

Estimates of seasonal variation in fossil fuel CO₂ emissions

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ABSTRACT

Seasonal variations are evident in the atmospheric CO₂ concentration, and attempts to understand the causes of the variations require an estimate of the seasonal pattern of the fossil fuel CO₂ source term. Estimates were made of CO₂ emissions resulting from fossil fuel combustion on a month-to-month basis for a recent typical year (1982). Twenty-one countries account for over 86% of the fossil fuel emissions. Monthly fuel consumption was used directly for those countries where such fuel data were available, and for the others (e.g., USSR and China) fuel use data were deduced from other factors.

Results indicate that CO₂ emissions from gas fuel use show the largest seasonal variation, from 6.2% of the annual total in July or August to over 11.8% of the annual total in January. Liquid and solid fuel use shows less variation, with summer fractions about 7.8% of annual and winter about 9.2% of annual. Seasonal patterns are consistent throughout the Northern Hemisphere which dominates the global totals. Based on data for 87% of the world's fossil fuel CO₂ emissions, the highest release rate is 389.1 million tons of carbon in January and the lowest is 307.8 million tons of carbon in August.

1. Introduction—purpose

Research during the past decade dealing with the sources and sinks of carbon dioxide within the global carbon cycle has been unable to account for all the carbon dioxide released to the atmosphere through fossil fuel combustion. A major test for any model attempting to account for the carbon is the extent to which the observations of the atmospheric CO₂ concentration match the output of the model.

Northern Hemisphere observations of atmospheric CO₂ show a distinct seasonal pattern. The CO₂ concentration reaches a maximum in early spring and then decreases to a minimum in early autumn. This is seen in Fig. 1, which is a plot of the mean seasonal cycle of atmospheric CO₂ observations at Mauna Loa Observatory (Bacastow and Keeling, 1981). Measurements at several locations over a period of years show that the magnitude of the seasonal variation is larger at some locations than at others and, in general,

is largest at high latitudes in the Northern Hemisphere.

Seasonal patterns in CO₂ (Fig. 1) correlate with postulated biological growth patterns for

Difference from Annual Mean (ppm)

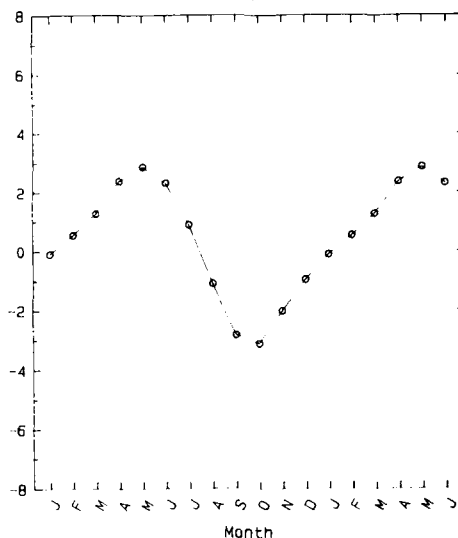


Fig. 1. Mean seasonal cycle of atmospheric CO₂ observations at Mauna Loa Observatory.

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several latitude bands, and models that allow for periods of growth and dormancy in the terrestrial biosphere of the Northern Hemisphere can be tuned to match the general characteristics. In tuning the carbon models many researchers have used the annual fossil fuel source term and have either assumed that fuel use is constant throughout the year or assigned a seasonal pattern based largely on Northern Hemisphere heating requirements. However, many of the uses of fossil fuel continues more or less uniformly throughout the year, while other uses increase and decrease as weather conditions and climate change.

The purpose of this work was to estimate month-to-month changes in carbon dioxide emission from fossil fuel combustion. It is hoped that the data developed herein will be of value to carbon cycle scientists in tuning their models with what they know about the seasonality of the natural carbon cycle.

2. Bounding the problem

Although annual CO₂ emissions aggregated for the total world are most accurately calculated from fuel production data, estimates for regions of the world or for periods of time shorter than one year require that consumption data be used. Thus to examine seasonal patterns of fossil fuel CO₂ emissions it is necessary to use fossil fuel consumption data. We can estimate annual fuel consumption data for most countries of the world and reconcile the totals with the global amounts that are estimated more accurately from production data. This is demonstrated in Rotty et al. (1984). However, the methods used in that work are only applicable to annual data—monthly or seasonal fuel consumption require more information and/or assumptions about end-use of energy.

The energy unit of the United Nations statistical office publishes no fuel data on a monthly or seasonal basis. Publications of individual nations usually place more emphasis on fuel production, and if monthly data are available, they are for fuel production and not fuel consumption. However, a few publications by individual countries or groups of countries, e.g., European Economic Community (EEC), Organization for

Economic Cooperation and Development (OECD), have been useful in providing monthly or seasonal fuel consumption data, or information from which such data can be deduced.

