A series of articles exploring and reviewing the rapidly-expanding study of the energy costs of production processes, encompassing foods and agriculture, transport, materials, petrochemicals and products, and their importance for policy making.

3. Goods and services:

an input-output analysis

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In this third article in the series on Energy Budgets, Dr Wright uses the US input-output table to trace all the inputs to each industrial process back to requirements for primary energy, and discusses the relative advantages of the input-output approach and the process analysis approach.

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The recent 'energy crisis' was not due to the fact that energy is a depletable resource, nor due to the fact that there are applications in which the substitutability of energy is limited. It was due to the fact that the producers were able to control the supply and hence the price of energy. However, any of these three reasons would justify a close appraisal of how much energy is used in the production of the various goods and services in our economic systems. This can be done by constructing an energy budget for each production process and results have been obtained by Bravard and Portal,[1] Chapman,[2,3] Leach and Slesser,[4] Smith[5] and Slesser.[6] Not only the direct inputs of energy to the process are counted, but also the secondary requirement of energy in the production of the other new materials input. Another way of calculating the energy requirements of different commodities is from published government statistics. A variety of such sources is used by Makhijani and Lichtenberg[7] and in the present article we use the input-output table. This table is a matrix showing the flows of products between the various industries of an economy.

Obtaining energy costs from input-output tables

The economy is divided into a number of industries and these are listed as both the rows and columns of the input-output matrix. The entries in the column corresponding to any selected industry give the direct requirements from each of the other industries to produce one unit of that industry's output. If the input-output matrix is denoted by A, then the element A_{ij} gives the requirement from industry i to produce one unit of the output of industry j. It is important that the matrix is square, as then, knowing these direct requirements, one can use the same matrix to find out what was needed to produce them. These one can call the secondary requirements, and it can be seen that they correspond to the matrix A^2. Similarly, one can calculate the tertiary requirements corresponding to A^3 and so on. Finally, the total requirements matrix, B, which represents all these indirect and direct inputs is given by

$$B = A + A^2 + A^3 + \ldots = (I-A)^{-1} - I$$

Thus a matrix inversion is all that is needed to obtain the total requirements matrix from the direct requirements one, and this inverted matrix is usually published along with the matrix A.

As regards energy requirements, everything has, in effect, been traced back to primary energy inputs in the matrix B, taking into account inefficiencies of the fuel conversion industries. Thus, if we identify those rows of B that correspond to inputs of primary energy (coal, crude oil, natural gas, nuclear and hydro-electricity), we can obtain the total primary energy requirement of any commodity by reading down the corresponding column of the matrix B.

The input-output tables are, of course, published in money terms and so we obtain the requirement:-

x dollars of primary energy per 1 dollar of cement (1)

for instance. Knowing the prices of the different forms of primary energy, this can be converted to:

y kWh of primary energy per 1 dollar of cement (2)

and, knowing the price of cement, we obtain:

z kWh of primary energy per 1 ton of cement (3)

However, many commodities are insufficiently homogeneous to be measured by a physical unit such as 1 ton, and we can obtain only (2) above, eg

y kWh of primary energy per 1 dollar of farm machinery.

Each of these measures is useful in different ways. Some applications are as follows:

(1) gives an idea of the short-term effect of changes in the price of energy on the costs of commodities. Comparing (2) for different commodities it can be seen whether there is any disparity between money costs and energy costs. (3) gives the relation between physical production and demands for primary energy. Results of type (1) can simply be read off the input-output table, and in the present article we concentrate on those of types (2) and (3).

Calculation of energy costs of US products

Input-output tables cannot be derived from the economic statistics normally available to governments in countries with market economies. The derivation of all the inter-industry flows requires a special census which is not conducted annually. Moreover, obtaining the input-output table from the census data is itself a time-consuming process with the effect that present input-output tables are, at best, five years out of date by the time they are published. The most recent UK table is for 1968[8] and this divides the economy into 90 industries, whereas for the US a bigger table is available, 363 industries square, for 1963[9]. The present author[10] has previously calculated energy costs from the UK tables; this article concentrates on the USA. In fact, results for the USA are easier to obtain as foreign trade (which introduces a complication into the calculation) is a much smaller proportion of GDP in the US than in the UK.

