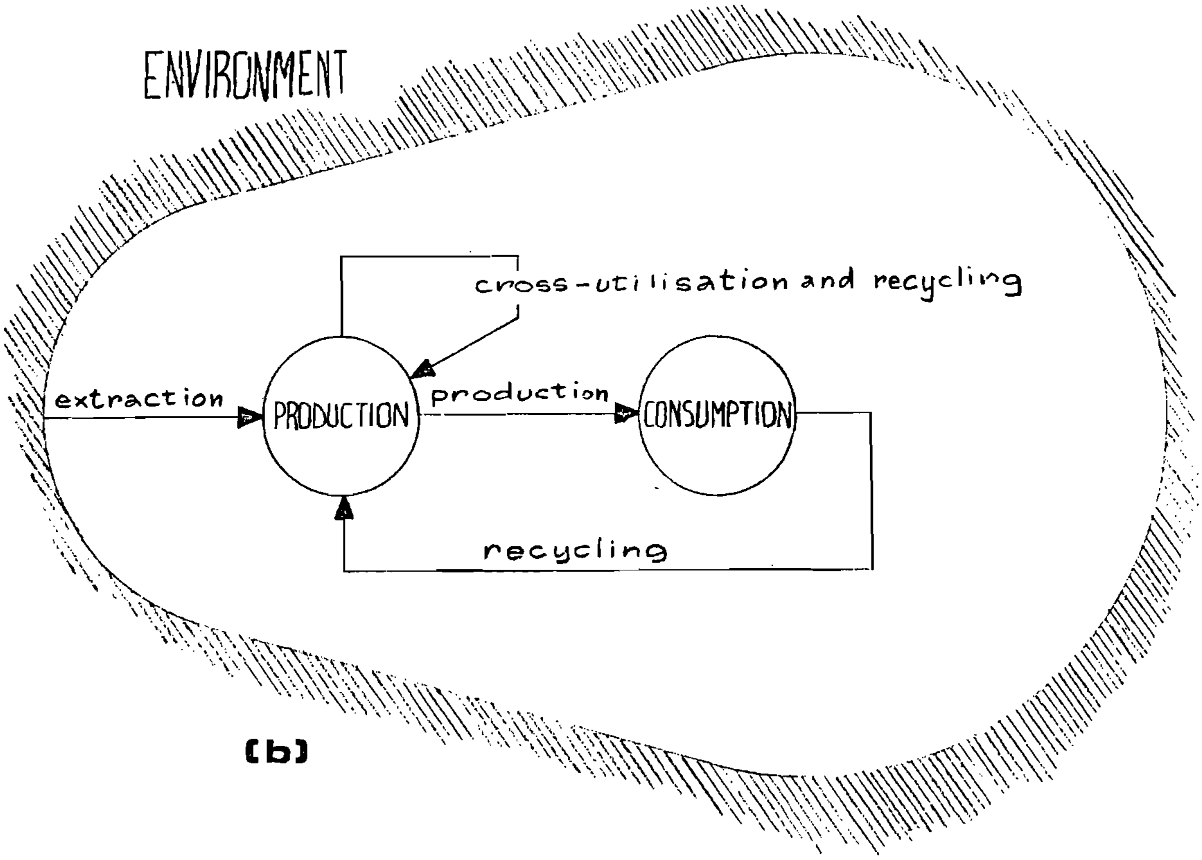
1. See for example R.U. Ayres and A.V. Kneese, Production, Consumption and Externalities, Am. Econ. Rev., 59, 282, (1969); A.V. Kneese, Environmental Pollution: Economics and Policy, Am. Econ. Rev., (Papers Proc.) 61, 153, (1971)


ENVIRONMENT
production waste
cross-utilisation and recycling
extraction
PRODUCTION
production
CONSUMPTION
consumption
waste
recycling

(a)


ENVIRONMENT
cross-utilisation and recycling
extraction
PRODUCTION
production
CONSUMPTION
recycling

(b)

Figure 1

to the greatest extent possible.[2] In the hypothetical limiting case when the waste flows are reduced to zero (Figure 1b), the mass and energy balance is perfect; all materials and energy that enter from the environment, remain in the production-consumption cycle. Such a system has no waste and therefore no pollution. This situation can never be achieved even in theory however, insofar as it contradicts the third law of thermodynamics which is perfectly obeyed because of the essentially chemical and physical nature of the systems involved.

In this paper we shall be concerned principally with the problem of waste-minimisation in the production process.[3] We shall not be concerned with the technological aspect which tends to consider waste-minimisation as an isolated problem relative to a particular process or processes,[4] but rather with the

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2. An important distinction must be made between the low entropy raw-materials extracted from the environment and the high entropy wastes given back. Although matter is not lost, it requires much more energy to retrieve after it has been dispersed into the environment.

3. In reality materials waste is as big a problem if not a bigger problem in the consumption process. To the extent that possible waste materials and energy flows between production and consumption are many and heterogeneous, a decomposition of the total system into production and consumption is only a zero-order approach to the total problem. Any results coming from such a partial systems study can have only limited validity. However, insofar as materials and energy balance are concerned, production and consumption differ basically only in the generally much longer time constants of the consumption process. Bearing this in mind a total systems discussion could be basically an extention of the present one.

4. For example minimising wastes in certain fine chemicals industries by increasing the reaction yields, or energy wastes by improving insulation.

systems aspect which considers waste minimisation relative to an entire system of processes by highlighting on the possible interrelations between all the processes and their wastes.