As a first step I have tried to reduce the problem to manageable size by determining which countries dominate the seasonal pattern of CO₂ emissions. In Table 1 I have listed for 21 nations the amount of CO₂ emitted from combustion of each fossil fuel type in 1982. These quantities were calculated for this purpose from fuel data for each country by the techniques described in Marland and Rotty (1984) and Rotty et al. (1984). The 21 countries include those responsible for 86% of the assignable CO₂ emissions from fossil fuels. In 1982, 4.749×10^9 tons C were assignable to consumption within countries, and the remainder of the 4.932×10^9 tons C estimated from fuel production data was from fuel used in bunkers and from gas flaring.

Seasonal fuel consumption data for these 21 countries should be representative of the seasonal pattern of global CO₂ emissions. It is interesting to note that the countries included in Table 1 contribute over 90% of the CO₂ released through combustion of solid fuels and gases, but only about 78% of the CO₂ from liquid fuels. This illustrates that the smaller and less developed nations rely on liquid fuels to meet most of their energy demand. The bulk of these are countries that are located in lower latitudes (mostly between 30°N and 30°S) where seasonal effects should be minimal.

3. Seasonal fuel data and CO₂ emissions

For the 21 countries in Table 1 some monthly or seasonal fuel consumption data were identified, and in cases where no such data could be found, information was collected from which the monthly fuel consumption pattern could be deduced. This entailed searching annual and/or monthly statistical reports from the nations listed and multinational organizations such as OECD and EEC.

For those nations for which monthly fuel consumption data are available, calculation of monthly CO₂ emissions was straightforward. Frequently monthly fuel production data were

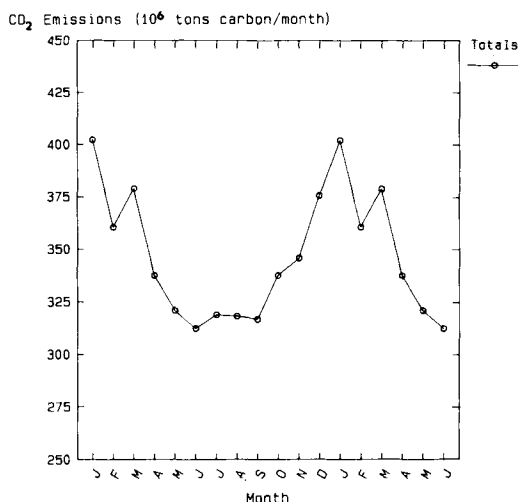
Table 1. *Estimated CO₂ emissions for 1982 by fuel type for 21 leading fuel consuming countries* (10⁶ tons C as CO₂)*

	Gases	Liquids	Solids	Total	Cumulative % of world total
1. USA	245.4	501.9	388.0	1135.3	23.9
2. USSR	205.6	335.6	359.7	900.9	42.9
3. China	6.2	66.3	340.6	413.1	51.6
4. Japan	13.6	148.5	64.3	226.4	56.3
5. FR Germany	23.0	71.5	86.0	181.4	60.2
6. United Kingdom	25.5	47.9	67.6	141.0	63.1
7. Poland	4.8	10.8	96.3	111.9	65.5
8. France	13.2	63.9	33.7	110.2	67.9
9. Canada	26.2	56.8	25.2	108.2	70.1
10. India	1.2	25.5	78.4	105.1	72.3
11. Italy	14.3	60.2	13.3	87.8	74.2
12. German DR	4.4	14.4	64.2	83.0	75.9
13. Mexico	12.9	56.3	4.5	73.7	77.5
14. S. Africa	—	7.3	59.3	66.6	78.9
15. Czechoslovakia	3.8	12.9	47.1	63.8	80.2
16. Australia	6.1	22.1	29.6	57.8	81.5
17. Spain	1.3	34.1	18.5	53.9	82.6
18. Romania	21.6	12.5	16.8	50.9	83.7
19. Brazil	0.6	34.3	6.6	41.5	84.5
20. Netherlands	17.1	15.0	3.4	35.5	85.3
21. Belgium	4.2	14.0	11.1	29.3	85.9
Total of 21 countries	651.9	1611.8	1814.2	4077.9	
% of world total	89.8	78.4	92.2	85.9	

* Calculated from UN fuel data.

located, but monthly consumption does not necessarily occur in the same pattern. As an example of the use of proxy data to obtain fuel consumption data, I found electricity data useful. Monthly or seasonal data for electrical production were used to estimate the amount of fuel that was used each month in the generation of electricity. Analyses based on knowledge of end-use of fuels in transport, in industrial operations, and in the residential and commercial sectors gave additional monthly values. In determining energy use for monthly residential and commercial heating, climatological data were analyzed and compared with similar data for the United States. In all cases, monthly fractions of annual totals were used to determine the amount of CO₂ emitted during combustion for each sector during each month.

The resulting monthly totals showed the effect of months having different lengths (Fig. 2). In

Fig. 2. Estimate of 1982 monthly totals of CO₂ emissions from 21 leading countries.

particular, February showed abnormally low fuel consumption (and less CO₂ emission) when compared with other months. A more logical "seasonal pattern" was obtained by normalizing the data to 30-day months. For each month, the emissions were adjusted by employing.

$$E_{i_{\text{norm}}} = \frac{30}{X_i} \times E_i,$$

where E_i is the estimated emission for month i , and X_i is the number of days in month i . Although this process results in a more pleasing and smoothed seasonal pattern, the sum of the emissions for all normalized months results in an annual amount that is only 360/365 (or 98.6%) of the correct annual total. Therefore, it is the monthly percentages as given in the lower part of Figs. 3, 7 that should be used to determine the monthly amounts, i.e.,

$$E_{i_{\text{norm}}} = (\%)_i \times 4749 \times 10^6,$$

where $(\%)_i$ is the percent of annual emissions in normalized month i .