[1] J.C. Bravard and C. Portal, *Energy requirements in the production of metals* (Oak Ridge Laboratory Report, USA, 1971)

[2] P.F.Chapman, *'The energy costs of producing copper and aluminium from primary sources'* (Open University Report ERG 001, UK, 1973)

[3] P.F.Chapman, *The energy costs of producing copper and aluminium from secondary sources* (Open University Report ERG 002, UK, 1973)

[4] G. Leach, and M. Slesser, *Energy equivalents of network inputs to the food production process* (Strathclyde University Report, UK, 1973)

[5] H. Smith, 'Cumulative energy requirements of some products of the chemical industry' *Transactions 20, Section E, World Energy Conference*, 1969

[6] M. Slesser 'Energy subsidy as a criterion for food policy planning' *Journal of the Science of Food and Agriculture*, Vol 24, Nov 1973

[7] A.B. Makhijani and A.J. Lichtenberg, 'Energy and well-being', *Environment*, Vol. 14, No. 5, June 1972, p. 10

[8] *Input-Output Tables for the UK, 1968*, Central Statistical Office of UK, (Her Majesty's Stationery Office, 1973)

[9] *Input-Output Structure of US Economy: 1963*, US Department of Commerce, 3 vols (US Government Printing Office, 1969)

[10] D.J. Wright, 'The natural resource requirements of commodities' Paper presented at conference on energy costing held at Imperial College, London, July 1973

Table 1 gives results of type 2 above in units of kWh/$ for each of the 363 industries in the US 1963 input-output table. The energy unit kWh has been chosen, not because of any electrical connotation, but as a well-defined physical measure avoiding the tons of coal equivalent in which primary energy is usually measured. The money unit is the 1963 $.

Some details relevant to this calculation are as follows:

(a) *Prices of primary energy*

Prices of the different forms of primary energy are obtained from the 'Statistical abstract of the US'[11] and checked against production figures and the financial data in the input-output table itself. Imports are also treated as an input of primary energy to reflect the importation of energy and also the energy used abroad to manufacture exports to the USA. An average figure is taken as the energy cost of imports. These prices are taken to apply to purchases of primary energy by any industry so that concessionary prices allowed to certain industries are a source of error in the calculation.

(b) *Prices of final products*

The unit of value assigned to any commodity is the factory gate price measured in 1963$. Thus transportation costs (energy and monetary) incurred by the producer directly, or indirectly, to transport his supplies and his supplier's supplies, etc, are included, but the costs of distribution to the final buyer appear separately under 'wholesale and retail trade' (items 69.1 and 69.2) and 'transportation' (industries 65.1-65.7).

(c) *Capital depreciation*

The inter-industry flows in the input-output table include repairs to, but not replacements of, capital. So if one regards depreciation as replacements of capital, then this energy cost is ignored in the analysis. We see below that there is a straightforward relationship between money and energy value of capital so that, given the monetary value of capital depreciation, one could easily translate this to an energy cost and some authors have done this for certain products. However, depreciation rates are not readily available for each of the 363 industries separately and so this energy flow is excluded from the present analysis.

(d) *Labour, profits and solar energy*

These are also energy inputs to the production process which have been excluded from the results in Table 1. They could be included but there is some arbitrariness as to the appropriate stage to do this. For instance, is it the physical energy contributed by the labourer to the production process, or the energy content of the food he eats, or the primary energy needed to produce all the goods and services he enjoys? Similarly, with solar energy in agriculture, should we include the total energy incident on the plants, or just that used in photosynthesis, or an opportunity energy cost of not covering the farm with solar cells? Different uses of the results give different answers to these questions. Excluding these three inputs of energy means that the results are

[11] 'Statistical Abstract of the United States', (US Department of Commerce, Washington, DC) (Published Annually)

