“Summary of article by P.F. Chapman: Energy Costs: A Review of Methods” in Frontier Issues in Economic Thought, Volume 1: A Survey of Ecological Economics. Island Press: Washington DC, 1995. pp. 201-204

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## “Summary of article by P.F. Chapman: Energy Costs: A Review of Methods”

The inadequate description of real input costs and the assumption of substitutability inherent in financial analysis of production systems can lead to false conclusions and poor decision making. As an alternative, a number of investigators have turned their attention to the energy costs of production. There are many methods used to evaluate the energy cost of a product, often yielding substantially different results. The purpose of this review is to explain these variations in results, which are often due to the different aims of the investigations.

### THE NATURE OF THE PROBLEM

There are three problems in evaluating the energy cost of a product. The first is choosing a sub-system for which all the inputs and outputs are known. For example, there are three simple sub-systems for production of a loaf of bread: the bakery, the bakery plus the baker's shop, and the entire production system (e.g., including all farming and transport systems, etc.). The energy costs increase as the size of the sub-system increases, but it is not possible to include all production processes in the world. The sub-system must therefore be restricted in such a way that those inputs that are left out make an acceptably small difference in the total energy cost. The second problem is deciding what types of energy must be included and how they should be added together. Solar energy is usually not included in energy cost calculations, and energy that is consumed in the production and delivery of fossil fuel may or may not be included. Energy inputs in the form of calorific value of food are also usually ignored. A third type of problem arises in dividing up energy costs when more than one product is produced. These problems do not have a single correct solution, but appropriate conventions for obtaining satisfactory results are needed.

### AIMS OF ENERGY STUDIES

The aims of energy studies can be classified in four categories:

1) deducing the energy efficiency of processes and making recommendations for conserving energy: Such studies are often carried out by individual industries using data that is not widely available.
2) analyzing energy consumption on a large scale so as to forecast or reduce future energy demand: This is the most popular type of study, and it is usually carried out using published national statistics.

3) analyzing the energy consumption associated with basic technologies (e.g., for food production, mineral extraction) in order to gauge the consequences of technological trends or energy shortages: These studies are often carried out in areas where conventional economics and "conservationists" disagree, and the conclusions are generally based on published data and presented in terms of national and global averages.
4) understanding the thermodynamics of an industrial system.

## METHODS

There are three methods used to calculate the energy costs of products:

1) **Statistical Analysis:** This method takes data on the supply of energy to various industries and on industrial output to estimate the energy cost per unit of output. For example, the Digest of Energy Statistics shows that the energy supplied to the iron and steel industries in the UK in 1968 was 6871 x $10^6$ therms, and the Iron and Steel Industry Annual Statistics gives the output of crude steel as 25.86 x $10^6$ tons. This yields a value for energy cost per unit of steel produced of 265.7 therms/ton. This result does not take into account the energy costs involved in generating the electricity and coke used in steel production, the energy sales by the iron and steel industry, and the energy costs of other inputs in the production process. However, these shortcomings can be overcome by using other available statistics. While this method gives a broad estimate of energy costs in an industry, it cannot distinguish between different products within the same industry.

2) **Input-Output Table Analysis:** An input-output table is a square matrix that includes all inputs and commodities necessary to make other commodities, and relates the currency values of the various inputs needed to produce a unit currency of output. One problem with the input-output table is that all firms in an industry are lumped together. In addition, the data is in financial rather than physical terms, so price fluctuations may lead to errors.

3) **Process Analysis:** The three stages involved in process analysis are:

a) identifying the network of processes that lead to a final product;
b) identifying the inputs involved in each process; and
c) assigning an energy value to each input.

The two problems associated with this method are choosing an appropriate sub-system and assigning energy values. The problem of assigning energy values arises because in some cases an output is also an input in its own production process (e.g., machines that are made of steel are used to produce steel). Therefore, to calculate the energy cost of producing steel, this same energy cost is needed as an input in the calculations. This problem can be solved by making an initial estimation of the cost and then using a set of simultaneous equations to further refine this estimate.

## RESULTS

Several examples of different energy value calculations indicate the care that must be taken in interpreting results:

1) **Copper Smelting:** This example of a detailed process analysis shows how the choice of sub-system influences the results. In copper smelting, an electric furnace has a 61% thermal efficiency and fuel-heated furnaces a thermal efficiency of 27%. The industry therefore finds that the electric furnace provides a substantial energy savings. However, if the sub-system is enlarged to include electricity supply and the production of electric furnaces, the opposite results emerge. Thus the copper smelting industry is improving thermal efficiency within its limited sub-system, but decreasing efficiency within the larger national sub-system.

2) **Supply of Electricity:** This example shows how the aims of a study can alter the results. According to the Digest of Energy Statistics, the primary inputs in the UK are coal, oil, gas, nuclear electricity and hydro-electricity, all of which are converted into coal equivalents. Using this convention, the energy cost of one kilowatt-hour of electricity (kWhe) consumed is 3.91 kilowatt-hours of thermal energy (kWhth). However, if the inputs are instead taken to be either the output of nuclear and hydro-stations and/or fossil fuels, different energy costs result. Similarly, differences in how the indirect energy consumption of power stations is accounted for will further affect results.

3) **Oil Refining:** This is an example of an industry where there is more than one output, so the question arises as to how inputs should be partitioned between different outputs. Crude oil is refined into fuels and chemical feedstock in oil refineries, and the chemical feedstock is then processed into organic chemicals. Different conventions can be adopted, including assigning all of the calorific value to the fuels, or dividing it between fuels and chemical feedstock.

## CONCLUSIONS

Energy analysis is valuable because it can show ways of conserving energy and highlight particular problems. But the results of energy studies must be carefully interpreted with regard to the sub-systems being analyzed and the methods used to measure energy inputs. Neglect of these factors could lead to misleading conclusions.