In recent times there has been much talk of achieving waste minimisation in the production process by means of novel waste-minimising industrial complexes.[5]

A waste-minimising complex is ideally pictured as a collection of production facilities in a localised region with every plant feeding materials and energy that would otherwise have been wasted to the environment, into plants which utilise them in their production process. Cross-feeding is seen as having the basic features of continuity in supply, and reservoirs exist between donor plants and receiver plants, as well as auxiliary feeds to ensure against random breakdown, maintenance shutdown and staggered production set-up discontinuities.

The trouble with such a naive picture is not so much the network flow control problem which is basically solved by using adequately large reservoirs, nor is it the waste recovery problem. Amazing advances have been made in recent years regarding technology of separation of wastes with positive utilities from complex mixtures. This is becoming so efficient as to be in many cases quite

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5. See for example the discussions between IIASA and UNIDO.

competitive on a cost or even profit basis with materials of more traditional origin. Moreover not all of this has been concerned with recovery for internal recycling.(6,7)

The real problem is how does one operatively define and then design such a thing as a waste-minimising industrial complex?

The basic questions to be asked in the simplistic transition indicated in Figure 2 are, how does one decide the identity of the plants and plant processes and how does one decide their capacity? Basically, how does one go from a wasteful polluting configuration to a waste-minimising complex?

But also how does one define minimum? Are we going to minimise as much as possible irrespective of what it might mean for the demand-supply relation and to the whole production spectrum? If we push the minimisation far enough and require that all wastes become by-products in the transition, we could well end up with a supply of products that was very strange indeed, and probably not ideal to support a happy, thriving population!

Production units are characterised by capacities and generally

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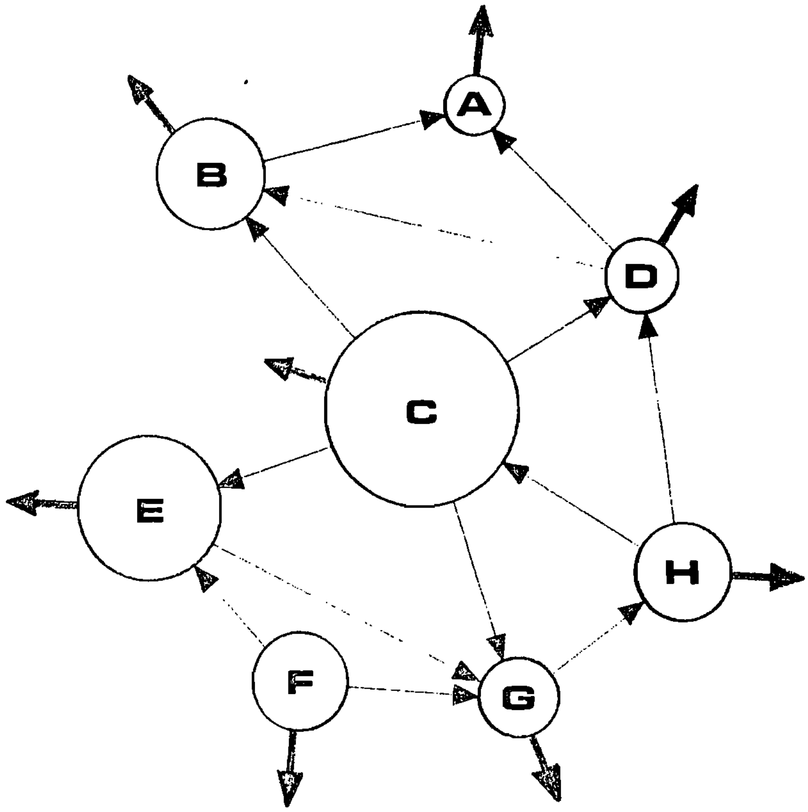
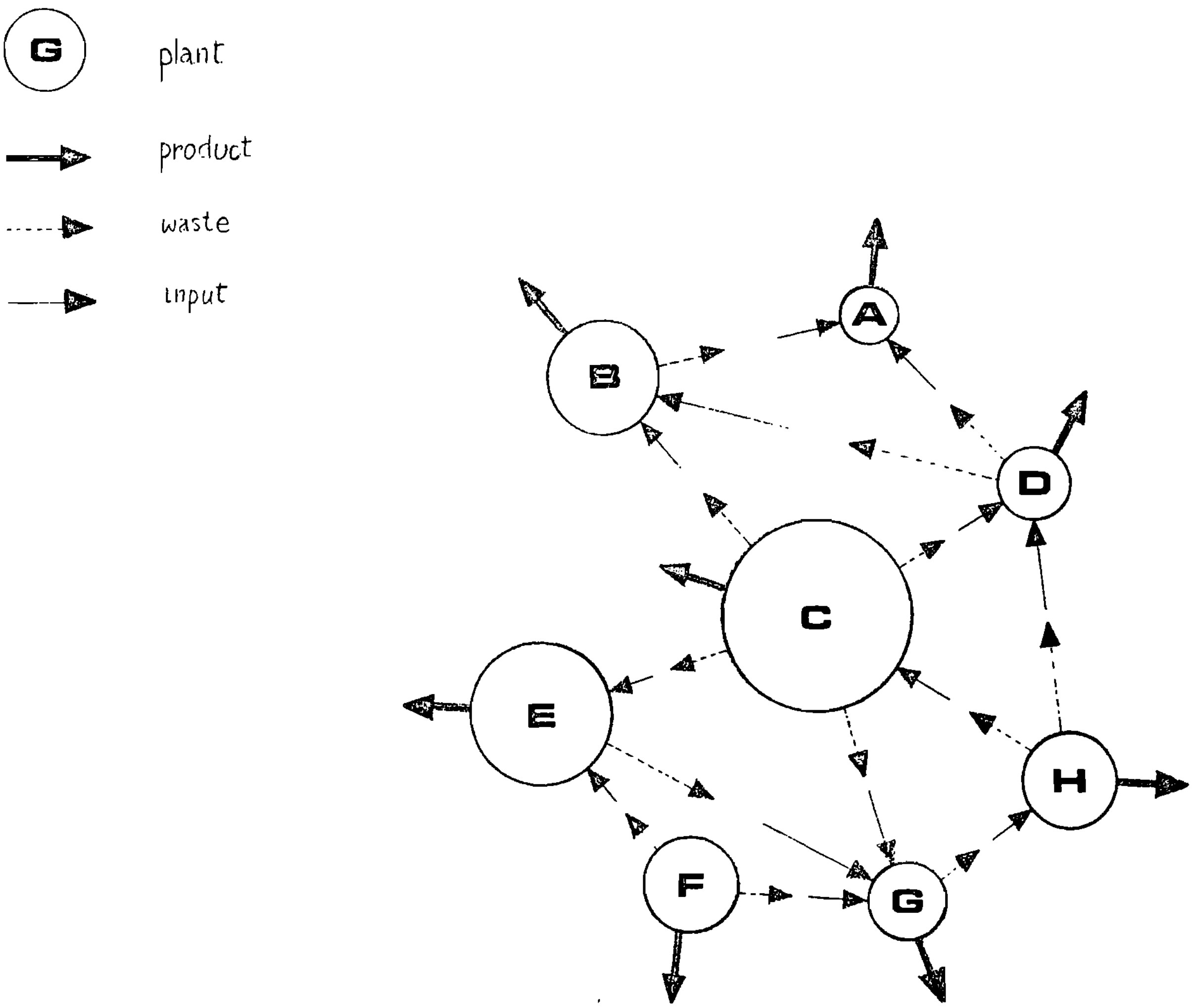
6. P.G. Barnard, A.A. Cochran and L.C. George, Recovery of Metallurgical Values from Industrial Wastes, Proceedings of the Second Mineral Waste Utilisation Symposium, Chicago, March, 1970, p. 8.

