Commentary on and extension of calculative procedure for CO_2 production

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ABSTRACT

Further refinements are made in the method of calculating amounts of carbon dioxide released to the atmosphere through the combustion of fossil fuels. Data available in the UN *Statistical Yearbook* are used as the basic sources rather than the summary, *World Energy Supplies*, U.N. Statistical Papers, Series J because the most recent data are available several months earlier in the yearbook and because data are included for natural gasoline, natural gas liquids, and cement production. Coal, lignite, crude petroleum, "marketed" natural gas, flared natural gas, and cement are itemized separately and revised CO_2 emission estimates are made for each year from 1960 thru 1971. These estimates average 2.3 % higher than Keeling's with the carbon dioxide production from flared gas being the largest difference. Natural gas which is flared at the well accounts for over 2 % of the total CO_2 produced from fossil fuels.

1. Introduction

A consistent and documented method for estimating the global CO_2 emissions from fossil fuels and other man induced sources is essential to the systematic analysis of atmospheric changes. The CO_2 increase which has occurred in the atmosphere is a clear indicator that there is an imbalance between what man has produced and what nature can remove and store in reservoirs other than the atmosphere. Clearly an understanding of the extent of imbalance and the ability of the total environment to adjust to these changes requires better estimates on total CO_2 emissions. Keeling (1) has presented such a method with assumptions carefully indicated and all data properly documented.

As with any calculation procedure the results depend on the validity of the assumptions and the accuracy of the initial data employed.

Keeling used the United Nations statistical data as presented in *World Energy Supplies*, U.N. Statistical Papers, Series J (2), for amounts of fossil fuel produced. Although this is an excellent source, it should be pointed out that similar data are available in the *Minerals Yearbook* (3) of the U.S. Bureau of Mines, and the U.N. *Statistical Yearbook* (4). All three sources are complete and are dependable to the same relative accuracy. There are differences, however, and care is necessary to avoid misinterpreting or double counting. The *World Energy Supplies*, U.N. Series J, discounts the low grade part of the coal mined in the USSR, treating it as lignite. This source also adds the natural gasoline produced from natural gas to the amount of crude petroleum produced while the *Minerals Yearbook* (3) and the U.N. *Statistical Yearbook* (4) do not. The data from the United Nations (and also the U.S. Bureau of Mines) present two basic problems in their use for calculating CO_2 production.

1. The UN data are basically commercial data; i.e., they are the fuel quantities that are sold and/or traded, not those which are opened to consumption. They are based on replies by officials of the various national governments to inquiries from the UN statistical office. Although care is taken to define terms carefully, the staff assembling the data still must do some estimating and cross-checking in order to have a series of data which are reasonable. Waste (flaring of natural gas, for example) is not included. In some cases this can add directly to the CO_2 emissions, while in others the result-

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Table 1. *Fators for calculation of CO_2 emissions*

	Coal	Lignite (As mined)	Lignite Coal equivalents	Crude petroleum	Marketed natural gas	Flared natural gas	Cement
Carbon fraction of fuel (by wt. except natural gas)	0.70	0.28	0.63	0..84	540 g m^{-3}	540 g m^{-3}	0.137
Fraction of carbon oxidized to CO_2	0.99	0.99	0.99	0.915	0.97	1.00	1.00
"CO_2 factor"[a]	0.693	0.277	0.624	0.769	0.524	0.540	0.137
Keeling error estimate, %	14.8		14.8	12.8	9.6		

[a] CO_2 emission obtained by multiplying weight of fuel reported (for coal, lignite, and petroleum) or by volume of fuel reported (for natural gas) by "CO_2 factor". For marketed natural gas, the volume in 10^9 cubic meters times 0.524 gives the weight of carbon in millions of metric tons.

ing CO_2 emissions are very difficult to estimate and it is likely that the oxidation will take place over a period of years. In the case of natural gas, beginning in 1970 the *Minerals Yearbook* (2) lists "gross production" and "marketed production". The data which agree reasonably well with those of the U.N. are the ones listed as "marketed production". Excluded is "gas used for repressuring ... as well as gas flared, or otherwise wasted, whether of not it has first been processed for the extraction of natural gas liquids".

