ANALYTICAL APPROACHES TO STATISTICAL PUBLICATIONS ON ENERGY

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Comparison of Statistical Aggregates

The role of statistics in each scientific work is very difficult to overestimate, especially as far as studies in the field of energy are concerned.

There are a lot of statistical publications on energy for regions and separate countries issued by national and international bodies as well as private ones. But only a few do so on a world wide basis (see Table 1.). Unfortunately their data differ from each other therefore they are not comparable. It is very useful for both the world energy consumption and calculation of energy resources to eliminate or to reduce these differences. It is the first but a very important step for the successful implementation of the energy project.

Table 1

Source	Scope of data	Note
1. U.N. World Energy Supplies, N.Y.	Statistical data on the energy production and consumption of different energy sources of the whole world, separate regions and countries, and also the data on trade in fuels.	1. It is issued annually and is the most regular and comprehensive of all relevant publications in this field. 2. The U.N. publication excludes lubricants and greases from its data. Crude petroleum as such is not included in the UN figures on liquid fuel consumption; rather, the United Nations - departing from its procedure for measuring the consumption of other fuels - begins its liquid fuel consumption calculation with figures on production of refined petroleum products. As a result that portion of crude oil consumption diverted to non-energy uses such as petrochemical feed stocks is excluded from the UN data. 3. Bunkers are excluded. 4. Data are given in million metric tons of coal equivalent. 5. 1000 Kwh of electricity equal 0.125 tons of hard coal equivalent.

2. Statistics of energy OECD, Paris	Statistical data on the energetics of OECD member countries	1. It is issued annually. 2. There is no summary table of the consumption or production of energy in coal equivalent units. 3. Data are given for separate sources in million metric tons, billion cubic metres at 4200 Kcal and billion Kwh.
3. OECD Energy policy (Paris, 1966)	The additional study about selected world energy totals.	1. The OECD adopts a method of converting hydroelectric data resulting in oil equivalents somewhat higher than if the hydro were converted at a calorific value, but considerably below that if it were measured at central station fuel-input. The OECD method introduces an allowance for conversion losses from the failing water to generating station terminals. However, since the efficiency assumed (74 %) is much higher than the efficiency of thermal production the coal equivalent value of hydro still understates hydro's contribution to primary energy.

		2. The OECD measures liquid fuel consumption inclusive of crude oil diverted to feed stocks. 3. Bunkers are included in total consumption. 4. The OECD study relied on the OECD's own statistics as well as on materials including, but going beyond, the UN data. That's why this publication shows higher energy consumption totals than the U.N.
4. Energy statistics, statistical office of the European Communities, Luxemburg	Statistical data on the overall energy balance - sheet of all countries EEC. There are also some world data.	1. It is issued annually. 2. Data of the overall energy balance sheet of all EEC countries are given in metric tons of coal equivalent. 3. World data for separate sources are given in million metric tons, billion cubic metres and billion Kwh. However, these data are not given for individual countries. 4. The recalculation of electricity in tons of coal equivalent is done on the bases of the average specific consumption of all conventional steam power stations in each EEC country, expressed in grammes of coal equi-

		valent needed for the production of 1 Kwh (brut) per year. This coefficient differs from country to country.
5. United Kingdom Commonwealth Economic Committee, "Sources of Energy" (London: Her Majesty's Stationary Office, 1966)	The same statistical data as in U.N. World Energy Supplies	1. Hydroelectricity has been converted at higher central station fuel-input equivalent. The U.K. conversion factor of 0.6 tons coal = 1000 Kwh hydro appears to us as somewhat too high as a world wide average for the mid-1960s. (about 0.4 tons coal = 1000 Kwh).