7. The Electroplaters are Polishing up, Environmental Science and Technology, 8 (5), 406, (1974).

Figure 2





need to be spread out over large geographic areas simply because consumption capacity tends to be, and relevant[8] market regions are generally smaller than geo-political units. Labour tends to be localised. Is it possible to distribute different capacity plants to satisfy only waste-minimising criteria? Clearly there are more objectives than just waste minimisation.

A very simplistic approach might view the problem as static and proceed by way of a total systems optimisation. The inputs to such a programme would include all known production processes, their utilities requirements, materials inputs and residuals, process production functions as a function of plant capacity, capital and operating costs, utility costs, transportation structure,costs and pollution, location of raw extraction materials, water availability, technological functions like efficiency of steam transmission, capital availability, spatial distribution of labour, permissible labour migration, relevant market regions for all products and intermediates, a demand spectrum, exports and imports and probably many others. The output would include location of the complexes, capital and labour requirements, local plant mix and respective capacities

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8. See L.H. Klaassen <u>Methods of Selcting Industries for Depressed Areas</u>, OECD, Paris, (1967), for an operational definition of "relevant market region".

and by-products coupling between the plants.[9]

The objective function would probably have to be hierarchically structured and such that the waste-minimising objective would not necessarily even occupy the highest level in the hierarchy. This is not to say that waste-minimising objective would necessarily lose priority in such a system but clearly some precedence may need to be given between minimising waste and say unemployment or water consumption if these are antogonistic. The objective function could have a trade-off rather than a hierarchical character if this is deemed more appropriate, or a mixture of the two. A hierarchical structure has the advantage from the programming point of view, that the dimension of the problem can precipitate considerably if a large number of possible alternatives are first filtered out by higher level objectives.

It seems to me that this total approach is doomed to failure. The reasons are many. Not only is it difficult to establish higher-level objectives and their hierarchy in a non-equivocal way or a trade-off structure for that matter, but even if a total objective could be defined satisfactorily, there is

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9. This approach is not necessarily as fanciful as it may sound: see for example, R. Ayres, J. Saxton and M. Stern, Materials-Process-Product Model, International Research and Technology Corporation, July 1974.

practically no hope of a possible client endowed with decision power, the planning agencies for example, ever accepting it, The higher levels include social policy objectives like minimising unemployment, economic policy objectives, regional policy objectives and others, These functions are generally taken care of by the political sector.[10] It would clearly be unrealistic and foolardy to attempt to dispossess the political element in this type of study, the results woul be meaningless even as general guidelines.

In principle a large scale static minimum waste complex has a very long economic life time, much longer than time constants for economic, technological and social change.[11] In view of this a device which simply defines a static best set of industries and by-products flows for a particular local situation generally cannot be considered an acceptable solution. What is needed is a flexible mechanism which can adapt to this frequency of

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10. Some arrangement of this type cannot be avoided especially in the short term if society is to remain adaptive. The political element plays a very convenient role. It is thanks to its taking on the task of solving the higher level objectives that the dimensionality of the problem drops by several orders of magnitude!

11. Since the constituent plants and plant units have different life times, their replacement occurs in a staggered manner. Replacement of a single production unit, however, has in general only a marginal capital cost impact on the rest of the complex. Replacements cannot in general respond to exogenous changes in technology and demand for example without affecting the minimum waste condition. As a consequence the total complex has a much longer life-time than any of the constituent plants and this increases with the size of the complex.

variations. A production structure that is too rigid can end up by becoming rapidly obsolete in market economies and by constraining patters of consumption in centrally planned economies.