2. The accuracy of the data presented is not indicated. If the data are to be of maximum value in scientific calculations the statisticians should assign confidence limits. Arthur J. Ramsdell (personal communication, 1972) of the U.N. statistical office indicated that the figures that are returned from the various countries are studied, equated, analyzed and when published are the best possible on the basis of all the information available at the time of publication. It is evident that U.N. fuel data cannot be published with scientific type confidence limits, but in spite of this difficulty it is as good a source of information as is now available. Keeling (1) has attempted to estimate an accuracy on the fuel production data, but this is difficult and the limits must be broad for the confidence to be high.

2. Caculation of CO_2 production

Fundamentally, what Keeling (1) has done is to present a study in which the average carbon content of each fuel type was estimated and then the fraction of this carbon which was immediately converted (on the average) into CO_2 during the combustion process was calculated. The appropriate quantities for the conversion to CO_2 of portions of the unburned fuel products and the non-fuel hydrocarbons were added. His analysis resulted in the factors summarized in Table 1.

3. Coal data

An analysis of the tabulation of coal production as reported by the UN and by the U.S. Bureau of Mines shows remarkable consistency. Essentially, the same UN data is available either in the UN *Statistical Yearbook* (3) or in the UN Statistical Papers, Series J, *World Energy Supplies* (4). The U.S. Bureau of Mines publishes data in the *Minerals Yearbook* (2) not only for the U.S. but other countries as well.

The differences among the three sources arises mainly from the tabulation of lignite data in coal equivalents in the Series J work, and in the handling of the USSR coal data. In Series J, *World Energy Supplies*, coal is treated on a ton for ton basis except in the case of the USSR. Checking all other countries shows excellent agreement among the reported amounts in each of these three sources. In the case of the USSR, Ramsdell in the preparation of Series J, has attempted to correct the reported coal data (as published in the U.N. *Statistical Yearbook*, for example) to reflect the fact that some of the coal is low quality. The Russian Yearbook reports solid fuels on the basis of equivalent weight of 7 000 Kcal/kg (12 600 BTU/1b) coal. The 1968 Russian data show 447.3 million metric tons of solid fuel (7 000 Kcal/Kg) and the Series J *World Energy Supplies* divides it 215.1 million metric tons of coal and 231.9 million metric tons of lignite "coal equivalents". The U.N. *Statistical Yearbook* shows 416.4 million metric tons of coal and 135.9 million metric tons of lignite. The reassignment of coal into the lignite category was not totally arbitrary; 215.1 million metric tons were from areas of quality coal and hence were taken at face value. The remaining 201.3 million metric tons were discounted by the proper amount and then added to the lignite so that the total of coal and lignite in coal equivalents totaled 447 million metric tons.

In both the *Statistical Yearbook* and the *World Energy Supplies* the data are revised and updated as reporting procedures change in the various countries. Users of the data will note changes since the publications always include four or more of the most recent years. It was indicated that it is sometimes a year or two before "washed" coal data are available for certain countries. Although pit head data on a washed basis is what the UN requests, such are not always supplied (at least without a delay). An example of such was a rather recent reduction in the amounts reported from Australia which resulted in about an 8% decrease as a consequence of a change in reporting procedures to account for washing (waste removal). The U.N. makes a formal request for data through established governmental channels and those data should be accurate within the understanding of the definitions. The U.S. Bureau of Mines relies on a variety of sources including questionnaires sent to the minerals authorities in the various nations.

The UN statisticians have found it necessary to rely on the same sources of information as the U.S. Bureau of Mines in obtaining estimated data on coal production in China. Therefore, agreement for China appears to be relatively good, but persons working with the data feel that the possible errors here are quite large compared with errors in other areas. Keeling (1) found the 1958–1960 data for Chinese coal were suspiciously high and tried to correct them. It is suspected that a portion of the amount tabulated is "low grade" and should more properly be included with the lignite. Hopefully, now that China is a U.N. member, data will be reported on the same basis and through the same procedures as other member nations.

The U.S. Bureau of Mines and the U.N. Statistical Office each send out questionnaires seeking data on production of fossil fuels. The degree to which the data contained in the replies are accurate and dependable varies with the care with which the information is handled in the various countries. In cases of incomplete or non-returned questionnaries, the U.S. Bureau of Mines makes estimates of production based on both governmental and private corporate reports as well as professional journals. Frequently when the U.N. is unable to obtain data from other sources they will use the U.S. Bureau of Mines data and an occasional footnot in UN data tabulations indicates this. Close agreement between the U.N. data and the U.S. Bureau of Mines data is noted. Sometimes the sources are identical and sometimes they are independent; the consistency between the resulting tabulations is reassuring.