There are differences however, not only among the structural components of statistics but also among the conversion factors. For example, the OECD assumes that 1 ton crude oil content equals 10^7 Kcal., in the UN World Energy Supplies it is $8.944 \cdot 10^6$ Kcal, in the EEC Energy Statistics, it is also about 10^7 Kcal, and in the International Petroleum Encyclopedia it equals $10.762 \cdot 10^6$ Kcal. The same situation is in coal conversion factors: the UN World Energy Supplies assumes that 1 ton hard coal equivalent is equal to $6.88 \cdot 10^6$ Kcal, in the EEC Energy Statistics it is $7 \cdot 10^6$ Kcal, in the OECD reports it is $7 \cdot 10^6$ Kcal and in the International Petroleum Encyclopedia $7.278 \cdot 10^6$ (see Appendices I, II, III, IV).

One of the more troublesome problems associated with the measurement of energy in a common denominator unit has to do with the treatment of hydroelectricity. One has translated hydro in terms of its inherent heat value - i.e. at the rate of 0.125 kg of hard coal equaling 1 Kwh of electricity; or, alternatively, hydropower can be expressed by using the coal-equivalent quantity of fuel required, under prevailing conditions, at thermal power stations. A roughly calculated world-wide estimate of this hypothetical equivalence is (for the recent years) that the equivalent of somewhat less than 0.40 kg hard coal equals 1 Kwh of electricity. The figure 0.40 also expressed commonly in Btu, is termed the "heat rate", the output - input ration of 0.125 to 0.40 represents "the efficiency" of fuel used in electricity generation in percentage terms, equalling about 30%; while the difference between 0.40 and 0.125 largely represents energy loss arising from the conversion of heat energy in the mechanical energy needed to turn the dynamos.

Both the first and the second methods have some virtues and shortcomings. For example, one of the main shortcomings of the first method consists in its distorting effect; it seriously understates the energy production and consumption of countries with substantial proportions of hydroelectric energy. For example, with Norway's hydropower measured at the inherent heat value, the total energy consump-

tion in this country in 1971 comes to about 20.3 million tons coal equivalent; with the hydro component measured at a hypothetical fuel input of 0.36 kg of coal per 1 Kwh. Norway's aggregate comes to 35.0 million coal equivalent tons, a nearly 72 % jump.
The main shortcoming of the second method consists in the difficulty of assembling meaningful conversion factors in a world wide statistical study, which vary for every year and for each country. It depends on the generating technology and efficiency of thermal power stations of these countries.

Moreover, quite apart from the problem of measuring hydroelectricity distortions in energy comparisons arise from the fact that in practice equal quantities of heat content in two countries may, depending on the efficiency and allocation of uses, be put to highly unequal amounts of productively used energy. Logically this would call for conversion adjustments, i.e. so called "coefficients of substitution" similar to the hypothetical fuel input procedure in the case of a hydropower country.

Bearing in mind all these differences for the future work in the Energy Group of IIASA it is necessary to establish a single approach to these factors. Concluding we may choose the following approaches to this problem:

1. To use the UN data, as a standard and widely used source, but to calculate 1 ton of crude oil at a conversion factor of 1.5 tons of hard coal equivalent (see Table 2).
On the one hand, we can translate hydro in terms of its inherent heat value (0.125 metric tons of hard coal equivalent equals 1,000 Kwh of electricity) and it seems that this would need not lead to any serious errors in calculations of world energy resources or world energy balance because the role of hydro has been declining and will continue to decline each year, both in the world electric energy production and in the world energy balance (see Tables 3,4).