4. Data sources and procedures

Many sources report fuel quantities in different units or with different standard definitions than those of the United Nations Statistical Office, which were used to develop the annual CO₂ emissions sequence. To maintain consistency between countries and with other emissions calculations, I have used the monthly or seasonal data reported by individual nations to estimate a pattern for the total annual emissions (i.e., the percent of the total attributable to each month). The pattern (percentage of the annual total) was used with the annual CO₂ emissions estimated for 1982 from the UN fuel consumption series to obtain values for CO₂ emissions by month. This process was followed for each fuel for each of the 21 countries and resulted in the estimates contained in Table A (Appendix). In effect, then, the problem was to find data that made it possible to estimate the fraction of the annual total that was consumed each month during a typical recent year (preferably 1982). When data for 1982 were not available, it was assumed that the fraction of a given fuel that was consumed in a given month was the same for 1982 as for any

other recent year, say between 1980 and 1984. Thus, it is possible that small errors could be introduced by extreme climatic anomalies during a particular period for a given country, but when the data are globally aggregated, errors introduced from this assumption are judged to be very small.

Specific procedures in the estimation process are now discussed for each country.

4.1. USA

Energy consumption by source is a monthly data series maintained and published by the US Department of Energy in the *Monthly Energy Review* (see for example EIA, February 1984). This series gives monthly consumption of coal, natural gas, and petroleum within the US. Petroleum consumption shows little month-to-month change except that the period December through April is slightly above the average value and May through November slightly below. A similar pattern is evident in the coal data, with December through March a period of higher consumption, although there is also above average consumption of coal in July and August. The July/August peak is presumably a result of increased electrical demand for air conditioning. In the United States gas is the fuel with the greatest seasonality. Data show values for January that are more than double the monthly values for May through September. Table 2 shows the percent of the US annual total consumed during each month for each fuel type.

Table 2. *United States 1982 consumption of gas, liquid and solid fuels (monthly percentage of annual totals)*

	Gas	Liquids	Solids
January	13.33	9.95	9.72
February	11.02	8.02	8.45
March	10.21	8.64	8.24
April	8.25	8.62	7.53
May	6.31	8.24	7.76
June	6.19	8.06	7.91
July	6.36	8.23	9.03
August	6.39	8.24	8.99
September	6.33	8.07	8.02
October	7.28	8.25	7.78
November	8.66	8.06	8.04
December	9.66	8.60	8.52

The monthly percentages in Table 2 were multiplied by the annual totals for each fuel (for the United States) from Table 1 to obtain values for the monthly emissions of CO_2 , which were stored in Table A (Appendix). This procedure was followed for each of the 21 countries.

4.2. USSR

The only seasonal fuel data that could be located for the USSR were for fuel production. In order to estimate monthly consumption, other information about energy use in the USSR was used. Heavy reliance was placed on data for the production of electricity. Quarterly amounts of energy production are given in *Quarterly Energy Review U.S.S.R. and Eastern Europe* (The Economist Intelligence Unit [EIU], 1984). The tabulated data include quarterly electricity production.

The 1982 production of electricity in the USSR was 1367×10^9 kWh (UN, 1985). Of this 1112×10^9 kWh are produced from fossil fuels, 175×10^9 kWh by hydroelectric plants, and 80×10^9 kWh by nuclear reactor-electric systems. Data available for 1982 show 789.5×10^6 tons coal equivalent (tce) for energy used for electricity and heating and 946.2×10^6 tce for "production and technology needs" (USSR Yearbook, 1984). It was assumed with reasonable confidence that the USSR Yearbook uses the same 29.31×10^6 kJ/tce as the UN. At 12,000 kJ/kWh

the production of 1112×10^9 kWh of electricity from fossil fuels would require 455×10^6 tce. Nuclear- and hydro-electricity contribute 31×10^6 tce to the total primary energy used in electricity generation, giving a total of 486 million tce. (Note that here 3600 kJ/kWh is used for the primary equivalent of nuclear and hydro-electricity.) Therefore, I assigned 455 million tce of energy (all from coal) in the seasonal pattern of electricity production (quarterly data) given in EIU (1984), and $789 - 486$ or 303 million tce to a seasonal heating pattern divided equally between oil and gas.

It then remained to estimate the month-to-month variation in fuel use for space heating. As a first cut at this, I made a quick climatological comparison of temperatures in the USSR and the USA. Assuming that heating fuel consumption follows the total fuel use pattern determined in Marland et al. (1985), I selected four cities in the USSR (Moscow, Kiev, Minsk, and Leningrad) to give a quick average of the climatic conditions determining heating fuel use. 30-year monthly average temperatures were obtained from Lydolph (1977), and a monthly average degree day data set was prepared for the USSR. Results of this exercise are given in Table 3 with population weighted degree days for the USA taken from NCDC (1984) listed for comparison.