Little difference results in the calculated amounts of CO_2 production whether the coal data from the U.S. *Minerals Yearbook*, the U.N. *Statistical Yearbook*, or the U.N. Series J *World Energy Supplies* are used provided that one is careful to make corrections for the handling of the coal from the USSR. Using the coal data *as reported* in the *Minerals Yearbook* or in the UN *Statistical Yearbook* will result in larger apparent coal consumption and thus greater CO_2 production. In section 9 the actual calculations are summarized and this point is discussed further.

4. Lignite data

Keeling (1) uses a single total for solid fuel which includes the data for lignite reduced to a coal equivalent basis. Such data are available from the U.N. Statistical Papers, Series J (4) where they have been calculated on the basis of quality of the lignite on a national basis. Such conversion factors were established early in the energy supplies reporting endeavors of the UN and are reviewed at irregular intervals. The same comments made above for the coal data from the USSR and from China apply to the lignite data. In the case of the USSR it is only a question of how to handle the data; when consistent procedures are followed, the results are consistent. The reported amounts of lignite produced appear to have the same high degree of accuracy as the data for coal production.

As in the case of coal, no significant differences in the resulting CO_2 production estimates are observed when using each of the three data sources, if care is taken to be sure that the lower grade coal from the USSR is handled in the same way when using data from each source. It does seem that there might be small merit in keeping the coal and lignite separate rather than combining them into a total "solid fuel" category. Keeling (1) has developed a "CO_2 factor" for coal of 0.693 and for lignite of 0.277 (or 0.624 for lignite quantities expressed in coal equivalents). Based on an average ratio of coal to lignite he has determined a CO_2 factor for solid fuels of 0.683. Little difference in calculated CO_2 production results whether the two solid fuels are combined or separated. In this work the lignite is kept separate and the sum of CO_2 produced from burning coal and burning lignite agrees very closely (averaging within 0.1%) with Keeling's results considering all solid fuels together. Only if the ratio of coal to lignite production changes, thus invalidating the 0.683 factor for the combined fuels, will the procedures give different results.

5. Crude petroleum data

In the case of petroleum data, the UN *Statistical Yearbook* (3) presents a table for crude petroleum in the section "mining, quarrying". In addition, in the section on manufacturing industry, tables are presented for the production of natural gasoline and for liquefied petroleum gas produced from natural gas. The U.N. Series J *World Energy Supplies* (4) presents data that Keeling (1) used in his estimates of CO_2 production. In preparing the data for the Series J publication the UN statisticans have added the natural gasoline into the crude petroleum amount reported. This is reasonable and apparently customary for the study of petroleum since the natural gasoline is used principally for blending with motor fuels refined from liquid petroleum. However, the use of such a figure in calculating the total CO_2 emissions raises some questions regarding *primary* fuel data.

In the collection of natural gas in the field efficient operation requires that liquids be kept out of the natural gas collecting lines. The removal of crude oil, water and gasoline condensates is accomplished through the use of scrubbers and drips. The oil and gasoline liquids collected in this manner are generally added to the crude oil being sent to the refinery. This is referred to as "lease condensate" in the *Minerals Yearbook* and is added into the crude oil production. For example, for 1970, the following are tabulated for the U.S.:

crude petroleum produced 3 350 666 thousand 42 gal. barrels
lease condensate 166 784 thousand 42 gal. barrels
total crude petroleum 3 517 450 thousand 42 gal. barrels

It is the total figure that is reported in the world summary of production by countries in the *Minerals Yearbook* and checks with the corresponding figures reported in the United Nations publications.

After the removal of the "lease condensate", the natural gas is generally measured by an orifice meter and the values obtained from these meters are reported as "marketed production". The gas may subsequently pass through a plant for extraction of natural gasoline and other natural gas liquids, and this results in a decrease in the volume of gas that is actually consumed as natural gas. In 1970 the United States and Canada together produced 85% of the world's natural gasoline and 95% of the liquefied petroleum gases. In the United States alone, the 24.3 million metric tons of natural gasoline and 34.3 million metric tons of liquefied petroleum gases produced in 1970 resulted in "extraction losses" of 25.6×10^9 cubic meters of natural gas. Thus, if the data used for the crude petroleum include natural gasoline amounts, the data for natural gas production should be reduced by an appropriate amount to avoid accounting for some of the hydrocarbons in two different primary fuel categories.