A static optimisation gives a solution for the complex which is fixed from the beginning of construction to the end of its days. In principle the complex cannot even begin to function until it is all built and this could take an inordinately long time. Apart from the large design, planning and organisational problems involved there is a further one for market economies. Here there is no certainty that industries would even be attracted without such extreme incentives that the complex as a whole loses its validity.

From a practical point of view it is difficult to even conceive of an integrated industrial complex based on materials and energy balance criteria as the result of a large scale planning effort in a market economy. The basic reason for this lies clearly in the antagonism between market economics and central planning economics. However a static, highly integrated, mixed industry complex working in unison has no place in a dynamic world whether it be embedded in a market or a centrally planned economy.

It seems to me that any serious study of the industrial complex based on materials and energy balance criteria cannot limit itself to defining the optimum industrial plant mix, which by the way could be optimal in any particular instant in both types of economy, but must also concern itself with how such a plant-mix could materialise and also react to keep pace with changes in the outside world.

This is a much more delicate problem than that of designing a particular optimum configuration, especially so in a market economy where it is not sufficient to give guidelines upon which planners may act but where market mechanisms must be escogitated which will induce the type of solution desired, one that is not only waste-minimising but also dynamic, to happen in a reasonably free way.

In this paper we shall be mostly concerned with the problem as it exists in the context of market economies. In such systems one is confronted with the added challenge of having to devise strategies for inducing waste minimisation which guarantee the essential nature of the market system even in the face of overall by-products integration between production sectors.

To talk of waste-minimising industrial complexes for market economies clearly has only academic sense unless a realistic, operative solution can be given to the attraction[12] problem, which preserves the market system.

There is a particular case in market economies for which the attraction problem does not exist and for which the total problem collapses basically to the problem in centrally planned economies: the definition and design of a dynamic optimum complex. This is the case of the whole complex belonging to a single enterprise, under government-imposed total materials and energy waste constraints.

There are examples even today of industrial complexes belonging to one single enterprise which tend towards waste minimising criteria. The large integrated steel plant with coking plant, gasification plant, anmonia and benzol recovery, permanganate recovery, slag-utilisation plants with sulphate and phosphate fertiliser production, water and heat recycling etc. is the prime example. However they utilise only a small percentage of

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12. This is not meant necessarily in the sense of attraction to one location, although in final analysis it will partly amount to this, but rather in the sense of attraction between different plants due to a by-products generating potential.

    The waste-minimising industrial complex need not be envisaged as a spatial agglomeration with small average inter-plant distance. By-products attraction between production facilities can be felt over considerable distances according to value-to-weight ratios and transportation costs. However the bulk of by-products have typically low value-to-weight ratios. If moreover special legislation is enacted to curb transportation pollution the waste-minimising industrial complex may well tend to spatial agglomeration.

the total waste (∿30 % by weight) and the effluent water and gases need considerable treatment as can be seen from Table 1 just for the coking plant. Furthermore the basic reason for emphasis on by-products recovery has been profit-maximising or cost-minimising rather than waste minimising.

Another mechanism that seems feasible in a market economy is something akin to the classical industrial estate. The objectives sought in establishing these estates in the past have varied; private groups seeking to make a profit, local and regional authorities seeking advantages of economic and social nature or government and private conglomerates seeking to promote industrial development.

The criteria for deciding upon what type of industry to attract have been entirely non-uniform and usually not very easy to identify. Broadly speaking the industrial estate authority was just interested in attracting industrial activity. This it did by a number of mechanisms such as providing the buildings, much of the auxiliary services, organising low cost utilities, tax exemptions, low rentals, benefits of agglomerative nature and a host of other incentives. In some cases a preference for non-polluting industries was shown but waste-minimisation criteria have never been used as a basis for attracting industry.[13]

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13. See for example, Establishment of Industrial Estates in Underdeveloped Countries, United Nations, 1961; Industrial Estates in Asia and the Far East, United Nations, 1962.

TABLE 1

POLLUTION FROM A COKING PLANT FOR A 10 MILLION TON/YR STEEL PLANT (@)

Air pollution	coal and coke dust	14800 tons/yr
	coke oven gas (§)	5200
	sulphur dioxide	4700
	hydrogen sulphide	900
	phenols	960
	aromatics (§)	1600
	hydrogen cyanide	500
	ammonia	1035
	pyridine bases	100
Water pollution	suspended solids	73900
	phenols	2439
	ammonia (§)	29560
	cyanides	100
	thiocyanates	800
	permanganates (§)	13300

@ From I.Codd, Pollution Control and the Iron and Steel Industry, Third Interregional Symposium on the Iron and Steel Industry, Brasilia, October 1973.

§ Presently recovered as byproduct.

The waste minimising industrial complex would probably be centred around some starting strategic industry like a steel plant or a refinery or a pulp and paper mill, with high material and energy wastes. Incentives for attracting industry need not be very different from what they are in the classical industrial estate. The basic innovation lies in the fact that the complex authority would decide at least partly if not principally, on the basis of waste-utilisation whether a particular applying industry can or cannot locate.

It is however difficult to conceive of a purely selective action that is effective in fostering cross-utilisation of wastes even if supplemented by a canopy of benefits. Industry would probably take exceedingly long time to locate or not locate at all. For one thing the classical industrial estate has no built-in incentive for by-products development. Incentives for attraction would have to take the form of subsidies and an economy built on subsidies is like a house made of cards.