Table 1. Energy intensities of US products in kWh/1963$

Ref. no		(kWh/1963$)
(1·01)	Dairy	18·5
(1·02)	Poultry	22·9
(1·03)	Meat	18·6
(2·01)	Cotton	21·4
(2·02)	Grains	25·4
(2·03)	Tobacco	20·9
(2·04)	Fruits	16·1
(2·05)	Veg. sugar	19·0
(2·06)	Oil crops	24·0
(2·07)	Forest prods.	16·2
(3·00)	For. & fish prods.	38·6
(4·00)	Ag. for. & fish serv.	16·2
(5·00)	Iron ore mining	47·4
(6·01)	Copper ore mining	21·5
(6·02)	Non-ferr. ore mining	38·2
(7·00)	Coal mining	257·0
(8·00)	Crude oil & nat. gas	33·5
(9·00)	Stone & clay mining	28·3
(10·00)	Chem. & fert. mineral mining	31·2
(11·01)	Constr. resid. buildings	14·9
(11·02)	Constr. non resid. buildings	16·6
(11·03)	Constr. public utilities	20·9
(11·04)	Constr. highways	30·8
(11·05)	Constr. other	27·8
(12·01)	Maint. resid. build.	13·0
(12·02)	Maint. other	14·4
(13·01)	Guided missiles	7·4
(13·02)	Ammunition	16·5
(13·03)	Tanks	20·6
(13·04)	Sighting & fire control	10·4
(13·05)	Small arms	21·9
(13·06)	Small arms ammo.	14·4
(13·07)	Other ordnance	13·6
(14·01)	Meat Products	18·0
(14·02)	Creamery butter	21·4
(14·03)	Cheese	21·6
(14·04)	Con. & evap. milk	21·7
(14·05)	Ice cream	17·0
(14·06)	Fluid milk	17·9
(14·07)	Canned sea foods	21·8
(14·08)	Canned specialities	17·5
(14·09)	Canned fruits & veg.	20·0
(14·10)	Dehydrated food	17·1
(14·11)	Pickles & sauces	18·9
(14·12)	Packaged fish	23·3
(14·13)	Frozen fruits & veg.	18·0
(14·14)	Cereal preparations	20·0
(14·15)	Animal feeds	19·9
(14·16)	Rice milling	21·2
(14·17)	Wet corn milling	30·1
(14·18)	Bakery products	15·8
(14·19)	Sugar	46·3
(14·20)	Confectionery	24·6
(14·21)	Alcohol	9·8
(14·22)	Soft drinks	16·3
(14·23)	Flavouring	18·8
(14·24)	Cottonseed oil mills	23·3
(14·25)	Soybean oil mills	25·4
(14·26)	Vegetable oil mills	50·3
(14·27)	Fats & oils	27·3
(14·28)	Roasted coffee	52·3
(14·29)	Cooking oils	23·5
(14·30)	Manufactured ice	22·6
(14·31)	Macaroni & spaghetti	16·5
(14·32)	Food preparations	22·1
(15·01)	Cigarettes	8·2
(15·02)	Tobacco stemming	20·1
(16·01)	Broadwoven fabric	24·4
(16·02)	Narrow fabric	19·9
(16·03)	Yarn	24·4
(16·04)	Thread	22·7
(17·01)	Floor covering	26·5
(17·02)	Felt goods	19·2
(17·03)	Lace goods	24·7
(17·04)	Paddings	20·2
(17·05)	Textile waste	22·9
(17·06)	Coated cord	21·9
(17·07)	Tyre cord	27·0
(17·08)	Scouring	37·5
(17·09)	Cordage	48·5
(17·10)	Textile goods	59·4
(18·01)	Hosiery	13·9
(18·02)	Knit apparel	14·2
(18·03)	Knit Fabric	21·4
(18·04)	Apparel other	13·0
(19·01)	Curtains	16·0
(19·02)	House furnishings	21·9
(19·03)	Textile products	18·2
(20·01)	Logging camps	23·6
(20·02)	Sawmills general	23·8
(20·03)	Hardwood	23·9
(20·04)	Special sawmills	33·5
(20·05)	Millwork	15·3
(20·06)	Veneer & plywood	23·6
(20·07)	Wood structures	16·7
(20·08)	Wood preserving	28·4
(20·09)	Wood products	23·4
(21·00)	Wooden containers	20·7
(22·01)	Wood furniture	14·2
(22·02)	Upholstered furniture	14·6
(22·03)	Metal furniture	21·8
(22·04)	Mattresses	18·4
(23·01)	Wood office furn.	15·3
(23·02)	Metal office furn.	19·3
(23·03)	Public build. furn.	18·7
(23·04)	Wood partitions	13·6
(23·05)	Metal partitions	21·0
(23·06)	Venetian blinds	20·3
(23·07)	Furniture & fixtures	17·3
(24·01)	Pulp	51·3
(24·02)	Paper	47·2
(24·03)	Paperboard	41·8
(24·04)	Envelopes	20·5
(24·05)	Sanitary paper	26·8
(24·06)	Wallpaper & board	37·5
(24·07)	Paper products	26·8
(25·00)	Paperboard boxes	24·7
(26·01)	Newspapers	14·2
(26·02)	Periodicals	14·1
(26·03)	Book printing	11·9
(26·04)	Misc. publ.	11·8
(26·05)	Commercial printing	18·4
(26·06)	Business forms	15·9