It has been estimated by L. L. Fanelli of the U.S. Bureau of Mines (private communication, 1973) that 37 or 38 cubic feet of gas are lost for every gallon of natural gasoline produced. Using the "CO_2 factors" as developed by Keeling (1) and presented in Table I, 37.5 cubic feet of gas produced will result in 556 grams of carbon in the emitted CO_2, while each gallon of gasoline adds 2 800 grams to the crude petroleum data and 2 150 grams of carbon in the CO_2 emissions. The difference is due largely to the fact that the "CO_2 factor" for natural gas was based on the analysis of typical natural gas as presented by Brame and King in *Fuel; Solid, Liquid and Gaseous*. There is more mass of carbon in the extracted liquids than in reported shrinkage volumes [of gas] resulting from the extraction of the liquids.

In order to accurately determine the CO_2 production it would be best to reduce the amount reported for "marketed production" of natural gas by an amount proper to cover the extraction losses in natural gasoline plants and then treat the natural gasoline and the natural gas liquids separately. This adds significantly to the calculations and also to the data needed to make reasonable CO_2 estimates. As pointed out above, the production of liquids from natural gasoline plants takes place mainly in North America, and the total production is small when compared with world wide crude petroleum and natural gas production. Total production of liquids from natural gas were much less a decade ago and thus errors in earlier years are small. Keeling's (1) use of crude petroleum data which included natural gasoline would appear to give good estimates on CO_2 production for past years. As natural gasoline plants become more numerous and their output larger, it is probably better to include both natural gasoline and liquefied petroleum gas along with the crude petroleum for the purposes of calculating CO_2 production. The carbon content of these hydrocarbons is 82% or more and is much closer to the 84% carbon which Keeling (1) deduced as an average for crude petroleum. The error is thus reduced by treating all the natural gas liquids as crude petroleum, and the relative error may be further reduced by subtracting from the marketed natural gas an amount for the extraction losses (shrinkage) at the natural gasoline plants.

Data are presented in both the U.N. *Statistical Yearbook* (4) and the *Minerals Yearbook* (3) for crude petroleum without including any liquids derived from natural gas. In the *World Energy Supplies*, UN Statistical Papers, Series J the values for crude petroleum include the natural gasoline produced from gas but not the other liquids. Since the basic data agree in all three sources it makes no difference in calculating CO_2 production which source is used provided that care is taken to include both natural gasoline and other natural gas liquids along with crude petroleum.

6. Data for marketed natural gas

As with other fossil fuels data are available for natural gas in the U.N. *Statistical Yearbook* (3), the U.N. Statistical Papers, Series J, *World Energy Supplies* (4) and the *Minerals Yearbook* (2). Reasonable agreement is found among the three with differences being attributable to later or revised data being available at the time of publication of one source as opposed to the others. The data presented are for "marketed production" (although in 1970 the *Minerals Yearbook* also started tabulating "gross production"), and no attempt has been made to subtract a volume to account for the extraction losses or "shrinkage" when the gas is passed through a plant for the production of natural gas liquids. Although the amounts have been small and the collection of natural gas liquids has occurred mostly in the U.S., the shrinkage should no longer be disregarded. It is probable that extraction of liquids from natural gas will increase on a global basis with an associated decrease in the fraction of marketed natural gas which will be used as "gas". In calculating the CO_2 produced from natural gas in Section 9, a correction has been made to the marketed production data to account for extraction losses.

Extraction losses are tabulated for the U.S. in *Minerals Yearbook* for years 1962 and later. Increasing the amounts in proportion to the ratio of total world production of natural gas liquids to U.S. production gives the estimates used.

A second difficulty with "marketed production" data for natural gas is the exclusion of "gas used for re-establishing pressure in the fields, as well as gas flared, vented or wasted". According to A. R. Kahn at the Eighth Arab Oil Congress (5), over 7×10^9 cubic feet per day of gas is now flared during oil production in the Persian Gulf area. The *Minerals Yearbook* (2) gives an estimate for each recent year which is of the order of 500×10^9 cubic feet per year for

