ACTA ALIMENTARIA POLONICA

Vol. XIII (XXXVII), No. 3 1987

T. NOWACKI

TECHNOLOGICAL VALENCY OF THE FOOD USABLE ENERGY AS A CRITERION OF EVALUATION OF ENERGY CONSUMPTION IN FOOD PRODUCTION

Warsaw Agricultural University

The methodology introduces and defines some basic terms and denominations used in food production energetics. A model study presents changes in unitary energy consumption and production of foodstuffs.

INTRODUCTION

In the earliest period of development, changes in the technology of food production tended towards substitution of manual labour and draught animal-work with mechanical force and thereafter towards replacing less efficient machines with more efficient ones, a process involving an increase in the power demand in the food production system. This demand increases also in with the parallelly increasing intensification of food production. This phenomenon attracted much interest lately in the face of the growing world energy crisis, as a result of which ways of cutting back on energy consumption in food production are also being sought.

In well developed countries the food production system takes up only a few per cent of the energy balance. However, in countries beasting a medium level of development the energy consumed by the food production system acconnts for only several per cent of the total energy input, and in developing countries for as little as tenths of one per cent. Therefore, the knowledge of trends in changes of energy consumed in the food production system and of the balance of energy consumption is particularly important in a rational design of the energy infrastructure of the food production system and of economical utilization of a country's energy resources, the more so since there is sometimes the possibility of replacing a difficult-to-come-by energy carrier with one more easily available. For this reason all decisions must be carefully studied and stated to prevent any impediment of food production intensification. After all, agricultural production, which provides man with the most efficient energy carrier in the form of food, determines the prosperity of every country in the world.

Given the considerable variation in the methodology of food production energy analyses [1, 3], it is difficult, to compare results. In addition one needs to take into account local conditions and the technological level of a given country. Price changes of energy carriers, agricultural products and foodstuffs, as well as changes in consumption structures of particular groups of energy carriers sometimes cannot be compared.

The technological method of energy balancing in agriculture (TEBER) introduced in this paper [2], is aimed at eliminating the aforementioned problems in evaluating the energetic effectiveness of food and agricultural productivity. The aplication of this methodology enables a more accurate evaluation of the changes and trends in the quantity and balance of energy consumption in food production than achieved heretofore. A particular feature of this method (TEBER) is the possibility of evaluating the quantity of energy consumption, its structure and costs in any technical and economic conditions in food production.

METHODOLOGY USED IN AGRICULTURAL AND FOOD PRODUCTION ENERGY ANALYSES

In the simplified scheme of the energy conversion chain in the Food Production System (FPS) one can distinguish (Fig. 1) five main areas: plant production (APP), animal food production (AAP), foodstuff processing (AFP), food distribution (AFD) and meal preparation (AMP).

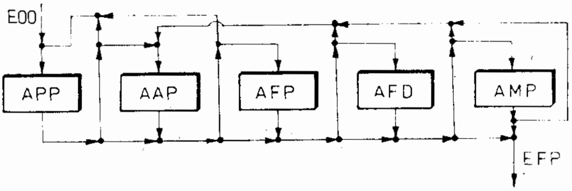


Fig. 1. Scheme of the energy conversion chain in the Food Producton system (FPS)

Energy input stream FPS is the energy of the natural environment EOO, and the energy output stream FPS is the energy contained in the foodstuffs (EFP). There are also five main energy streams distinguished in energy balance of the Food Production System (FPS), namely three incoming streams: energy of natural environment — EOO, direct production energy — E10, indirect production energy — E20, and two outgoing

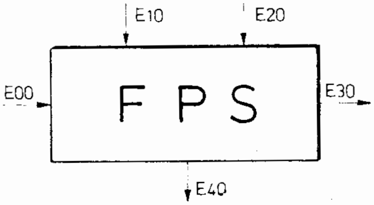


Fig. 2. Scheme of energy flow in the Food Production System

streams: energy gained from FPS — E30 and energy losses — E40 (Fig. 2). Becauce of difficulties in estimating natural environment energy EOO and energy losses E40 these two energy streams are usually omitted in partial energy balances Fig. 3.