Table 2

Conversion Factors a)

Units	Joule- (Newton x meter)	BTU	Kcal	Kg hard coal equivalent	Kwh (th)	Watt (th)
1 MEV	$1.6\cdot10^{-13}$		$3.83\cdot10^{-17}$			-
1 BEV	$1.6\cdot10^{-10}$					-
1 ER^{cy}=1Dyne·centimeter	10^{-7}					-
1 ton of TNT	$4.2\cdot10^{9}$	$4.0\cdot10^{6}$	10^{6}	$1.46\cdot10^{2}$	$1.17\cdot10^{3}$	
1 g of matter (energy equivalent)	$9\cdot10^{13}$	$8.52\cdot10^{10}$	$2.15\cdot10^{10}$	$3.12\cdot10^{6}$	$2.5\cdot10^{7}$	-
1 atom of U-235 energy of fission	$1.6\cdot10^{-12}$					
1 kg of U-235 ≈ 2000 t TNT	$8.4\cdot10^{13}$	$8\cdot10^{10}$	$2.1\cdot10^{10}$	$2.91\cdot10^{6}$	$2.33\cdot10^{7}$	
Earth's Daily Receipt of Solar Energy	$1.49\cdot10^{22}$	$1.41\cdot10^{19}$	$3.56\cdot10^{18}$	$5.17\cdot10^{14}$	$4.14\cdot10^{15}$	-
Sun's Daily Output of Energy	$3\cdot10^{32}$	$2.84\cdot10^{29}$	$7.17\cdot10^{28}$	$1.04\cdot10^{25}$	$8.33\cdot10^{25}$	
1 foot-pound	1.356					-

a) Calculations are based on some sources such as Ch.Starr "Energy and Power" "Scientific American" Sept. 1971 No.3. Vol 224, pp. 48-49; UN World Energy Supplies 1962-1965. Statistical Papers, Series J, No.10, 1967 p.6-8.

1 B.T.U. (mean)	$1.056 \cdot 10^{3}$	-	0.252	$3.66 \cdot 10^{-5}$	$2.93 \cdot 10^{-4}$	-
Q	$1.056 \cdot 10^{21}$	10^{18}	$2.52 \cdot 10^{17}$	$3.66 \cdot 10^{13}$	$2.93 \cdot 10^{14}$	-
1 Kcal	$4.184 \cdot 10^{3}$	~4	-	$1.45 \cdot 10^{-4}$	$1.16 \cdot 10^{-3}$	-
1 Kwh	$3.6 \cdot 10^{6}$	3.412	860	0.125 b)	-	-
1 kg hard coal equivalent	$28{,}824 \cdot 10^{3}$	27,295	6.880	-	8 b)	-
1 ton hard coal equivalent	$28{,}824 \cdot 10^{6}$	$27{,}295 \cdot 10^{3}$	$6.88 \cdot 10^{6}$	1,000	8000 b)	-
1 ton of crude oil	$43{,}235 \cdot 10^{6}$	$40{,}943 \cdot 10^{3}$	$10.320 \cdot 10^{6}$	1500	12000	-
BTU/second						$1.056 \cdot 10^{3}$
Q/year						$3.34 \cdot 10^{13}$
Q/day						$1.22 \cdot 10^{16}$
Kilowatt						10^{3}
Megawatt						10^{6}

b) The conversion to electric energy in tce is done taking into account the mean specific consumption of all the conventional thermal power plants of each country: this conversion factor corresponds thus to the mean consumption of the fuel quantity, given each year in gram coal equivalent necessary to produce one gross Kwh. This factor varies every year and for each country.

Table 3

Year	Total billion Kwh	of them in %		
		hydro	thermal	nuclear
1961	2453.3	29.6	70,2	0.2
1965	3378.2	27.1	72.2	0.7
1968	4206.6	25.1	73.7	1.2
1969	4571.9	24.6	74.0	1.4
1970	4910.2	24.0	74.4	1.6
1971	5222.5	23.0	74.9	2.1
1980[a)]	9800	19.3	60.7	20.0

Source: World Energy Supplies 1961-1970 U.N. 1972, p.322
Statistical Yearbook 1972., N.Y. 1973, p.p. 366,374
a) Estimation of ESSO AG, Volkwirtschaftliche Abteilung October 1969, p. 11