Table 2. *Gas flared—1971 (in millions of cubic feet)*

N. America	
Barbados	29
Canada	86 183
Mexico	144 364
Trinidad	32 801
United States	300 503
S. America	
Argentina	57 331
Bolivia	23 138
Brazil	33 266
Chile	—[a]
Columbia	23 027
Ecuador	9 120
Peru	44 250
Venezuela	570 901
Europe	
Austria	2 497
Czechoslavakia	5 226
France	91 430
Germany, W.	7 585
Netherlands	3 390
U.S.S.R.	452 200
Africa	
Algeria	200 000
Angola	31 400
Congo (Brazzaville)	55
Gabon	9 535
Libya	347 993
Nigeria	440 555
UAR (Egypt)	28 000
Asia	
Bahrain	—[a]
Brunei	112 000
India	27 050
Indonesia	76 711
Iran	1 006 266
Iraq	189 278
Japan	780
Kuwait	416 705
Oman	20 000
Qatar	112 938
Saudi Arabia	738 597
Trucial States:	
Abu Dhabi	325 794
Dubai	26 000
New Zealand	2 035
World Total	5 998 933

[a] Entire difference between "Gross production" and "Marketed production" was used in repressuring.

gas flared and/or vented in the United States. These two total 10% of the reported world-wide marketed production. Clearly world-wide flaring of natural gas is an important consideration in the calculation of CO_2 emission.

7. Data for flared natural gas

Beginning with the 1970 *Minerals Yearbook* the U.S. Bureau of Mines published global figures for gross production of natural gas as well as marketed production. The difference is the sum of gas used for repressuring and that flared or vented. For the U.S. the amount used for repressuring is nearly 3 times that vented and flared, however, for the rest of the world no simple ratio or proportion seems to hold. With the assistance of Mr Charles Kimbell of the Office of Technical Data Services of the U.S. Bureau of Mines, and Mr David Carleton of the Division of Fossil Fuels of the U.S. Bureau of Mines, it was possible to estimate on a nation by nation basis the amount of gas which was flared. For some nations data were available on amounts used for repressuring, but most often some data or good estimates were available only for flaring. However, in all cases the sums of the estimates for flaring and repressuring were equal to the differences between the "gross production" and "marketed production" published values. The resulting estimates on gas flared in 1971 are tabulated in Table 2.

A similar table was prepared for 1968, 1969, and 1970. The 1970 *Minerals Yearbook* gives values for gross production and marketed production for 1968 and 1969, but only data on marketed production are available for years prior to 1968. For 1968, 1969, and 1970 the difference between reported gross and marketed production was divided between gas used for repressuring and gas flared on the basis of the best information available in the U.S. Bureau of Mines.

In order to obtain estimates on natural gas flared prior to 1968 when data for many countries are extremely sparse, a procedure was developed which related gas flared to crude petroleum produced. From data for the four years, 1968 thru 1971, a regression line was determined to be:

$$\Delta_2 = 1387 + 2.205\Delta_1$$

where:

Δ_2 = for a given year, gas flared world-wide minus gas flared in the U.S.

Table 3. *Calculation of CO_2 emissions (all entries in million metric tons, except natural gas, lines 9, 10, 12 in 10^9 cubic meters)*