Although the USSR has nearly twice as many degree days as the USA (and therefore would

Table 3. Heating degree days: USSR (estimated) and USA (in degrees F: 65°F as base)

	USSR		USA		% of annual US residential and commercial fuel use
	degree days	% of annual total	degree days	% of annual total	
January	1444	16.7	966	20.6	16.6
February	1289	14.9	785	16.7	14.6
March	1184	13.7	649	13.8	12.0
April	734	8.5	343	7.3	9.6
May	345	4.0	159	3.4	5.7
June	128	1.5	36	0.8	4.3
July	25	0.3	7	0.1	3.8
August	106	1.2	13	0.3	3.8
September	366	4.2	68	1.5	4.6
October	711	8.2	270	5.8	5.6
November	1015	11.7	553	11.8	7.9
December	1324	15.3	845	18.0	11.7
Total	8671		4694		

require a much higher per capita heating fuel consumption if other factors were the same), the fractions of the annual degree days attributable to a given month are quite similar. Only the percentage of annual degree days during the winter months of December, January, and February show a difference with the United States running slightly higher in these months. Also in Table 3 is a column giving the monthly fractions of annual residential and commercial fuel use in the US (compiled and computed from EIA, 1984). The fuel used in the residential and commercial sectors is almost equivalent to the sum of fuel used in space heating, water heating, and cooking. Note that this is not all the energy used for these purposes, only the direct fuel use. Finally, in proportioning the 303 million tce deduced from USSR statistics as being consumed in heating (presumably including cooking), it appears that very little error is introduced in making the assumption that the total is apportioned among the twelve months with the same fractions as in the USA. This procedure allows for the use of heating fuel in cooking and water heating as well as space heating. The remaining 946 million tce which the USSR yearbook attributes to energy used in industry (including losses during stocking and transport) was assigned uniformly throughout the year. The monthly fractions for each fuel type in the USSR were then determined from the formulae:

$$(\text{gases}) \quad \% (\text{of annual})_i = 0.29 Y_i + 0.71 \frac{100 X_i}{365},$$

$$(\text{liquids}) \quad \% (\text{of annual})_i = 0.26 Y_i + 0.74 \frac{100 X_i}{365},$$

$$(\text{solids}) \quad \% (\text{of annual})_i = 0.927 (\% \text{ of annual electricity})_i + (0.073) \frac{100 X_i}{365},$$

where X_i is the number of days in month i , and Y_i is the percent of fuel use in US residential and commercial sector in month i .

In the first two of these formulae, the coefficient of the Y_i term is the fraction of that fuel type that is used in residential and commercial heating. For example, in the case of gas, $1/2 \times (303 \times 10^6)$ tce, or 4.44×10^{18} joules, were used in 1982 for residential and commercial

heating out of a gas total of 15.315×10^{18} joules, i.e., 29%. 455×10^6 tce of solid fuel was used to generate electricity, so the coefficient of the monthly fraction of the annual electricity amount was $455/491$ (491×10^6 tce was the USSR total solid fuel consumption in 1982). For each fuel type the amount not otherwise assigned was allocated uniformly throughout the year, e.g., for gases $(1 - 0.29) = 0.71$

4.3. China

Monthly statistics for China are contained in the publication, *Tong Ji*, but as with other national publications the emphasis is on production, not consumption. Electricity production is strongly correlated with fuel consumption, and *Tong Ji* provides production data on both total electricity and hydroelectric. Using methods similar to those described above for the USSR, it is possible to make reasonable estimates on monthly fuel consumption.

For 1982 the UN statistical office reports 253×10^9 kWh of electricity were produced by thermal power plants in addition to 74×10^9 kWh from hydroelectric plants. At 12,000 kJ/kWh the thermal power plants required 104 million tce out of the total coal use of 465 million tce, so I deduced that 22.4% of Chinese coal consumption was used to generate electricity. The more recent *Tong Ji* data suggest that the fraction may be slightly higher, so I have estimated that 23% of the solid fuel consumption follows the monthly fractions of the annual non-hydro-electricity production given in *Tong Ji* (1984).

During the 12 months covered by the 1984 issues of *Tong Ji*, (November 1983–October 1984), 35.9 million tons of "organic carbon" were produced. This appears to be the same as what is usually called coke plant output. Making this assumption and the further assumption that coke production in China is about as efficient as the 62.3% for US coke plants, the coal required to make 35.9 million tons of "organic carbon" is

$$35.9 \times 10^6 \times \frac{1}{0.669} \times \frac{1}{0.7} \times \frac{1}{0.623} = 123 \times 10^6,$$

where 0.669 converts Chinese coal to coal equivalents, and 0.7 is the carbon content in coal when expressed in tce. Thus, coke plants required 123 million tons of coal, or about 17% of the coal consumed in China during this period.