Table 4

Year	Total energy mill. metric tons coal equivalent	of them in %				
		coal and lignite	crude petroleum	natural gas	hydro electricity	nuclear electr.
1925	1567	81.7	14.6	3.1	0.6	-
1961	4270	47.4	34.8	15.7	2.1	-a)
1965	5316	42.7	37.6	17.5	2.2	-a)
1968	6140	37.0	41.4	19.3	2.1	0.1
1969	6514	35.8	42.0	19.9	2.2	0.1
1970	6988	34.3	43.0	20.5	2.1	0.1
1971	7260	33.0	43.7	21.0	2.1	0.2
1980	11195	32.3	41.3	22.2	2.1	2.1

Source: Statistical Yearbook 1972, U.N. 1973, p.p. 36,374
a) less than 0.1 percent
b) J.Darmstadter "Energy in the World Economy" 1971, p. 44

Moreover the ratio of output to input has been declining each year, but accordingly to the second law of thermodynamics the maximum possible thermal efficiency of the cycle (Cycle Carnau) is determined by the maximum and minimum absolute temperatures of the cycle (T_0 and T_1);

$$\eta_t = \frac{T_0 - T_1}{T_0}$$

If a usual steam turbine had worked on Carnau's cycle its efficiency at the usual temperatures of the steam turbine $T_0 = 773^{\circ}K$ and $T_1 = 293^{\circ}K$ could have been equal only to

$$\eta_t = \frac{773-293}{773} = 0.62 \text{ or } 62\ \%$$

According to calculations of Soviet Scientists the maximum efficiency of steam power stations may be equal to 45 %. In this case the specific consumption of hard coal equivalent would have been 0.278 Kg/ /Kwh. If the MHD - generators are put into operation the efficiency steam power stations will manage to increase to 50-60 % (0.208-0.250 kg/Kwh). On the other hand, the share of nuclear electricity will grow each year and for the year 2000, it is estimated to be equal 50 % of the entire world electricity production and more than 20 % of the whole world energy consumption. That is why if we calculated hydro and nuclear on the basis of their inherent value, world energy demand in 2000 (about 23 billion tons coal equivalent) (in the case of steam power station's efficiency equal 0.208-0.250 kg/Kwh would increase to 15.7-23.5 % and to 28.7 % (efficiency equals 0.278 kg/Kwh).

2. To measure energy in kilowatt hours, although the decision to use coal equivalents (or rarely oil equivalents) as the unit of energy measurement conforms to wide spread usage. Our goal is not to invent new measurement but to use the more convenient and more correct ways of translation of different units into a common denominator unit. The measurement of primary energy resources in kilowatt hours is necessary in our opinion for the following reasons:

a) Such conversion factors as ton coal equivalent (tce) or ton or barrel of oil equivalent were created historically. TCE arose when coal was the main energy source in the world (more 83% in 1925). Ton oil equivalent followed the coal equivalent because oil began to substitute coal and now the oil accounts for 44% of world energy consumption and only 31 % of solid fuels.

b) Using barrel of oil equivalent, which is a volumetric unit, for conversion barrels into tons, we must take into consideration different specific gravities at different kinds of oil. That is why there are difficulties for precise calculations of energy balance.

c) There is a trend in the world economy: more and more primary energy sources are transformed into electricity. For example, if in 1960 about 20% of all energy resources were transformed into electricity, in 2000 this share is expected to increase up to 50 %. In the more distant future this share is likely to increase again. The changes in consumption of primary energy by sources in the past as well as in the future is due to the social needs for economic and technical development. Society has required and will continue to require cheaper and more convenient forms of secondary energy, e.g. electricity.

d) Kilowatt hour is not metric, not volumetric unit, that is why we don't need to use nor metric units (the USSR, European countries except England) or barrels (english speaking countries)

e) Primary fuels will be calculated in kilowatt hours at an average heat rate for the actual production of electricity. In this case there is no necessity to use double calculations 0.125 and 0.40 how some people suggest.

f) This measurement gives a possibility to take into account technical progress in thermal as well as in the nuclear power stations.