As a means of persuasion or dissuasion some type of money-commodity flow mechanism is necessary that takes into account the new meaning that industrial wastes acquire in a materials and energy balance oriented economy. One that readily comes to mind if the authority is an arm of the government, is for the authority to exact a waste and pollution tax from industries in the complex until their waste is utilised either by already existing facilities or by a new locating industry. Industry is encouraged to locate by industrial complex benefits but foremost by the prospect of being able to dispose of its wastes in a profitable way in the future and by a lower than market price for input materials that are otherwise waste outputs of other industries.[14]

For example a sulphur polluting industry like pyrites smelting could attract sulphuric acid production by a lower than market price for the sulphur equivalent set by the smelting industry to maximise profit from sales or minimise loss due to development and treatment. The smelting plant may even find it convenient to install its own sulphuric acid plant.[15]

It is worth mentioning that another factor of attraction to the type of waste minimising complex described is the fact that new add-on plants need not work at classical economic optimum capacity. The new rewards and penalty structure implied

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14. Such a mechanism presupposes that waste and pollution are taxed irrespective of where industry locates, whether it be in a waste minimising complex or not.

    Clearly investment in by-products development will be oriented according to by-products markets and to achieving a by-products price that is not greater than the market price.

15 Something like this is already current in the Four-Corners region of the United States. See for example, F.A. Ferguson, K.T. Semran and D.R. Monti, <u>SO_2 from Smelters, By-Products Markets a Powerful Lure</u>, Environmental Science and Technology, 4(7), 562 (1970)

can well make small plants that are sub-optimal in classical economics, optimal from the point of view of the modern welfare economics in question. The same clearly applies to production processes; the best process is not necessarily the same in the two types of economy.

In a market economy it is also conceivable to rely on the profit motive to encourage creativity in the cross-utilisation of wastes. One can imagine an industrial complex set up by a private group with the characteristic that the complex authority would take on all responsibility to the environment control authorities for any waste emitted to the environment from the complex and that the industries involved relinquish all claim to the wastes they produce once they are located.

This may sound like suicide or an extreme form of masochism, but one should not neglect the economies of scale associated with waste treatment technology, which can come about as a result of concentrating wastes in the hands of one processor. Waste heat is a clear example where dispersion of activities lead to loss.[16] Chromium recovery from tannery effluents,

16. Before 1965 most sulphur acid production in Italy was dispersed and not amenable to energy saving practices such as recovery of waste heat. With more recent concentrated capacity (~600,000 tons / yr. in Follonica for example) energy recovery in the form of medium pressure steam occurs to the extent of 500 MW equivalent.

just to take one further example is presently profitable only if large quantities of wastes are treated.[17]

The complex authority powered by the profit motive, would take on the task of waste treatment and by products development and moreover would have discriminatory power over the type of industry it allows to locate, mainly with an eye to internal consistency for the complex it is developing.

Evidence that a mechanism of this type may develop is forthcoming from the large number of recycling and reclamation enterprises that mushroom[18] in the United States as industrial and municipal wastes acquire a value.[19]

Clearly waste utilisation enterprises need not be associated with particular locations and could exercise their activity over the whole terrain. Low value-to-weight ratios for most

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17. Private communication.

18. Names like The National Association of Secondary Material Industries (1913), The National Slag Association (1918), The National Institute of Scrap Iron and Steel (1928) and The National Ash Association (1968) bear witness to historical developments of this nature in the United States.

19. Examples of municipal wastes are much more publicised. See for example, Refuse-to-Energy Plant Uses First Von Roll Incinerators in U.S., Environmental Science and Technology, 8(8), 692, (1974); Plastics Resource Recovery Dilemma, Environmental Science and Technology, 7(10), 894, (1974).

by-products and wastes however should favour a localised type of development.

The dynamic element of the type of mechanisms described is provided by the individual enterprises which would be free to come and go as it suits their particular business objective, which is mainly maximising profit.[20] The waste-minimising element is the responsibility of the complex planning agency or group working under government legislation constraints which would decide unpon detailed attraction strategies to minimise total waste from the complex and maybe make a profit out of it.

Development is industry oriented insofar as it is based on a core industry[21] and the complex would expand or contract in a step-by-step manner. Clearly this solution is sub-optimal at any given instant of time, but it is quite likely to be close to the desired dynamic optimum over a sufficiently long time horizon.

Ayres and Kneese[1] have given a convincing argument that the type of partial equilibrium iteration implied in the industrial complex step-by-step growth described, converges towards the general equilibrium or total systems solution. However it

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20. This type of objective responds well to economic, social and technological variations.

21. This is not necessary but practical.

should be noted that the general equilibrium is very much a dynamic equilibrium and with staggered construction and development lag-time in the order of years, the question of convergence or no convergence is really quite academic.

Both the single enterprise and the industrial estate presuppose a basic spatial location and a supervisory structure to orient and organise location. They are moreover only particular cases of a more general mechanism which involves the whole economy and is therefore basically not location oriented. I am referring to the possibility of inducing waste minimisation in the economy as a whole by the effective use of normative legislation which puts a price on the use of the environment. Insofar as the environment is becoming a scarce commodity, the economic argument goes, it is inevitable to attach a price on its use and the only possible custodian of the environment is the government.

Such a solution preserves the essence of the market system and is therefore dynamic as well as waste-minimising. Furthermore it would not require special planning authorities as government sponsored industrial estates imply, although some central organ would be necessary to investigate and set the best price on the environment.

It is worth while emphasising that the other two mechanisms described are perfectly compatible with this mechanism. Both single-enterprise and estate-type waste-minimising complexes would be well-defined and cohabit in an economy in which use of the environment was priced. Furthermore, although localised waste-minimising complexes are not a prerequisite of a minimum waste economy, it is quite likely that a sufficiently aggressive environmental pricing system could induce a shift to an economy based essentially on localised industrial complex nodes of the waste-minimising type with minimal by-products transportation.