The 23% of the coal accounted for in electricity generation and the 17% accounted for coke production leaves 60% to be divided between industry and residential and commercial heating. I have assumed an equal division between these two uses, i.e., 30% for industry, 30% for residential and commercial heating. The portion attributed to heating was distributed among the months in the same proportions as US residential and commercial direct fuel use. This is at least partially justified by noting that those parts of China with the major part of the population, with the most industry, and the greatest CO₂ emissions as indicated by Marland et al. (1985), are similar climatically to the eastern US. The latitude is approximately the same, and the location of both countries on the east side of a large continent contributes to the similarity.

I then determined the monthly fraction of the CO₂ emissions from coal according to the formula:

$$\% \text{ (of annual)} = (0.17 + 0.30) \frac{100 X_i}{365} + 0.3 Y_i + 0.23 Z_i,$$

where X_i is the number of days in month i , Y_i is the % of fuel use in US residential and commercial sector in month i , and Z_i is the % of total annual non-hydro electricity produced in month i . The use of coal in coke plants and in other industries is assumed to be distributed uniformly throughout the year, yielding the coefficient $(0.17 + 0.30)$.

Production data for gas and oil in China do not show any seasonal trends, but as indicated in Table 1, in China these fuels contribute much smaller amounts of energy to the total national requirements than coal. Oil is probably used mostly in transportation (buses, trucks, and planes). The very small amount of natural gas consumed must be used mostly in special applications. Consequently, the CO₂ emissions from these fuels are allocated to each month in accord with the number of days in the month (that is, uniformly throughout the year).

4.4. Japan

The Statistics Bureau of the Prime Minister's Office publishes a bulletin, *Monthly Statistics of Japan* (see Japan, 1984). This publication presents monthly data on the "demand and

supply of energy". A column headed sales is the closest to consumption, and presumably the monthly sales of most fuels cannot be very far from the consumption. There is a listing of stocks which clearly are stocks at the point of production or at the point of importation. In most cases these data on stocks show only very small month-to-month changes. I have been unable to find other consumption data or develop proxy methods that are not subject to uncertainties greater than those introduced by equating monthly sales to monthly consumption. The annual total consumption estimated this way from data in *Monthly Statistics of Japan* was made to agree with the value reported in the UN Statistical Office energy data set by multiplying 0.9025 to transform tons of coal as imported by Japan to tce.

In the natural gas data from the *Monthly Statistics of Japan* (Japan, 1984) a reasonable seasonal pattern is observed in the "gas shipped" (to consumers) data. Monthly percentages were determined and these were applied to the annual (1982) emissions from gas fuel previously estimated for Japan from the standard UN data. Japanese liquid fuels consist of gasoline, naphthas, jet fuel, kerosene, diesel fuel, and heavy fuel oil. The total sales of these products for each month were used to determine a fraction of the annual emissions of CO₂ from liquid fuels that can be attributed to each month. Again, annual totals were reconciled with the figure given in the UN Statistical Office liquid fuel consumption data set.

4.5. Countries of the European Economic Community (EEC)—Federal Republic of Germany, United Kingdom, France, Italy, Netherlands, Belgium

The EEC publishes monthly bulletins on both hydrocarbons and coal. In addition the United Nations publishes a quarterly bulletin on coal statistics for Europe but unfortunately data are missing for several of the key countries. For each of the six EEC countries included in Table 1, data were extracted from these sources for recent years and used to construct a typical seasonal pattern for consumption of each fuel type.

For gases, the *Monthly Bulletin of Hydrocarbons* (e.g., Eurostat, 1983) lists data for each of the EEC countries "Gross Inland Consumption".

These data consist of values for "domestic production" plus "supplies from Netherlands" plus "imports from third-party countries". They show about the same seasonal pattern as the gas data for the USA. These data were used directly, and monthly percentages of the annual total gas consumption were determined. The *Monthly Bulletin of Hydrocarbons* (e.g., Eurostat, 1983) lists monthly "inland deliveries" of individual petroleum products, and the sum of all products was used as the primary data for monthly liquid fuels consumption.

The *Monthly Bulletin of Coal Statistics* (e.g., Eurostat, 1984) contains monthly values for deliveries of hard coal. The *Quarterly Bulletin of Coal Statistics for Europe* (United Nations, 1983) gives monthly values for consumption of both hard coal and brown coal for FRG, Netherlands, and Belgium, but values are consistently missing for UK, France, and Italy. For the three countries with data in the *Quarterly Bulletin of Coal Statistics for Europe*, the arithmetic total of hard coal and brown coal was used to determine a % of annual solid fuels used each month. Because the relative amounts of hard coal/brown coal did not change much from month-to-month it was unnecessary to weight the quantities for heating value, and the simple arithmetic total was used as descriptive of the monthly changes in solid fuel use. For the other three countries, I relied on the monthly hard coal statistics of the EEC publication *Monthly Bulletin of Coal Statistics* (e.g., Eurostat, 1984). Using these hard coal statistics has the result of equating "deliveries" to "consumption". For each of the few years examined there was an irregularity in at least one month in the UK data for "deliveries to power stations", but in the world aggregate the effect of this irregularity is negligible. For each of the countries, the "deliveries" data show a logical seasonal pattern with higher values in the winter months and lower ones in the summer. These data for hard coal were used to estimate monthly percentages of annual solid fuel consumption.