(26·07)	Greetings cards	12·6
(26·08)	Misc. printing	9·3
(27·01)	Industrial chemicals	61·9
(27·02)	Fertilisers	36·3
(27·03)	Agric. chemicals	47·0
(27·04)	Misc. chem. products	42·0
(28·01)	Plastics materials	42·2
(28·02)	Synthetic rubber	60·3
(28·03)	Cellulosic fibres	45·0
(28·04)	Organic fibres	27·9
(29·01)	Drugs	14·0
(29·02)	Cleaning preparations	27·1
(29·03)	Toilet preparations	16·1
(30·00)	Paints	40·3
(31·01)	Petroleum refining	375·0
(31·02)	Paving mixtures	109·0
(31·03)	Asphalt	83·6
(32·01)	Tyres	25·9
(32·02)	Rubber footwear	15·0
(32·03)	Reclaimed rubber	24·1
(32·04)	Misc. plastic products	21·9
(33·00)	Leather tanning	19·0
(34·01)	Footwear	16·1
(34·02)	Footwear except rubber	11·1
(34·03)	Other leather products	12·7
(35·01)	Glass	18·8
(35·02)	Glass containers	23·1
(36·01)	Cement	11·2
(36·02)	Brick	39·7
(36·03)	Ceramic tile	28·9
(36·04)	Clay refractories	29·7
(36·05)	Clay products	37·6
(36·06)	Plumbing fixtures	18·5
(36·07)	Food utensils	18·1
(36·08)	Porcelain elec. supplies	15·1
(36·09)	Pottery products	16·6
(36·10)	Concrete block	30·1
(36·11)	Concrete products	24·4
(36·12)	Mixed concrete	39·9
(36·13)	Lime	100·0
(36·14)	Gypsum products	24·3
(36·15)	Cut stone	22·4
(36·16)	Abrasive products	18·2
(36·17)	Asbestos products	27·5
(36·18)	Gaskets	18·1
(36·19)	Minerals	28·9
(36·20)	Mineral wool	20·2
(36·21)	Non-clay refractories	32·8
(36·22)	Non-metal mineral prod.	23·5
(37·01)	Blast furnace	68·9
(37·02)	Iron & steel foundries	21·1
(37·03)	Iron & steel forgings	41·2
(37·04)	Primary metal products	21·2
(38·01)	Primary copper	32·9
(38·02)	Primary lead	29·1
(38·03)	Primary zinc	39·7
(38·04)	Primary aluminium	49·2
(38·05)	Primary non-ferr.	58·1
(38·06)	Secondary non-ferr.	12·3
(38·07)	Copper rolling & drawing	25·6
(38·08)	Alum. rolling & drawing	32·9
(38·09)	Non-ferr. rolling & drawing	24·8
(38·10)	Non-ferr. wire drawing	21·5
(38·11)	Alum. castings	24·0
(38·12)	Brass castings	19·0
(38·13)	Non-ferr. castings	20·1
(38·14)	Non-ferr. forgings	27·6
(39·01)	Metal cans	35·4
(39·02)	Metal barrels	35·6
(40·01)	Metal sanitary ware	20·7
(40·02)	Plumbing fittings	20·1
(40·03)	Heating equip. not elect.	18·4
(40·04)	Structural steel	31·4
(40·05)	Metal doors	20·8
(40·06)	Plate work	28·7
(40·07)	Sheet metal	28·3
(40·08)	Architectural metal	21·5
(40·09)	Misc. metal	33·4
(41·01)	Bolts, etc.	23·9
(41·02)	Metal stampings	25·6
(42·01)	Cutlery	20·0
(42·02)	Hand tools	19·9
(42·03)	Hardware	18·3
(42·04)	Engraving, etc.	18·3
(42·05)	Misc. wire prod.	41·2
(42·06)	Safes	20·9
(42·07)	Steel springs	35·7
(42·08)	Pipe fittings	20·3
(42·09)	Collapsible tubes	20·1
(42·10)	Metal foil	24·8
(42·11)	Metal products	23·0
(43·01)	Steam engines	21·4
(43·02)	Int. comb. engines	14·7
(44·00)	Farm machinery	22·9
(45·01)	Constr. machinery	18·3
(45·02)	Mining machinery	17·3
(45·03)	Oil field machinery	17·7
(46·01)	Elevators	17·3
(46·02)	Conveyors	17·4
(46·03)	Hoists	20·5
(46·04)	Industr. trucks	17·3
(47·01)	Mach. tools cutting	14·8
(47·02)	Mach. tools forming	19·7
(47·03)	Special dies & tools	14·7
(47·04)	Metalworking machinery	15·2
(48·01)	Food prod. mach.	17·8
(48·02)	Textile machinery	20·2
(48·03)	Woodworking mach.	18·0
(48·04)	Paper ind. mach.	21·9
(48·05)	Printing mach.	15·0
(48·06)	Special mach.	19·4
(49·01)	Pumps	15·5
(49·02)	Ball bearings	23·1
(49·03)	Blowers	15·7
(49·04)	Indust. patterns	9·3
(49·05)	Power transmiss. equip.	17·5
(49·06)	Furnaces	16·8
(49·07)	General ind. mach.	16·1
(50·00)	Machine shop prod.	13·0
(51·01)	Computing machines	9·0