The point to be made here is that in such a system localised minimum-waste complexes might develop irrespective of the existence of authorities to supervise the location.[22]

Pricing the use of the environment is in itself a complicated mechanism to put into practice, basically because the environment is very extensive and requires an extensive custodian mechanism with high operating and capital costs[23], but also because it is an extremely large and difficult systems problem to decide on the right price to put on all the different aspects of the environment in order to achieve overall waste-

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22. See for example footnote 11 and also footnote 22.

23. The high cost of the extensiveness of a custodian mechanism largely devolved upon industry as a function of its dispersion, could also be a factor in favouring the growth of localised waste-minimising complexes.

minimisation, assuming this is the objective.

How should the environment be priced? This question is crucial to the whole idea of the waste minimising economy and of the waste-minimising complex for that matter, because no waste-minimisation will ever be forthcoming unless use of the environment is priced and priced correctly. With this in mind, a feasibility study of the waste-minimising complex is equivalent to the study of alternative environmental pricing policies which will foster its growth.

A material and energy balance ideal would require pricing the use of the environment irrespective of whether the pollutant or waste was dispersed or separated out in an apparently harmless form and then dumped or stockpiled.

Especially high social costs can be associated with stockpiling and dumping of bulky wastes such as slag from steel plants or fly ash from coal fired power plants. At present only a small percentage(24) of these wastes are finding a use as can be seen from Table 2. The colliery spoil stockpile in Great Britain has reached 3×10^9 tons. Of this the National Coal Board

24. In Great Britain essentially all 9×10^6 tons/yr. of blast furnace slag are being utilised as roadstone, railway ballast, aggregate for concrete, fertiliser and cement manufacture (see footnote 25). However this situation is atypical.

TABLE 2

(a) SLAG SOLD IN THE UNITED STATES IN 1968 (1000 short tons) (@)

Use	Blast furnace	Steel
portland cement concrete............	3381	-
bituminous concrete pavements.......	3910	479
concrete masonry block..............	1833	-
railroad ballast....................	4223	792
bases for cement and bituminous concrete............................	11199	4379
cement manufacture..................	1131	-
roofing slag (cover and granules)...	519	-
mineral wool........................	416	-
agricultural slag...................	61	85
glass...............................	181	-
sewage trickling filter medium......	24	-
anti-skid and ice control...........	107	93
paths,driveways and parking areas...	40	54
fill................................	1461	70
miscellaneous.......................	258	258
total slag sold.....................	28744	6210
total slag produced.................	41742	18486

(b) PRODUCTION AND UTILISATION OF ASH IN THE UNITED STATES ($)

Year	Production	Utilisation	Utilisation
	millions	of tons	%
1955	15	0.3	2.0
1965	25	1.3	5.2
1966	25.2	3.1	12.0
1967	27.5	3.8	13.8
1968	29.6	5.2	17.9
1969	33.4	5.3	16.2

@ From H.K.Eggleston,The Successful Utilisation of Iron and Steel Slags,Proceedings of the Second Mineral Waste Utilisation Symposium,Chicago,March 1970,p.15.

$ From J.H.Faber and P.G.Meikle,Ash Utilisation Techniques Present and Future,Proceedings of the Second Mineral Waste Utilisation Symposium,Chicago,March 1970,p.24.

spoils alone cover an area of 110 sq. km. at an average height of about 15 m. Presently only about 7×10^6 tons are used per year, which is considerably less than annual production.(25) Colliery spoil has great potential in concrete manufacture among other uses. A hefty penalty for colliery spoil dumping would probably encourage development for aggregate use especially if adequately coupled with penalties for extracting aggregate from the environment. There is probably enough aggregate in the form of colliery spoils in Great Britain to satisfy all demand at least until the year 2000.(26)

The basic point behind the rationale implied in this type of argument is that a price is put on the extraction of materials from the environment that industry does not use in the production process. Environmental pricing based on this rationale encourages technology advances in the cross-utilisation of wastes, rather thatn technology advances in the elimination of pollution, as it is fuzzily called. If industry has to pay a price

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25. W. Gutt, The Use of By-Products in Concrete, Resources Policy, September 1974, p.29.

26. Positive systems repercussions of waste minimising policies can be be illustrated by reference to bulk wastes such as colliery spoils that can be used as building materials. If an effective penalty-reward mechanism was enforced that could encourage development of bulk wastes for construction purposes rather than the present trend in expensive and luxurious but not very efficient building materials, part of the net result would be a 30 % decrease in space heating and cooling requirements. See Panorama, no. 445, October 31, 1974.

for wastes irrespective of what it does with them, then it will react by using them in the way that involves the highest returns or the least cost, which means developing a use for them.

At present industry is more worried about eliminating pollution than finding an economic use for wastes. Treatment plants are not infrequently more polluting than the pollution they are trying to eliminate in that more often than not they do not provide an economic use for the separated residues. At present most treatment plants convert a pollution problem into a waste dumping problem. In a broad economic setting they are usually extremely wasteful in materials and technology which is diverted from concentrating on by-products development.

At present environmental legislation generally takes the form of a standards structure. It is highly debatable that this is better than a penalty structure which prices the environment according to the amount of waste actually dispersed or dumped.

In a penalty system based on the quantity of pollution each plant is taxed according to the amount it pollutes and is therefore encouraged to find its own lowest cost pollution. With a standards system every plant is forced below a threshold regardless of its size and the extent it pollutes. This can involve the loss of considerable degrees of decisionlmaking freedom.

The environmental control cost seems to be considerably higher and the control more difficult to implement for a standards based structure. Solow[27] mentions the advantages of decentralised decision making and the economising on information inherent in a penalty-based structure. Moreover there is no built-in money flow to defray the costs of an emission standards control. The costing is basically through the public taxation system and thus the onus rests directly on the public sector rather than on the industrial intermediary. In fact in final analysis the public sector is taxed twice; first for the environmental control costs and second for the increased costs of production due to expensive waste-treatment.

