COMMENT: ENERGY ACCOUNTING: THE CASE OF FARM MACHINERY IN MARYLAND

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Prior to the 1970s, energy accounting was the primary domain of physical scientists or engineers. The world of thermodynamics, rigorous concepts of energy ratios and entropy, seemed safe within their laboratories where, for example, the relative energy efficiency of solid and liquid fuels was assessed for powering an industrial heating system. This apparent orderly state of affairs—measurement primarily in controlled laboratory conditions—seemed to change abruptly in 1973 with the OPEC oil embargo. Energy accounting became the chore, if not the mission, of a myriad of scientists, engineers, businessmen, bureaucrats, and politicians. Understandably, the journals and other periodicals of our profession now abound with proposals on how to measure energy and how to employ these measures in making decisions and developing government policies.

Set against this background, the July, 1980, *SJAE* article by Foster et al., provides some useful and interesting empirical estimates on the energy consumption associated with individual farm machines. Although the proportion of on-farm energy attributable to farm machines has been counted (e.g., Steinhart and Steinhart), the precise accuracy of previous estimates is open to question. Regarding this problem, Foster et al. conclude that "58 percent of the energy used in agricultural commodities in Maryland was accounted for by farm machinery" (Table 4). Accordingly, the primary rationale for their research is "because farm machinery accounts for a large proportion of the energy devoted to agricultural production" (p. 192).

Even though there has been a great deal of work on measuring energy used in agriculture, few previously published studies have measured energy expended for producing individual farm machines. Indeed, very little work of any sort has been conducted on indirect energy usage in agriculture. The 1977 study by Doering et al., as Foster et al. note (p. 189), provides "estimates only for energy value added in manufacturing." In a 1980 CRC handbook by Pimentel, Doering (pp. 9–14) presents some guidelines for estimating pre-manufacturing energy as well as the energy needed for machine repairs resulting from on-farm use. The Foster et al. article is consistent with Doering's later work and thus provides "a more complete, disaggregated agricultural equipment energy analysis," (p. 189) one which attempts to account for most of the fossil fuel energy embodied in farm machines.

The purpose of this article is not to quarrel with the accuracy of individual estimates presented by Foster and his colleagues. Rather, its thrust is to question some of their measurement procedures, and particularly to examine their methodology for allocating embodied energy across the years of a machine's use and among farm commodities. The discussion follows the same basic order as their presentation, which centered on results presented in four closely related tables. Hence, the separate questions and criticisms are outlines (numbered), followed by some elaboration on each. Some thoughts on the nature of a more appropriate accounting methodology are presented in the concluding paragraphs.

COMMENTS ON MEASUREMENT PROCEDURES

1. Foster et al. list embodied energy (EE) estimates for 20 of the most important farm machines (their Table 1), but they do not describe the technique(s) used to obtain these numbers. Was it process analysis, or input-output (I/O) analysis, or some combination of, say, process analysis at the machine fabrication-assembly stages combined with I/O for pre-fabrication processes? Because they employ a disaggregated analysis, one would guess that their numbers are obtained via process analysis. They cite the work by Bullard et al., which indicates awareness of these two basic accounting techniques and possibilities for their joint use. Since subsequent results depend upon Table 1, this omission may limit the article's usefulness.

2. Embodied energy per year? How can energy that has been expended be allocated among future years using, for example, a 10-year straight line depreciation scheme (Table 1)?

   Allocation of EE among years cannot be

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defended upon grounds that it is analogous to depreciating the dollar amount invested in a machine. As farm machines become older, they have a undepreciated (remaining) dollar value. Among other things, depreciation is an accounting scheme to estimate this dollar value. But the moment a machine arrives at the farm gate, all so-called embodied energy (EE) has been expended (lost forever). Energy-using processes to produce a farm machine are directly related to time, and, thus, as any output is produced, each process is irreversible. Insofar as the solar system is concerned, each process (each farm machine that is produced) moves us to a higher entropic state. Of course, it is possible for energy to be conserved in future machine production processes by recycling materials (parts of machines) produced by previous processes. In reality, however, farm machines rarely are recycled, a point made by Foster et al., since, in effect, current forces dictate that recycling probably is not economically feasible and may even be a waste of energy.

Even if recycling becomes feasible, the logic of allocating EE among years is not sound. There is, it seems, virtually as much energy recycling value in steel and various other machine components after a farm machine is 10 years old as there was the day the machine was newly purchased.