4.6. Poland

In Poland the large CO₂ emissions from solid fuels is a result of Poland's dependence on coal as its chief energy supply. Only 4% and 18% of Polish CO₂ emissions are attributable to gas and liquid fuels, respectively. UN data show that in

1982, 46% of the gas consumed was produced domestically, and 54% was imported from the USSR. Poland exports large amounts of coal which could be used in industry, but imports more expensive gas from USSR. On the other hand, the USSR has excess gas and can afford to use large amounts in industrial operations (earlier I estimated that only 29% of gas was used for residential and commercial heating in the USSR). These economic considerations suggest that a smaller fraction of the gas is used in industry in Poland than is the case in the USSR. In 1982 in the USA, 40% of gas was used in the residential and commercial sector for heating and cooking. I assumed that the relatively small part of the CO₂ emissions in Poland from use of gas can be attributed 40% to heating (and cooking) and 60% to industry and other uses that distribute use uniformly throughout the year. Then for gases,

$$(\% \text{ of annual})_i = 0.4 Y_i + 0.6 \frac{100 X_i}{365},$$

where X_i and Y_i are as previously defined.

No data could be found on the monthly consumption of liquid fuels in Poland. Because of the dependence on coal in meeting most energy demands and the use of gas as a provider of a large portion of the heating and cooking, it is reasonable to assume that most of the liquid fuels are used in transportation and distributed uniformly throughout the year.

Monthly consumption values for both Polish hard coal and brown coal are available in the *Quarterly Bulletin of Coal Statistics for Europe* (UN, 1983). About 81% of solid fuel consumed is hard coal and the remainder (19%) is brown coal (or lignite). Assuming that the mix of hard coal to brown coal does not change from month-to-month, the addition of the two categories on a ton-for-ton basis provided a suitable monthly series on which to base monthly fractions of solid fuel use. These data show a small seasonal pattern indicating that coal still shares a portion of the seasonal heating load as well as reflecting the increase in electricity use in winter months.

4.7. Canada

The *Quarterly Report on Energy Supply-Demand in Canada* is published each quarter by Statistics

Canada (e.g., September 1984). This publication gives a well organized and internally consistent data set on both the production of primary fuel types and the consumption of refined fuel products. No individual monthly fuel consumption data were available, so each quarterly value was divided among the months of that quarter in proportion to the number of days in the month.

The Statistics Canada data showed expected seasonal variations in each fuel type, with gas having a much greater winter peak, summer valley pattern than either coal or oil. The procedure followed was the same as for the countries discussed earlier in which a monthly percentage of the annual total of each fuel type was applied to the 1982 CO₂ emissions determined from the UN annual energy data.

4.8. India

Because India is located mostly between 10°N and 30°N, it was assumed that no seasonal pattern of fuel use should be expected except for the reduced thermal generation of electricity during periods of abundant hydroelectricity.

Monthly statistics for India are contained in *Monthly Abstract of Statistics* published by Department of Statistics, Ministry of Planning, Government of India (India, 1984). As usual these statistics emphasize production and no seasonal variation in consumption could be deduced from fuel production data. However, electricity data are useful in deducing a seasonal pattern of consumption of solid fuels.

During the period July through October the generation of electricity in thermal power plants is observed to be about 20% less than that during other months. UN data (UN, 1985) for electricity suggest that of the coal consumption of 107 million tce in 1982, over 34 million tce were used to generate electricity. This represents 32% of solid fuel consumed in India. The fraction of solid fuel used each month was therefore apportioned according to the formula:

$$(\% \text{ of annual})_i = 0.32(ET_i) + 0.68 \frac{100X_i}{365},$$

where ET_i is the % of annual production of electricity from thermal sources in month i , and X_i is the number of days in month i . Monthly data for electricity generation (which are given separately for thermal plants, hydroplants, and

nuclear plants) are contained in India (1984), and these data were used in the formula above.

4.9. German Democratic Republic

GDR is another country in which fuel use is heavily dominated by solid fuels. Gas use contributes about 5% to the CO₂ emissions, and liquids contribute about 17%. No data were available on gas consumption. Making the assumption that the same fraction of the gas is used as a heating fuel as in FRG, and that the climates of the two are similar, the same monthly percentages for gas were used for GDR as were indicated for FRG in the Eurostat data. Most liquid fuels are used in transportation, and hence CO₂ emissions from liquids were apportioned uniformly throughout the year.

GDR is largely dependent on solid fuels, and 95% of the solid fuel is lignite; 5% is imported hard coal. From the *Quarterly Energy Review, USSR and GDR* (EIU, 1984), 42% of lignite production is used for electricity generation. The 42% used in electricity generation was increased to 48% on the assumption that the small use of solid fuels in residential and commercial heating and cooking will follow a pattern similar to that of seasonal variation in electricity generation. This is partially justified through an analogy with FRG where only 6% of solid fuel is used in other than industry and for electricity generation, i.e., residential and commercial heating and cooking. For solid fuels, my assumption was to use the data in the quarterly review for electricity generation by quarters and apply the formula:

$$\begin{aligned} (\text{solids}) (\% \text{ of annual})_i \\ = 0.48 \frac{X_i}{Q_i} (EL)_i + 0.52 \frac{100X_i}{365}, \end{aligned}$$

where X_i is the number of days in month i , Q_i is the number of days in the quarter containing month i , and $(EL)_i$ is the % of annual electricity generated that is generated in the quarter containing month i .