(51·02)	Typewriters	11·9
(51·03)	Scales	15·3
(51·04)	Office mach.	16·8
(52·01)	Aut. vend. mach.	16·6
(52·02)	Laundry equip.	18·7
(52·03)	Refrig. mach.	16·6
(52·04)	Measuring pumps	17·4
(52·05)	Serv. ind. mach.	15·9
(53·01)	Elec. meas. instr.	10·8
(53·02)	Transformers	23·2
(53·03)	Switchgear	12·7
(53·04)	Motors & generators	16·1
(53·05)	Industrial controls	12·0
(53·06)	Welding apparatus	20·6
(53·07)	Carbon products	40·7
(53·08)	Elect. ind. apparatus	16·6
(54·01)	House cooking equip.	18·6
(54·02)	House frig.	18·8
(54·03)	House laundry equip.	18·8
(54·04)	Elec. housewares	17·8
(54·05)	Vacuum cleaners	13·6
(54·06)	Sewing machines	13·1
(54·07)	Household appliances	18·8
(55·01)	Electric lamps	9·9
(55·02)	Lighting fixtures	25·4
(55·03)	Wiring devices	20·3
(56·01)	Radio & TV sets	16·5
(56·02)	Phonograph records	15·6
(56·03)	Telephone apparatus	10·8
(56·04)	Radio & TV commun. equip.	8·7
(57·01)	Electron tubes	13·1
(57·02)	Semiconductors	13·7
(57·03)	Electronic components	13·4
(58·01)	Storage batteries	18·3
(58·02)	Primary batteries	13·8
(58·03)	X-ray apparatus	15·8
(58·04)	Engine elec. equip.	15·5
(58·05)	Elec. equip.	15·9
(59·01)	Bus bodies	20·3
(59·02)	Truck trailers	19·8
(59·03)	Motor vehicles	17·4
(60·01)	Aircraft	8·8
(60·02)	Aircraft engines	15·0
(60·03)	Aircraft propellers	13·9
(60·04)	Aircraft equip.	10·6
(61·01)	Shipbuilding	15·5
(61·02)	Boatbuilding	15·0
(61·03)	Locomotives	14·3
(61·04)	Railroad cars	27·6
(61·05)	Motorcycles	35·6
(61·06)	Trailer coaches	16·9
(61·07)	Transportation equip.	26·4
(62·01)	Eng. & sci. instruments	11·1
(62·02)	Mech. meas. devices	12·3
(62·03)	Aut. temp. controls	12·5
(62·04)	Surgical instruments	16·8
(62·05)	Surgical appliances	13·3
(62·06)	Dental equipment	17·9
(62·07)	Watches	11·4
(63·01)	Optical instr.	18·7
(63·02)	Opthalmic goods	18·8
(63·03)	Photo equip.	17·0
(64·01)	Jewellery	31·6
(64·02)	Mus. instr.	17·8
(64·03)	Games	17·5
(64·04)	Sporting goods	14·4
(64·05)	Pens	17·9
(64·06)	Artifical flowers	43·5
(64·07)	Buttons	18·1
(64·08)	Brooms	19·3
(64·09)	Floor covering	20·2
(64·10)	Morticians goods	15·7
(64·11)	Signs	18·0
(64·12)	Misc. manu.	20·5
(65·01)	Railroads	17·3
(65·02)	Local highway pass. trans.	27·2
(65·03)	Motor freight trans.	18·5
(65·04)	Water trans.	45·4
(65·05)	Air trans.	43·5
(65·06)	Pipe line trans.	29·4
(65·07)	Trans. services	5·2
(66·00)	Communications	5·5
(67·00)	Radio & TV broadcast	6·1
(68·01)	Electric utilities	104·0
(68·02)	Gas utilities	197·3
(68·03)	Water & sanitary serv.	25·2
(69·01)	Wholesale trade	11·5
(69·02)	Retail trade	8·2
(70·01)	Banking	4·3
(70·02)	Credit agencies	16·2
(70·03)	Security brokers	6·4
(70·04)	Insurance carriers	8·9
(70·05)	Insurance agents	7·1
(71·01)	Owner-occupied dwellings	2·7
(71·02)	Real estate	10·5
(72·01)	Hotels	9·7
(72·02)	Repair services	12·5
(72·03)	Barber & beauty shops	4·0
(73·01)	Misc. bus. serv.	8·3
(73·02)	Advertising	11·6
(73·03)	Misc. prof. serv.	7·0
(75·00)	Auto repair	11·0
(76·01)	Motion pictures	13·8
(76·02)	Amusements	6·8
(77·01)	Doctors & dentists	3·7
(77·02)	Hospitals	9·2
(77·03)	Other medical serv.	12·1
(77·04)	Education	13·2
(77·05)	Non-profit organisations	10·0
(78·01)	Post office	7·2
(78·02)	Federal elec. util.	239·0
(78·03)	Commodity credit corp.	–
(78·04)	Other fed. gov.	19·8
(79·01)	Loc. gov. pass. transit	14·9
(79·02)	State elec. util.	108·0
(79·03)	Other state ent.	22·2
(80·01)	Direct imports	–
(80·02)	Transferred imports	–
(81·00)	Business travel	24·8
(82·00)	Office supplies	19·0