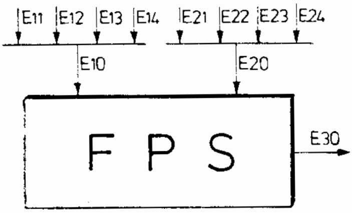


Fig. 3. Scheme of partial energy balance in the Food Production System

In direct energy (E10) one can distinguish energy equivalent to: personnel work (E11), machine work (E12), work performed by electric equipment (E13) and work performed by heat generating devices (E14). In indirect energy (E20) one can distinguish energy equivalents of chemical products (E21), buildings and water system structures (E23) and infrastructure of FPS (E24). The energy gained from FPS (E30) consists of energy contained in different kinds of foodstuffs and energy contained in residues and wastes.

For each of these streams, an energy input or output consists of different energy kinds (Eij) and each particular kind of energy can appear as one of three energy forms, namely: rated energy (Eijr), usable energy (Eiju), and cumulative energy (Eijc).

The term "rated energy" (Eijr) denotes a record containing basic information about energy input or output in FPS. This record is usually made in natural (traditional) units commonly used in data recording in enterprises, such as man-hour (M • h), draught horse-hour (H • h), kW • h, etc.

The term "usable energy" (Eiju) denotes the actual amount of energy supplied to or gained during the production process in FPS. The usable energy outlay can be determined by a direct measurement during machine operation or may be estimated using rated energy records and an appropriate conversion coefficient. Usable energy appears in different degrees of conversion, and therefore, similarly as rated energy, can be balanced to a limited extent, within a range of this energy form in a particular degree of conversion.

The calculation of usable human energy input (E11u) and machine work input (E12u) in any considered technological process enables determination of the index of their technological levels. The index of technological level (W) is defined as the ratio of machine work (E12) to the sum of personnel work (E11) and machine work (E12) input: $W = \frac{E12u}{E11u + E12u} \cdot 100(\%)$.

The term "cumulative energy" (Eijc) denotes the sum of all energy outlays born to generate a considered amount of usable energy (Eiju). Cumulative energy is expressed as equivalent of fossil (primary) energy of fossil coal on its gaining level.

A direct convertion of rated energy (Eijr) into usable energy (Eiju) is possible with the use of the emprical coefficient of rated energy utilization $(\beta): Eije = \beta ij \cdot Eijr$.

The coefficient β incorporates measures of: energy conversion effectiveness in the power transmission system, technical effectiveness of machine sets, wor organization pattern, and efficiency of an FPS service.

For converting usable energy (Eiju) into cumulative energy (Eijc), an empirical coefficient ϑ is used. This coefficient is described as the technological valency of usable energy $\vartheta ij = \frac{Eijc}{Eiju}$ and thus $Eijc = \vartheta ij \cdot Eiju$.