On the other hand a pricing system based on the quantity of waste actually emitted has a built-in circular goods and money flows. The penalty money or price for using the environment which should depend on the fate of the wastes, can be used to help defray the costs of the environmental control mechanism.[28]

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27. R.M. Solow, The Economist's Approach to Pollution and Its Control, Science, 173, 498, (1971).

28. It only helps to defray the costs because income from this source tends to zero as the waste-minimising condition is approached. However, at least the initial impetus for financing the control mechanism would come directly from the industrial sector rather than from the public sector.

If society decides on a standards structure at all costs, there remains the problem of deciding on the minimum standards. At the moment this is done in an extremely fuzzy was. A study in which the basic objective is expressly inducing waste-minisation, and for which the penalty input is based on a standards structure would at least help obtain a well-defined strategic set of standards!

To what extent is it possible to reduce wastes and pollutants from production processes in a constructive way? This depends largely on the demand for products but fundamentally on by-products technology and the penalty structure of the environmental pricing system. There is a lingering suspicion that adequate legislation, partly by boosting developments in by-products technology and partly by changing the whole cost structure of materials, would make the production sector far less wasteful than it presently is without any basic impact on the demand-supply equilibrium.

Some very coarse estimates of the allocative cost of not pricing the environment indicate for the United States something in the order of 30 billion dollars per year or about 5 % of GNP(1). This is to be compared with the 0.01 %(29)

29. D. Schwartzman, The Burden of Monopoly, J. Pol. Econ., 68, 627, (1960).

and 0.07 %[30] estimates of the welfare cost of monopoly.

In order to answer these questions it is necessary to study the effect of alternative environmental pricing policies on real systems under pertinent technological scenarios. It is not only a question of what is the best mechanism, but also one of what are the best penalty functions to achieve the desired effect?

Considerable modelling activity, basically simulation oriented, is already under way which investigates the effect of different types of pollution penalties on production costs and production spectra. However none of this takes into any account whatever the possibility of waste cross-utilisation. The studies are directed at forecasting increases in production cost[31] and possible changes in production processes[32]. This seems to be a very short-sighted way of approaching the problem. It cannot be seriously maintained that industry will stop at installing extremely costly treatment equipment and let the matter end with an increase in production costs or a change

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30. A.C. Harberger, Monopoly and Resources Allocation, Am. Econ., Rev., Proc., 44, 77, (1954).

31. R.M. Thrall and R.G. Thompson, Industrial Economic Models of Water Use and Waste Treatment, Proceeding of the Joint Automatic Control Conference, Austin, 1974; J.A. Callaway, A.K. Schwarz and R.G. Thompson, Industrial Economic Model of Water Use and Waste Treatment for Ammonia, Water Resources Research, 10 (4), 650, (1974).

32. See reference to footnote 9.

in production process!

Both of these effects may be important in the short-term especially if dead-lines for achieving minimum standard effluent discharge are imposed as in the Federal Pollution Control Acts. But in the longer term and not necessarily much longer term, industry will react by finding new profitable uses for its pollutants and wastes.(33)

Any modelling effort that does not take into account the adaptive nature of industry can only give a distorted view of what is the best pollution penalty structure, which is basically what these models are trying to do.

The results of any modelling activity are extremely sensitive to the technological variable as it concerns by-products develop-

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33. Every other article in Environmental Science and Technology is about advances in the use of industrial wastes.

    It is interesting to witness how rapidly some industries can react under pressure from local and regional government authorities. Most of the ferric sulphate wastes (red mud) from the production of titanium dioxide that was being dumped off the coast of Corsica at a complete loss also to the Corsican fishing industry, can in fact be used at a profit as barium and strontium ferrate magnetites for electronic components parts. Previously the magnetites were either imported into Italy or made from scrap iron, which under the circumstances is more profitably recycled to steel plants. The technology jump has not exceedingly great and all it needed was just a push from local authotities.

ments. For example the amount of sulphur oxide wastes from non-ferrous smelters, from coal and oil-fired power-plants and from sour refinery gases is sufficient to quite swamp the world market for sulphur products: mainly sulphuric acid, elemental sulphur, liquid sulphur dioxide and the ammonium sulphates. Unfortunately by-products development in this field is severely limited by the low cost of sulphur from the Frasch process and the very low value-to-weight ratios for sulphur products which is reflected in the small size of the market regions. Still it can be foreseen that if an advanced technology is eventually developed for pure sulphur recovery at low cost, and people are working very hard at it[(34)], then the Frasch process may be all but forgotten for the next twenty years at very least.

It would be useful to have some basic standard with which to compare the effect on the economy of different environmental policies. A basic standard could be a zero-order solution to the minimum waste economy. This would involve considering all materials in the same environmental light whether they be inputs to the production process or outputs. All input and output materials associated with each production process would ideally cover the whole spectrum of available materials. For example all the different sulphur grade coals would be different materials. The output materials of each process would include

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34. See reference to footnote 15.

main products, by-products and wastes. The programming problem would be determining the production processes and associated throughputs to minimise total waste in the economy as a whole, subject to demand for products constraints and a materials input-output matrix constraints for each production process.

The level of aggregation of such a study, the whole economy, warrants the use of fairly highly aggregated materials and process inputs, and one could probably get away with using 2 or 3 digit SIC aggregation.

This solution is zero-order in that it neglects costs, spatial disaggregation of productive forces, scale of production, in fact everything except waste-minimisation objectives. If not operatively useful it does nevertheless provide a picture of what the production sectors could look like under different technological scenarios in an aggressively waste-minimising economy. It is "the impossible solution" but one that can be fruitfully used for comparison purposes. It roughly corresponds to maximum pricing of the environment.