appropriate to an investigation of demands made on terrestrial energy sources, solar energy being used to the extent to which it is today, and people enjoying consumption for its own sake rather than to facilitate their contribution to the production process.

(e) *Feedstocks*

It is not possible to distinguish in the input-output table between, for instance, petroleum used as a feedstock and petroleum used to provide process energy. Hence both are automatically included, giving a very high energy costing for plastics, etc. The figures therefore include the opportunity cost of not using the feedstock energy elsewhere.

(f) *Technology assumption*

All figures are inevitably based on the technology of US industry in 1963. This is important to bear in mind for industrial outputs produced by a mixture of technologies. For instance, the energy cost of aluminium reflects a weighted average of the energy cost of recycling and that of extraction from bauxite. This sort of factor is probably more important than the changes in technology since 1963, since energy consumption and real GDP have risen at approximately the same rate since then (at just over 4% in the USA from 1963 to 1971). Only with the recent rise in primary energy prices can one expect technical change towards energy saving.

To summarise, the factors included and excluded are listed in Table 2.

Interpretation of results

We now describe three different areas of application of these results:

(1) *Energy cost of capital investment*

Table 1 shows the 'energy intensities' (kWh/$) of the different commodities produced in the USA. The 'flow' of energy in final products at these different 'intensities' can be represented by the

Table 2. Factors included and excluded in energy costings

Included	Excluded
Mining, quarrying of raw materials	
Metal extraction, refining, fabrication	
Transportation of intermediate products between industries	Transportation and distribution of finished product to final buyer
Lighting, heating of factories and offices	
Et cetera at all previous stages of production process	
Repairs to capital	Replacements of capital
Feedstocks	
	Labour and Profits
	Solar Energy
Energy lost in fuel conversion	

histogram in Figure 1. The vertical axis shows the money cost of purchases by final buyers (personal consumption, capital investment, government purchases, exports). The average energy intensity for the whole economy is 23·4 kWh/$ but there is quite a spread about this value (standard deviation 52·9 kWh/$) because of some commodities, which we shall consider below, whose energy intensity is too high to fit on the horizontal axis of Figure 1. Within this histogram, a separate histogram is drawn for capital investment, and shows that, although 115 of the industries make contributions to this, the spread of energy intensities of capital investment is relatively small. (Mean value = 16·5 kWh/$, standard deviation = 4·4 kWh/$). This is similar to results obtained from an analysis of UK input-output tables by the present author[10] where a narrow range of energy intensities of capital goods was also observed (mean value 44·1 kWh/1963£ = 15·8 kWh/1963$, standard deviation 3·3 kWh/1963£ = 1·2 kWh/1963$). One of the advantages of the input-output method of deriving energy costs, over the more detailed process analysis approach, is in rapidly identifying broad classes of products, such as capital goods, which have roughly the same energy intensity. One can then say with some degree of certainty that a $1 million investment programme will require roughly 16·5 x 10^6 kWh of primary energy, without going into the details of what buildings and machinery, etc, are involved.

(2) *Energy flows in foreign trade*

Another straightforward result from Table 1 and Figure 1 is to identify those commodities whose energy intensity is much higher than average. Excluding fuels, whose energy intensity is obviously high, the most striking are some foods, textiles, paper, chemicals, plastics, paints, asphalt, cement, metals, transportation. These energy intensity figures are particularly relevant to trade, as they show whether we are gaining or losing energy when we exchange commodities of equal money value. Of those listed above the most important in trade are paper, chemicals, iron and transport. Chemicals take oil as a feedstock and it is a preferred