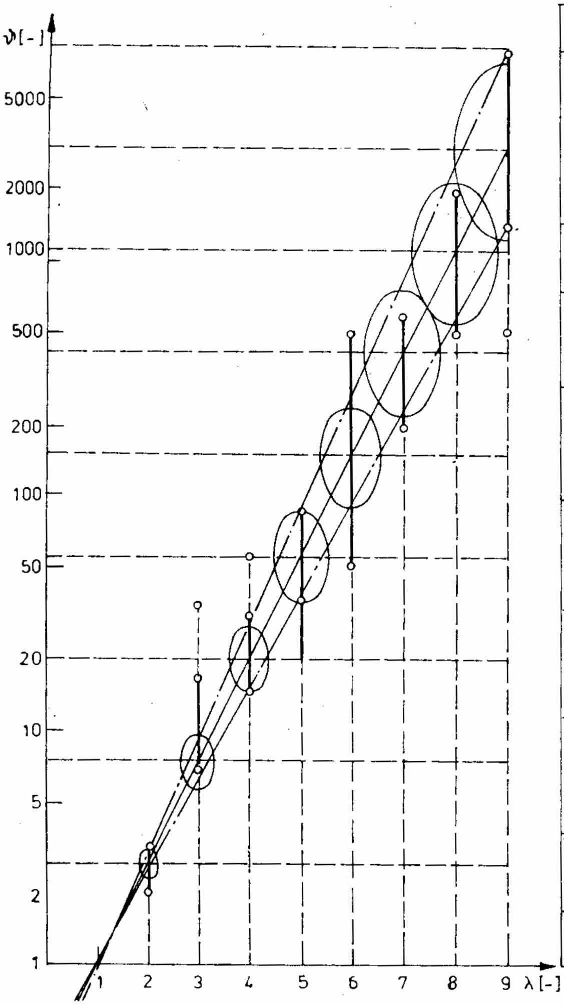
The cumulative energy used in the generation of a specific amount of usable energy can usually be estimated only roughly, with a complex cumulative calculation. Technological valency of usable energy may be also assessed for practical purposes as the ratio of unitary cost of usable energy in the considered degree of energy conversion (kij) to the unitary cost of primary energy (k_o) on its gaining level: $\vartheta ij = \frac{kij}{k_o}$.

When quantifiying "k_o" the costs are expressed in the currency of a particular country, taking into consideration the weighed average of the most commonly used energy carriers. An increment of the degree of energy conversion (λ) is accompanied by an exponential increase in the value of technological valency of usable energy (ϑ).

Thus $\vartheta = e^{\lambda - 1}$, and hence $\lambda = \ln \vartheta + 1$ (see Fig. 4).

The data in Fig. 4 concern the technological valency of chosen energy carriers and energy sources applied to the food production system in relation to the degree of energy conversion (λ) as mean values for several European countries.

By defining the "technological valency" of energy it has been proved that human work should be quantified differently than it was done heretofore.



	ϑ	λ
labour: - of managerial staff	2000- -8000	9
- highly skilled	1000- -4000	
- skilled	500-1500	
animal products	400- -2000	8
farm machinery work	200-600	7
food products	100-500	6
butter, milk	200-300	
bread, sugar	50-150	
plant products	20-80	5
potatoes	40-80	
wheat	15-25	
electric energy	15-50	4
thermal energy	10-50	
petrol	13-30	3
fuel diesel oil	7-12	
fertilizer	7-9	
stove coal	2-3	2
conventional fuel unit	1	1

Fig. 4. Ratio of the index of technological valency of usable energy (ϑ) and degree of energy conversion (λ) for selected energy carriers and foodstuffs

Also food products — a form of highly processed energy suitable for further metabolic transformation in living organisms — should be placed adequately high in the energy balance. It is wrong to consider the "calorific value" of food products identically as an equivalent of the calorific value of primary fuels. It is worth stressing that the so-called carriers of primary energy also differ sharply in terms of their technological energy valency. Being a scalar quantity, the index ϑ may be used to compare different countries regardless of monetary units, currency exchange rates, etc. This index can be applied additionally as a criterion in evaluation of the food production cumulative energy consumption.

Index ϑ often depends on the level of the technological development index (W) of the considered country. The scalar form of both indices

(W, ϑ) not only facilitates the examination of changes and trends in energy consumption, but also makes it possible to determine the effectivenes of this consumption and shows the directions of rationalization in energy consumption generally. The Technological Method of Cumulative Energy Balancing in Agriculture (TEBER) employed all the above terms and denominations used in FPS energetics. When applying the TEBER method to the energy analysis of any of the considered technological processes, the total energy input may be limited to five basic components which dominate in the FPS energy balance, namely: personnel work, machine work, work performed by electrical equipment, thermal energy, and energy sequestered in chemical products.