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971 *a*
1. Coal production reported (adjusted for low grade coal from USSR)	1 802.7	1 623.8	1 672.5	1 736.7	1 797.9	1 816.5	1 848.5	1 749.6	1 812.7	1 873.0	1 922.1	2 026.5
2. Carbon in coal converted to CO_2[b]	1 249.27	1 125.29	1 159.04	1 203.53	1 245.94	1 258.83	1 281.01	1 212.47	1 256.20	1 297.99	1 332.02	1 404.36
3. Lignite production reported (adjusted for low grade coal from USSR)	896.7	922.0	926.2	986.4	1 026.2	1 047.5	1 064.5	1 054.0	1 066.4	1 094.5	1 135.2	1 163.5
4. Lignite production (in coal equivalents-Ser. J)	383	396	396	423	440	452	460.60	456.46	460.53	470.99	488.07	
5. Carbon in lignite converted to CO_2[b]	248.39	255.39	256.56	273.23	284.26	290.16	294.87	291.96	295.39	303.18	314.45	322.29
6. Crude oil production	1 053.6	1 122.2	1 217.2	1 305.8	1 409.7	1 510.7	1 641.6	1 761.1	1 923.4	2 072.6	2 278.4	2 404.8
7. Natural gas liquids	37.8	39.3	41.2	44.5	48.4	51.1	54.1	61.9	66.2	70.3	74.3	75.6
8. Carbon in petroleum + NG liquids converted to CO_2[b]	839.29	893.19	967.71	1 038.38	1 121.28	1 201.02	1 303.99	1 401.89	1 530.00	1 647.89	1 809.23	1 907.43
9. Natural gas "marketed"	468.4	505.4	552.2	603.6	658.2	705.1	765.2	817.0	888.8	973.9	1 071.4	1 133.4
10. Less extraction loss for liquids[c]	17.8	18.9	20.2	22.6	24.9	26.6	26.1	27.4	28.4	30.7	32.5	31.8
11. Carbon in "marketed" natural gas converted to CO_2[b]	236.11	254.93	278.77	304.44	331.85	355.53	387.29	413.75	450.85	494.24	544.38	577.23
12. Natural gas "flared"	99.27	102.05	104.74	108.44	113.41	118.61	126.86	135.97	147.85	152.42	165.3	169.9
13. Carbon in "flared" natural gas converted to CO_2[b]	53.61	55.11	56.56	58.56	61.24	64.05	68.50	73.42	79.84	82.31	89.26	91.75
14. Cement production	317	334	358	377	415	434	464	480	514	542	571	590
15. Carbon converted to CO_2 in cement production	43.43	45.76	49.05	51.65	56.86	59.46	63.57	65.76	70.42	74.25	78.23	80.86
16. Total carbon in CO_2	2 670.1	2 629.7	2 767.7	2 929.8	3 101.4	3 229.1	3 399.2	3 459.3	3 682.7	3 899.9	4 167.6	4 383.9
17. Total CO_2 from fossil fuels and cement	9 783	9 635	10 141	10 735	11 364	11 831	12 455	12 675	13 493	14 289	15 270	16 063

[a] 1971 figures from U.S. Bureau of Mines — 1971 *Mineral Yearbook* (in press).
[b] Obtained by multiplying data above by "Co_2 factor" from Table 1.
[c] Extrapolated from U.S. extraction loss data (80 to 90 % of N.G. liguids are produced in U.S.).

Δ_1 = for a given year, crude petroleum produced world-wide minus crude petroleum produced in the U.S.

Crude petroleum amounts are in millions of metric tons.
Natural gas quantities are in 10^9 cubic feet.

This made it possible to estimate the gas flared from the non-U.S. portion of the world for 1960 thru 1967 and since good data are available for amounts flared in the U.S. for this period, simple addition then gave a world-wide total. Since data are available for the gas flared in the U.S. in the *Minerals Yearbook* back at least to 1935, the same procedure can be used for previous years.

The amounts of gas flared in the United States has decreased to less than 1/3 the amount flared in 1946 or 1947. Gas flared in other areas of world will also peak and begin to decrease in the 1970's as the commercial value of gas makes it economical to provide for its collection and marketing rather than flaring it. This phenomenon is not yet apparent in the world-wide data because as new petroleum fields are developed in remote areas the associated gas is flared. The rate of growth of gas flaring through the 1960's was 5.4% per year as determined by the above procedure. It should properly be less than the 7.9% growth rate of petroleum production and it is expected that the growth rate of gas flaring should decrease even though the growth rate for petroleum production may remain approximately constant for the next 5 to 10 years.

8. Data for cement production

In the section of the UN *Statistical Yearbook* on manufacturing, a table is included on world-wide cement production. The data presented are on a nation by nation basis for each year and the world-wide total agrees closely with data in the *Minerals Yearbook* for the same year. It is evident that for countries from which the statistical office has trouble obtaining data, they rely on *Minerals Yearbook* estimated data.

9. Summary of CO_2 calculation

Table III shows the summary of calculations for the production of CO_2 for the years 1960–71. In the case of each fuel, data were taken from the UN *Statistical Yearbook* (3) and the appropriate "CO_2 factor" applied from Table 1. In the cases of coal and lignite corrections were applied to the data to account for the low grade coal from the USSR as discussed above. "Flared" natural gas data were not available in the *Statistical Yearbook* and were developed as described in Section 7.

The resulting values for total CO_2 production for the decade of the 1960's average 2.3% higher than those determined by Keeling (1). There are three distinct differences in the calculation procedure.

(*a*) The keeping of the coal and lignite separate gives nearly the same CO_2 production as the combination of "solid-fuel" when care is taken to see that the low grade coal from USSR is handled in the same way.