4.10. Mexico

Liquid fuels are used to meet over 75% of Mexico's fuel requirements. Monthly data are available for gas production, crude oil production and electricity produced "para consumo". Even the monthly production of refined petroleum

products is available in *Boletín Mensual de Información Económica* (Mexico, 1979), but these data are not directly helpful in estimating fuel consumption.

Use of electricity is growing so fast in Mexico that the small seasonal effect (if it is present at all in the data) is masked by the rapid growth. The growth rate may also be a contributor to my inability to discern any seasonal pattern in any of the fuel production data during the short period for which monthly data were available. Because Mexico is between 15°N and 30°N, little seasonal effect should be expected except in higher altitude locations. Even the record for monthly average temperatures for Mexico City (elevation 2234 m) show very small month-to-month variations.

For these reasons, I made the simple assumption that all fuel consumption in Mexico is spread uniformly throughout the year.

4.11. South Africa

South Africa's fossil fuel CO₂ emissions are derived almost 90% from the use of coal. The *Bulletin of Statistics* (South Africa, 1980), gives monthly data for both production and "sales" of coal. The data for coal sales show a small amplitude with above average values in the period June through November (Southern Hemisphere winter).

South Africa is a low latitude country, lying mostly between 25° and 35°S. Most industry depends on coal for its fuel and consequently any heating variations effect from warmer or cooler weather will be largely masked by the much larger industrial demand. For these reasons it appears that the data for coal "sales" gives an accurate picture of the month-to-month fuel use in South Africa. These data resulted in monthly values for the fraction of the annual total CO₂ emissions from coal that range from a high of 8.85% in September to a low of 7.18% in February.

It was assumed that petroleum products are used mostly in transportation and burned in uniform quantities throughout the year.

4.12. Czechoslovakia

Nearly 74% of the CO₂ emissions from Czechoslovakia are from the combustion of coal. Over 90% of the gas consumed is imported and

the small amount produced domestically shows a large seasonal amplitude with the highest quarter showing production about twice that of the lowest quarter (EIU, 1984). The gas must be largely used in residential and commercial heating and cooking, much as is the case in Poland, and %s for monthly use of gas in Czechoslovakia were taken to be the same as for Poland. Liquid fuel consumption was assumed to be mostly in transportation and the resulting CO₂ emissions were divided uniformly throughout the year.

The *Quarterly Bulletin of Coal Statistics for Europe* (UN, 1983), gives monthly values for Czechoslovakian coal production and consumption for both hard coal and brown coal. 76% of the solid fuel is brown coal, but it is assumed that the mix of hard coal and brown coal did not change much from month-to-month, and therefore the arithmetic sum of the two gives a good basis from which to determine the monthly fraction of solid fuel consumption. The month-to-month variation is not large because such a large fraction is used in industry and does not show much of an effect of warmer or cooler climate.

4.13. Australia

Both original quantities and seasonally adjusted quantities are given in *Seasonally Adjusted Indicators, Australia, 1980* (Australian Bureau of Statistics, 1980). As usual, quantities are given for fuel production and not consumption. In the case of natural gas the original production data shows substantial change during the year with highest values in July and August (Southern Hemisphere winter) and well below average values during December through April. Assuming that there is very little change in gas storage from month-to-month, the monthly production provides an image of the monthly consumption, and these were used to determine monthly fractions as with other countries.

Electricity data show a seasonal pattern with highest values in July and August and a minimum in January and February. In 1982, 89.9×10^9 kWh of electricity were produced from thermal power plants in Australia in addition to the 15×10^9 kWh produced from hydroelectric plants. At an estimated 12,000 kJ/kWh, the thermally produced electricity required 36.8×10^6 tons of coal equivalent, or about 91%

of Australia's total coal consumption of 40.5×10^6 tce. It is likely that some oil and/or gas is used for electricity generation, but the seasonality is small enough that only small error is introduced by assigning all electricity seasonality to coal. Then solid fuel consumption was allocated to the individual months according to the formula:

$$(\text{solids}) \% (\text{of annual})_i = 0.91 Z_i + 0.09 \frac{100 X_i}{365},$$

where X_i is the number of days in month i , and Z_i is the % of annual thermally produced electricity produced in month i .

The liquid fuel consumption was assumed to occur uniformly throughout the year.

4.14. Spain

Data for gas and oil consumption in Spain for 1982 are available on a quarterly basis in *Quarterly Oil and Gas Statistics*, (OECD, 1984). Monthly consumption of gas and oil was estimated from the quarterly quantities without attempting to allocate larger fuel amounts to those months within a quarter when fuel demand may have been higher (colder periods). The data for gas consumption showed greater amounts in winter months as expected, and oil consumption data had a slight tendency to do so also.

There were no data available on coal consumption and electricity generation for periods shorter than annually. Consequently, for Spanish coal consumption I spread the CO_2 emissions uniformly throughout the year. Note that CO_2 emissions from coal use in Spain are small enough that this introduces only a very small error.