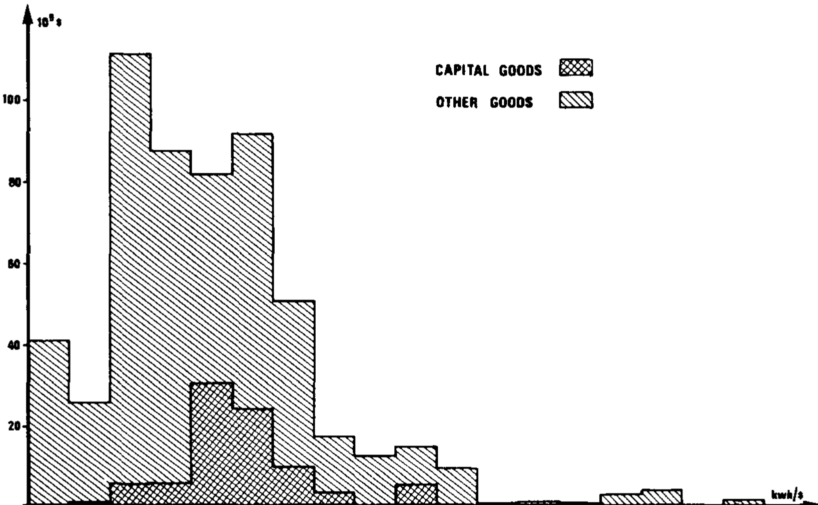

Figure 1. Energy flow at different 'intensities' in US 1963

fuel for transport, but paper and iron can be produced without it. Hence if we hypothesise that oil prices will rise relative to the cost of other primary fuels to 12-15 times the 1963 figure, it will be possible to save the same amount of energy by reducing exports of paper and iron as by increasing imports of crude oil (for the same foreign exchange cost). At present (1974) oil prices are 4-5 times their 1963 values.

A more comprehensive analysis of energy flow in foreign trade is shown in Figure 2. As mentioned above, foreign trade is more important for the UK than for the USA, and so the histograms are similar to Figure 1 but derived from the UK results.[10] In Figure 2 one histogram shows energy flowing from UK in all exports excluding fuels (mean = 41·8 kWh/1968£, standard deviation = 29·8 kWh/1968£, total energy flow = 336 x 10^9 kWh) and the other histogram shows the comparison for imports (mean = 51·7 kWh/1968£, standard deviation = 30·7 kWh/1968£, total energy

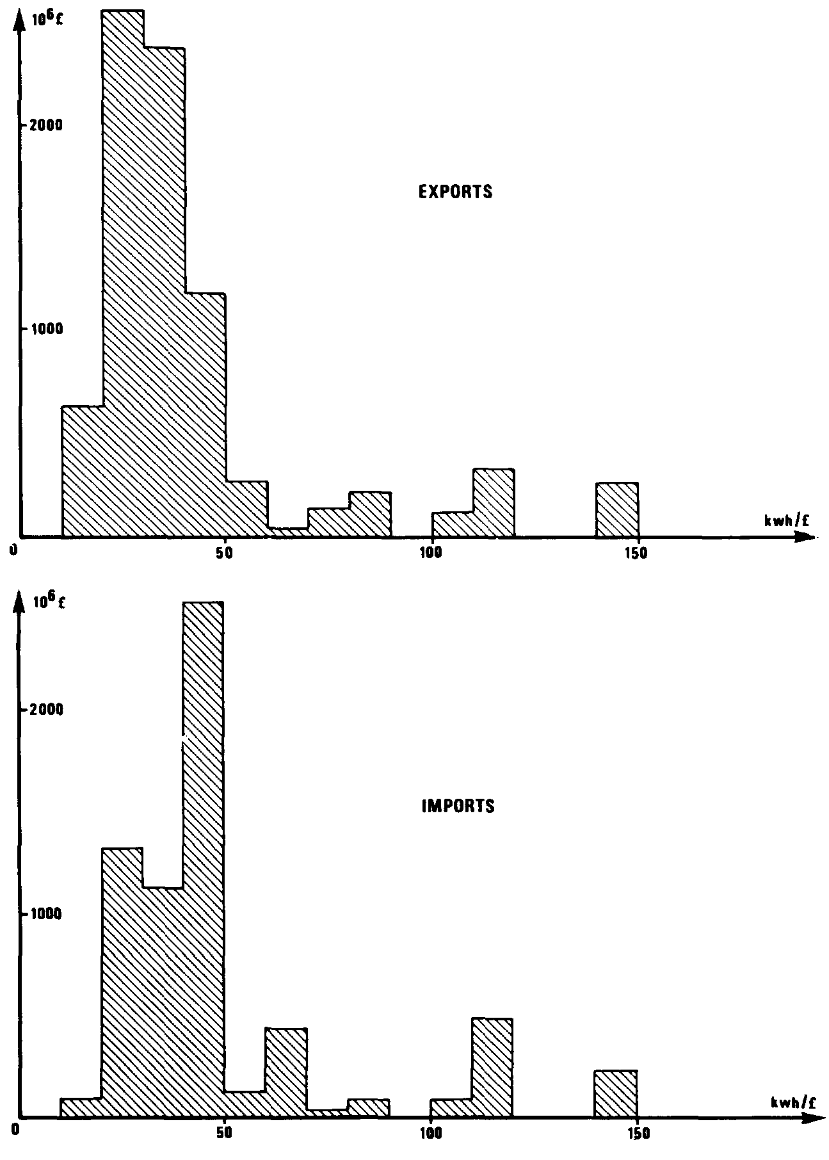

Figure 2. Energy flow at different 'intensities' in UK foreign trade 1968

flow = 339 x 10^9 kWh). Thus the energy flows balance, but imports are, on average, more energy intensive than exports (the difference is significant at the 2·5% level).