(*b*) Additions to the Crude Petroleum Production to account for the natural gasoline and other liquids produced from a part of the "marketed" natural gas by passing it through processing plants result in increased CO_2 from petroleum. The corresponding reduction in the volume of "marketed" natural gas accounting for extraction losses partially balances the increase in CO_2 produced. The net result is a small (0.3% of the CO_2 from petroleum and natural gas) increase in the calculated values for CO_2 production. The quantities of liquids obtained from natural gas are increasing rapidly and considering them in future CO_2 calculations will become more necessary for accurate estimates.

(*c*) Including the natural gas which is flared adds about two percent to the CO_2 estimte.

It should be noted that most of the data needed in the calculations summarized in Table 3 are available in the U.N. *Statistical Yearbook* (3). Figures for cement production, natural gasoline, and other natural gas liquids are included. For flared natural gas estimates, for extraction losses for natural gas liquids, and for information on the adjustments to be made for low grade coal from the USSR it is necessary to consult other sources and/or to make estimates.

10. Concluding remarks

As pointed out by Keeling (1), great effort will be required before the accuracy of estimates of global CO_2 emissions can be substantially improved. There are two distinct aspects to the further improvement of these estimates.

There is great need to improve the accuracy and reliability of the reported production of fossil fuels. Careful definitions of terms are required and must be understood and adhered to by all who assemble and use the data. As Keeling suggests, the goal of the assembly of these data should be broadened to reflect a concern for the emission of byproducts of energy utilization as well as the magnitude of the consumption of fuels in the process.

Secondly, effort must be made to determine and tabulate the carbon content of each fuel and from each country or region of the world. Particularly the lignite and coal vary widely from place to place, but the same problem is present in the case of reported amounts of oil and gas production.

From the standpoint of calculating the CO_2 emissions, it must be remembered that the UN data is for *commercial* fuels. It was estimated by Guyol in the preparation of the first volume of the Series J, Statistical Papers (6), that nearly 1/5 of the world energy supply in 1949 came from non-commercial fuels. Of the non-commercial fuels, 181 million metric tons of coal equivalent were consumed in developed countries and 411 million metric tons of coal in developing countries or underdeveloped countries.

The non-commercial sources of energy include peat, mainly in the USSR and Europe; sugar cane, mostly in Latin America and Asia; fuelwood and wood for making charcoal; wood fuel as a byproduct of lumber mill operations; structural wood reclaimed for use as a fuel; trimmings from forests and orchards; coconut shells; grass, straw; and vast quantities of cattle and camel dung, especially in southern Asia and the middle east. Much of this non-commercial fuel would rapidly oxidize to CO_2—rapidly meaning within a few years—if it were left to decay rather than being used as a fuel. Hence, the contribution to the atmospheric CO_2 levels resulting from burning this material must be carefully determined after consideration of the relative time spans for oxidation to CO_2 by natural processes compared to man induced combustion processes. Clearly peat and much of the wood fuel would exist for long time spans before oxidizing, while sugar cane, grass, straw, and animal dung would not. Ultimately estimates must be made on the yearly magnitudes of each of these materials, and "CO_2 factors" similar to Keeling's factor for coal, lignite, oil, and gas developed with the time considerations included in the factor.

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КОММЕНТАРИЙ НА РАСШИРЕНИЕ РАСЧЕТНОЙ ПРОЦЕДУРЫ ДЛЯ ПРОИЗВОДСТВА CO_2

Делаются дальнейшие улучшения в методе расчета количеств двуокиси углерода, выпускаемого в атмосферу при сжигании ископаемых топлив. В качестве основного источника используются данные, имеющиеся в «Статистическом ежегоднике ООН», а не суммарные данные «Источников энергии мира» (Статистические статьи ООН, серии J), поскольку наиболее свежие данные доступны в ежегоднике на несколько месяцев раньше и поскольку в нем содержатся данные для естественного бензина, естественных сжиженных газов, сжигаемого естественного газа и по производству цемента. Каменный уголь, бурый уголь, сырая нефть, коммерческий естественный газ, сжигаемый на скважинах естественный газ и цемент рассматриваются порознь и даются пересмотренные оценки выпуска CO_2 в атмосферу для каждого года с 1960 по 1971. Эти оценки в среднем на 2,3 % выше, чем оценки Килинга, причем наибольшая разница в производстве углекислого газа приходится на сжигаемый газ. Естественный газ, который сжигается на скважинах, ответственен за более чем 2 % общего количества CO_2, производимого из ископаемых топлив.