After analysing the obtained results, one concludes that a minimum of energy input exists in the range between $W = 50\%$ and $W = 70\%$. For the same range of "W", the partial energy production effectivenes (the ratio of cumulative energy output of foodstuffs to the considered cumulative energy inputs) has its maximum value [2].

CASE STUDIES

Using the records of energy inputs and outputs in selected enterprises of different technological level one can construct models of changes in the energy balance composed of inputs calculated on the basis of cumulative energy per unit of production. Such models can be constructed within a relatively wide range of the technological level index ($10\% < W < 90\%$); the optimization calculus as well as prognostic methods are thus applicable. In this study particular model dependencies are formulated on the basis of statistical data. The considered values pertain to one man acting in agriculture and are presented (Fig. 5) as a function of technological production level (W). The models are:

fdu [MJ/M · d] — food daily usable energy equivalent (consumption by one man acting in agriculture) — Fig. 5. 1.

ϑ 61[-] — technological valency of food usable energy (consumed by population) — Fig. 5.2.

fdc [GJ/M · d] — food daily cumulative energy equivalent — Fig. 5.3. ($fdc = \vartheta 61 \cdot fdu$);

fac [GJ/M · a] — food yearly cumulative energy equivalent by five person family — Fig. 5.5. ($fac = 365 \cdot fdc \cdot 5$);

yac [GJ/M · a] — foodstuff yearly cumulative energy equivalent produced by one man acting in agriculture — Fig. 5.4.

yac and fac [GJ/M · a] — balance (yearly) of cumulative energy — Fig. 5.5.

ε [-] — index of foodstuff productivity of one man active in agriculture — Fig. 5.6.