(3) *Energy cost of services*

It is often said that, as per capita income rises, the consumption pattern tends more towards services than goods which, being less energy intensive, allow some slackening in the rate of growth of demand for energy. Certainly this tendency has not had an appreciable effect on the energy/money ratio for different nations in recent years. Cross-section and time series analyses[12] of energy comsumption per capita/GNP per capita show this ratio tending to an upper asymptote as income per head rises rather than declining. Table 1 throws some light on this point to the extent of identifying the energy intensity of services. Financial and personal service industries, health, education, etc, all have an energy intensity of about 10 kWh/$, ie just under half the figure for the whole economy. So, although the energy intensity of services is certainly less than average, it is not so small that the current trend towards a 'service economy' produces a noticeable effect on overall energy consumption.

Energy costs in physical terms

So far we have been concerned with energy costs per money value of the product, and now we turn to energy costs per physical unit, ie the measure of type (3) described earlier. This is only available for those commodities which are sufficiently homogeneous to be measurable in physical units and a list is given in Table 3. As stated above these are figures for the average technology employed, so that for metals the energy cost given is lower than the cost of extraction from ore, because some is produced by (less energy intensive) recycling. Another reason for some of the figures being too low is that concessionary prices for bulk purchases of fuels have not been taken into account.

The figures in Table 3 can be expected to be less accurate than those in Table 1 because no industry produces a completely homogeneous output. Also the input-output approach is more useful for obtaining overall results for a broad range of commodities as described above, and where interest centres on a specific product a detailed process costing may be called for. For instance, the very high figure for paint in Table 3 corresponds to a similar high figure obtained from the UK input-output tables,[10] and probably indicates that a process energy costing is advisable to identify where energy savings can be achieved.

Summary

Energy costs of all commodities produced in the USA in 1963 have been derived from an input-output table. All intermediate inputs to the production are traced back to the primary energy needed to produce and transport them. Other authors have performed energy costings of individual processes and obtained more detailed results, whereas the input-output approach is more

[12] L.G. Brookes, 'More on the output elasticity of energy consumption', *Journal of Industrial Economics*, Vol 21, No 1, Autumn 1972, p. 83

Table 3. Energy costs in US in 1963 units kWh/kg unless otherwise stated

No.	Commodity	Energy cost
(1·2)	Poultry	7·32 (per kg live weight)
(2·1)	Cotton	15·7
(2·3)	Tobacco	26·4
(5·0)	Iron ore	0·504
(14·2)	Butter	27·4
(14·3)	Cheese	20·3
(14·6)	Milk	7·35
(14·14)	Flour	2·36
(14·16)	Milled rice	4·09
(14·19)	Sugar	5·74
(14·24)	Cottonseed oil	5·33
(14·25)	Soybean oil	4·98
(14·28)	Coffee	41·9
(15·1)	Cigarettes	0·0370 kWh/cigarette
(20·6)	Plywood	1·41 kWh/ft^2
(24·1)	Pulp	7·83
(24·2)	Paper	17·02
(27·2)	Fertilisers	8·63 (per kg plant nutrient)
(28·2)	Synthetic rubber	35·8
(30·0)	Paints	199·7 kWh/gal.
(32·3)	Reclaimed rubber	6·10
(37·1)	Pig iron	4·34
(37·2)	Steel (ex-foundry)	3·27
(37·3)	Steel forgings	6·39
(38·1)	Copper	22·1
(38·2)	Lead	7·14
(38·3)	Zinc	10·5
(38·4)	Aluminium	24·4
(38·8)	Aluminium sheet	30·4

appropriate for producing results for a range of commodities, eg capital goods, imports, exports, etc. Input-output tables are usually available in published form whereas data for process costing are sometimes less easy to obtain. However, input-output tables are at least 5 years out of date because of the time currently taken to carry out the required census and then compile the table. This applies to the technology used, not to the prices. The availability of input-output tables facilitates comparisons between countries although this is not attempted in this article. Also the input-output approach can readily be applied to any other natural resource, or combination of resources, besides primary energy.

We have presented above energy costs per unit of money value (Table 1) which are appropriate to comparing money and energy costs for different commodities, and also energy costs per physical unit (Table 3) which are useful in obtaining a relation between physical production and demands on primary energy sources. It is difficult to estimate the accuracy of these figures but anything better than 10-15% would be optimistic.

Acknowledgement

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