A first order solution would involve introducing costs to industry of pricing the environment. In this case alternative environmental pricing policies, each associated with environmental costs of extracting material from the environment and of dumping wastes into the environment would be involved as inputs to the programme. The programme in this case would minimise total cost to industry[35] rather than total waste from industry. The same level of aggregation can be used as in the zero-order solution.

The results from this programme can be used to evaluate the different environmental pricing policies from the point of view of approaching the minimum waste condition. In other words what pricing policy corresponds to the minimum total waste? Unlike the zero-order solution this type of programme is non-linear and perhaps difficult to solve if unfortunate penalty functions are chosen for pricing the environment.

Both zero order and first order solutions are static and disregard some very important variables associated with the real world such as scale of production and the fact that the economy has spatial characteristics. They can however be used to make more credible estimates of the allocative cost of not pricing the environment that are at present available.

A second order static solution which disaggregates the economy into regions may not have much real meaning since different

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35. This would include also normal production cost as well as environmental cost.

products have different market regions. If an intelligent criterion for disaggregation can be found a second order solution could be attempted with the different regions minimising environmental costs independently.

One would then probably have to jump to a high order fine solution such as stochastic simulation study of industrial growth in a national economy, under different environmental pricing policies. In order to minimise the dimensionality of the problem, this can be either an idealised economy with a limited number of possible industrial locations or a real world situation for a country in which the number of actual industrial regions was small.

I would like to emphasise that such a simulation study does not <u>have</u> to be a computer programme. It would certainly involve a computer interface to take care of all routine calculations. On the other hand a many-player non-zero sum game must preserve the human judgemental element which cannot be left to the computer except by assuming improbably simple human behavioural mechanisms.

The simulation would have to take the form of a game somewhat reminiscent of Monopoly but clearly much more complicated. Actions would be taken through a terminal and the scenario of industrial growth would be available on video and computer printouts.

The game would be played over the whole terrain with the players free to locate in the different allowed industrial regions as they please, subject to their own personal business objective of making as much profit as possible. The time discretisation would be in the order of a month or so and the real-time scaling about 1 to 3000, with the players being allowed to pass if they don't intend to invest.

The players would each represent a different production sector so that they could specialise but their interests could be more highly fragmented if more players and sufficient terminals are available. They would ideally not be in contact with one another except through a common data base which would be updated upon every move of a player with adequate deterministic or stochastic time lags.(36)

The data base would include all information necessary for assessing the opportunity of investment either in research and development in by-products technology or in production facilities. It would include exogenous variables such as forecast demand for products over the time horizon and price elasticity, investment and operating costs as a function of plant capacity, local and regional constraints such as maximum water availability and labour, location of raw material, transportation costs of materials,

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36. Construction time and by-products research and development time, for example.

time and investment dependence of the probability of success of research and development in different by-products technologies as a function of by-products production costs,[37] and of course also the environmental penalty functions. It would also include endogenous variables such as industries located in the different regions and waste flows, by-products available with quantities and costs, production processes and cost estimates as a function of plant capacity, and others.

In order to minimise the time necessary to make venture assessments, an information retrieval system would be avilable with standard routines to calculate all useful economic indeces. The individual players might be interested in total supply of a particular product, total estimated demand three years later, materials costs in different industrial regions and quantity available at different costs,[38] optimum plant size at particular locations, investment cost, production cost, profit and loss estimates, payback time and discounted cash flow, just to mention a few.

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37. These would probably be the most difficult inputs to forecast and would require very expert treatment. It is largely because of this fundamental variable that the time horizon for a study of this nature would have to be limited to about 10 years at very most.

38. This is especially important if the material is a by-product insofar as the material flow is generally limited by the production capacity of the output plant.

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The game would start with each player picking a starting industry out of a hat and choosing the best location and optimum capacity for it on the basis of the information available in the data base.

Over time plants would open, others would close, some would be sold, by-products technologies would be developed,(39) some players would drop out of business altogether, others would stay on as is normal in a market system.

Somewhere in the entrails of the computer an integrator would be totally up all wastes and all extraction over the simulation horizon. These would be compared for different environmetal pricing policies including a no-pricing policy. After averaging over many games of this type played with a given environmental pricing mechanism, an allocative gain can be estimated for every individual pricing policy relative to the no-pricing policy.

Rationale behind environmental legislation is still very confused. The basic reason for this is that the benefits of different types of legislation are very difficult to estimate. The involvement of legislation in pollution and the environment has been generally concerned with the health aspect. This is probably only a minor

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39. If not,all players would quickly go out of business because of the high environmental costs. The environmental pricing has to be such that it is not profitable to be in business without investing in extensive cross-utilisation of wastes.

part of a very complicated systems problem and one furthermore, for which experimental data is incomplete, contradictory and difficult to obtain.

More data is available for the effect on flora and fauna but the analysis of the whole ecosystem is in such a state of infancy that it may not be the best approach to solving an urgent problem.

Environmental legislation whether we like it or not, it a steering mechanism and as such it must be steering us somewhere. Presumably what society basically wants is to maintain the ecosystem as stable as possible through time. If this is the case then it will have to be much more subtle than it presently is.

Waste minimisation is not a total panacea to this problem insofar as the stability of the ecosystem depends also on demographic and economic growth. However a mechanism that favours the minimisation of wastes in the production and consumption processes is also a mechanism that alters the state of ecosystems as little as possible, at least to the extent allowed by economic and demographic growth.

In this sense it is a good rationale for environmental legislation.