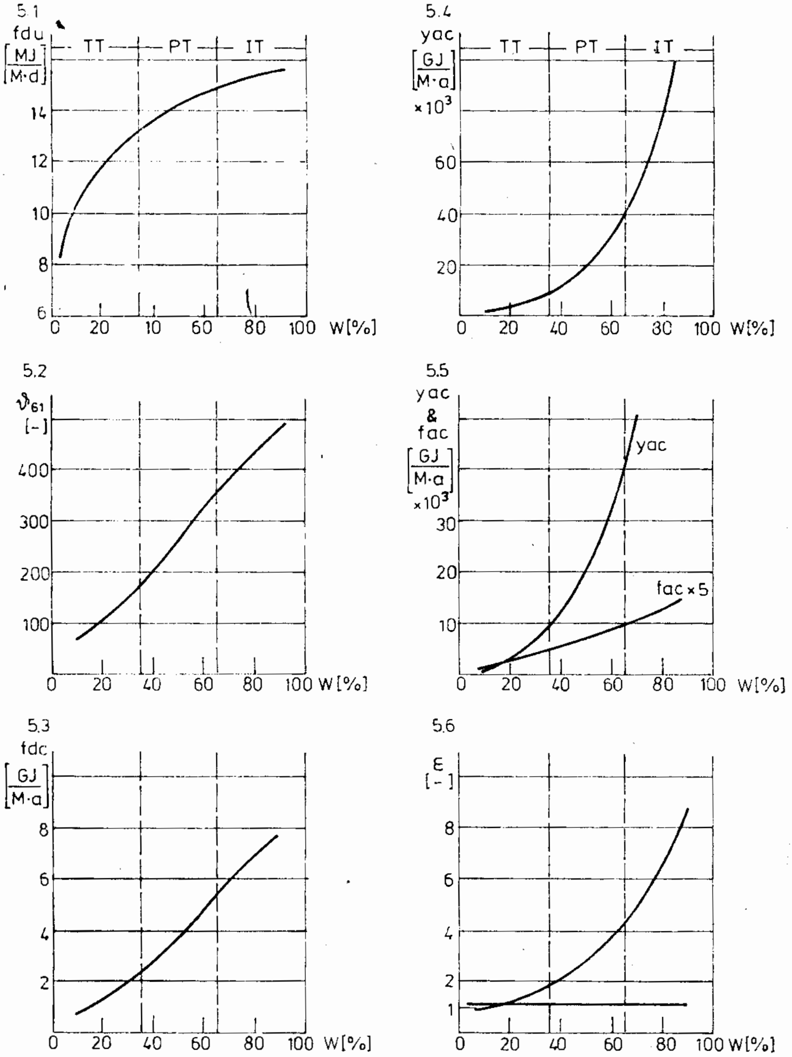


Fig. 5. Set of models dealing with food production effectiveness

The diagrams in Fig. 5 prove that with the increase of the index of technological level, from the traditional technology sub-range (TT) through progressive technology (PT) to industrial technology (IT), the energy effectiveness of food production increases.

CONCLUSIONS

1. In the energy analysis of the food production system, information concerning energy outlays or energy gains can be expressed as one of three recording forms: rated energy, usable energy, and cumulative

energy. Only the last mentioned form should be used in preparing energy balances.

2. In converting rated energy into usable energy an empirical coefficient of rated energy utilization is used. This coefficient incorporates the converting efficiency of rated energy, its utilization degree, and a factor converting traditional units to SI units.

3. In converting usable energy into cumulative energy an empirical coefficient is used, described as the technological valency of usable energy. This coefficient can be applied as a criterian of evaluating food production cumulative energy consumption. Both coefficients, of rated energy utilization and of technological valency of usable energy, depend on actual production conditions in the considered enterprise as well as on the index of technological production level.

4. Before a common method of balancing energy consumption in food production is accepted, it seems necessary to present simultaneously data concerning the consumption of rated energy in traditional units and the data concerning the usable energy and the cumulative energy in SI units along with specified factors of conversion.

5. The presentation of data concerning energy requirements in food production, expressed in traditionally applied units, is of a great practical value because of the universal use of such units.

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Author address: 02-528 Warszawa, Rakowiecka 26/30

T. Nowacki

TECHNOLOGICZNA WARTOŚCIOWOŚĆ UŻYTECZNEJ ENERGII ŻYWNOŚCI JAKO KRYTERIUM OCENY ZUŻYCIA ENERGII NA PRODUKCJĘ ŻYWNOŚCI

Szkoła Główna Gospodarstwa Wiejskiego — Akademia Rolnicza, Warszawa

Streszczenie

Zastosowana w pracy metodologia wprowadza i definiuje pewne podstawowe znaczenia i określenia stosowane w energetyce dotyczącej rolnictwa i przetwórstwa

żywności. Przede wszystkim uściślone są pojęcia określonych form energii: energia nominalna, użyteczna i skumulowana. Wprowadza się i definiuje współczynniki wykorzystania energii nominalnej, a także stosunek technologicznej wartościowości energii użytecznej; elementy te podlegają zmianie, zależnie od wskaźnika poziomu przetwórstwa żywności. Współczynniki te obejmują sprawność zamiany energii, wykorzystanie energii i stopień zamiany energii.

Wprowadza się również średnią jednostkowego kosztu energii kopalin, co pozwala na bezpośrednie obliczenie przybliżonego kosztu nakładów energetycznych na podstawie kosztu energii kopalin. Dodatkowo pozwala to porównać koszt poszczególnych elementów nakładów energetycznych w skali międzynarodowej i uniezależnia bilansowanie energii od fluktuacji cen nośników energii, a także od zmian wskaźników przeliczeniowych różnych walut.

Szczególną uwagę zwraca się na właściwe wywartościowanie nakładu pracy ludzkiej w bilansach energii, zarówno w zakresie pracy fizycznej, jak i umysłowej. Podane są wyniki badań modelowych zmian jednostkowego zużycia energii w produkcji, jak również struktura komponentów bilansu energii w zależności od poziomu technologicznego produkcji. Prostota i uniwersalność przedstawionej metody TEBER pozwala na jej zastosowanie w warunkach każdego kraju.