There is another argument for allocation of EE that is implicit in the 1977 work by Doering et al., that of the Steinharts, and in some parts of the 1980 handbook by Pimentel. It runs as follows: EE should be allocated among years (depreciated) because for each added year that a current (older) machine is used, energy is saved in not having to purchase a replacement. But this argument ignores the very essence of complete flow accounting of energy. In any given time period (e.g., year), the older machine may require more added energy for maintenance, repairs, and for added fuel usage than the extra energy required to produce a new machine. Virtually no data are available on the energy required for repairs. Hence, the real problem needing attention requires a solid, comprehensive data base used in a time flow approach, coupled with a valid replacement criterion. A "valid" replacement criterion could require either an optimizing model (see Perrin, 1972) or a predictive model.

Depreciation of embodied energy (EE) is misleading at best and will quite likely lead to a host of other logical errors. Indeed, the term "embodied energy," through commonly used, has a misleading connotation and probably should be replaced by different terminology, for example, "indirect energy" (Bradford et al.).

3. The "distribution" (Foster et al.) of yearly EE among selected commodities also rests upon shaky ground (their Table 2). Any sort of distribution, regardless of the weighting scheme, is arbitrary unless the EE is clearly tied to only one commodity. Just as the farm management analyst looks askance when allocating joint fixed costs, the energy analyst should acknowledge the subjective nature of this sort of exercise. But Foster and his co-authors attempted to rationalize their calculations, saying: "It therefore seemed appropriate to distribute. . . ." (p. 190).

4. Combining embodied energy (EE) with direct energy (DE) required to power farm machines (their Table 3) is an exercise that is laden with all the problems mentioned above. Such a procedure compounds the time allocation illogic (point #2) with the commodity distribution misrepresentation (point #3). One can only speculate on the accuracy of the ratio, that is, the relative accuracy of DE and EE—2.66 (DE) to 1 (EE)—for all commodities in Table 3.

5. The validity of comparing EE of machinery to that for annual inputs, such as fertilizers, rests on the questionable logic of the previous tables. For example, suppose an average life of 20 years had been assumed for machines listed in Table 1, as opposed to the 10 years. The machinery EE as a percentage of the total would have been 8.6, rather than the 15.8 that was shown (their Table 4). Which number is correct?

MEASUREMENT BY A FLOW APPROACH

A valid aggregate analysis of energy usage should be consistent with economic theory and thermodynamic laws. It seems that any such analysis should account for four separate components of energy use associated with farm machines: (a) direct and indirect energy required to produce and transport new farm machines to the target economic sector (e.g., to the farm gate), (b) energy required to dispose of (junk) machines being retired from service, (c) energy required to maintain and repair each separate period's inventory of machines, and (d) the energy required to operate (fuel, etc.) each period's inventory.

The accounting procedures used by Foster et al. to estimate the total indirect (embodied) energy per each type of farm machine appear to be valid. However, rather than aggregating across the entire current year's inventory of machines in order to estimate total indirect energy (IE), a valid time flow approach calls for multiplying the number of newly purchased machines of each type in each period (e.g., year) by the IE required per machine. Inasmuch as periodic sales data from sources such as the Farm Industrial Equipment Institute may be more accurate than total on-farm inventory data, the accounting results obtained by Foster and his co-authors would be improved by a flow approach. The length of this comment precludes a detailed delineation and description of such an approach.

Finally, at the very root of the embodied energy accounting problem, one must examine any sort of measurement on the grounds that calorie counting does not automatically translate into energy measurement. Purists such as Turvey and Nobay argue that measuring energy in common physical units (calories) is replete with theoretical problems and is inferior to using dollar expenditures in constant prices. Others, for example Edwards, accept physical energy accounting, provided the analysis is directed to positive rather than normative analysis. As Edwards notes: "Discussion of energy efficiency in agriculture sometimes reveals an energy fundamentalism, the acceptance of which requires rejection of basic tenets of production economics as well as consumer sovereignty." Foster et al. obviously do not embrace such excesses, although in their final paragraph, there appears to be an implicit approval of what might be called "the energy theory of value."

On balance, such problems are not common to the work by these authors. Previous work on energy embodied in machines has followed at least some of the same approaches. Even so, the methodology and measurement techniques of their article should be viewed with at least some skepticism. This is particularly true of the results beyond Table 1, where numbers rest upon an arbitrary allocation of embodied energy measures among time (years) and among farm production processes and commodities.

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