4.15. Romania

Monthly or seasonal data for fuel consumption in Romania were unavailable. However, from what is known about Romanian energy use we can deduce some probable seasonal patterns. Gas is the dominant fuel and nearly all the gas is domestic. Romania has special technical experience from its many years of gas and oil production and as discussed in EIU (1984), the USSR and Romania are cooperating on several energy projects. In exchange for Romanian know-how and equipment in oil and gas fields,

the USSR is helping Romania in the construction of power plants and new refineries. An example is a new 330-MW power plant using oil shale to generate electricity.

The large domestic production of gas suggests that this fuel may be used for the same kind of things that gas is used for in the USA. I assumed the same monthly proportions for gas use as in the USA, and distributed the use of coal and oil uniformly throughout the year.

Because these seem to be the most arbitrary of all assumptions in this study, a brief check was made of the impact large differences in Romanian month-to-month energy use could have on world totals. The total of CO_2 emissions from Romania in 1982 was 50.9×10^6 tons carbon, or about 1% of the world total. Thus if I am off in a given month as much as from 8% of the annual amount to 12% (50% error in the estimate) for each of the three fuel types, the world aggregate for that month may be 0.04% (of the world annual total) too high or too low. The average month should have 8.3% of the annual total, and thus the error would be 0.04/8.30 or less than a half of 1%.

4.16. Brazil

CO_2 emissions in Brazil are dominated by those from liquid fuel combustion—83%. Monthly consumption of petroleum products is given in *Conjuntura* (Brazil Institute of Economics, 1982). The sum of values for fuel oil, diesel oil, and gasoline were used to construct a monthly liquid fuel consumption data set. The result showed a very flat pattern, nearly the same as spreading the consumption uniformly throughout the year. This confirms the assumption made for other low latitude countries that they should have no seasonal pattern.

Gas consumption in Brazil is very small (1% of total) and was assumed to be used mostly in cooking and hence emissions were spread uniformly throughout the year.

Electricity data that were available were for Rio de Janeiro and Sao Paulo for 1980 and 1981. No seasonal pattern was evident. Most electricity in Brazil is generated in hydroelectric plants, and coal is used mostly in coking plants. These considerations support the assumption that coal is burned uniformly throughout the year.

5. Seasonality on a global scale

The data collected and analyzed for the 21 countries include 12 monthly CO₂ emission estimates for each of 3 fuel types. The 756 values can be summed or grouped in a number of different ways depending on the analysis being conducted. Fig. 3 presented one of the simplest, the sum of all CO₂ emissions for each of the 12 months of

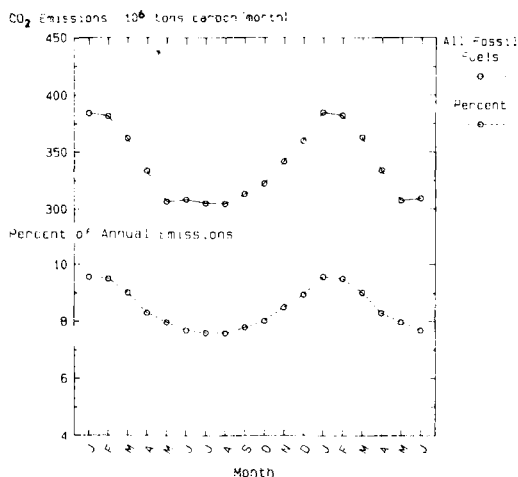


Fig. 3. Seasonal CO₂ emissions based on 30-day months (upper curve) and monthly % of annual emissions (lower curve) for 21 countries. Data include 92% of all CO₂ emissions from solids, 78% of all CO₂ emissions from liquids, and 90% of all CO₂ emissions from gases. Total represents 86% of CO₂ emissions assignable to countries (4749×10^6 tons C assignable in 1982; 4932×10^6 tons C total estimate for 1982).

the year. In this figure, the months were normalized to have equal lengths of 30 days as discussed earlier. The impact of greater fuel consumption during the colder months of the Northern Hemisphere winter is evident with the highest monthly emission rate of 389.8×10^6 tons C/30.417 days occurring in January and the lowest of 308.6×10^6 tons C/30.417 days occurring in August—a peak to valley difference of 24% of the mean monthly amount.

Average monthly percentage of the annual emissions must be 8.33%, and the variation about this mean from 9.56% in January to 7.57% in August shows the same relative pattern. Table 4 gives the summary of monthly emissions for the 21 countries. The emissions for each fuel type are plotted in Fig. 4. The values plotted are for 30 day months and give the pattern; for monthly amounts that sum to proper annual totals values of Table 4 should be used. For the 21 countries used in this analysis, solid fuel and liquid fuel combustion produce 84% of the CO₂ emissions, with solids running a bit higher than liquids, although for the entire world the position of these two contributors is reversed. Combustion of natural gas produces only 16% of the total CO₂ emissions but contributes proportionately more to the seasonal variations.

Included in the 21 countries which dominate the global CO₂ emissions there are only two Southern Hemisphere countries (Australia and South Africa) and three low latitude countries (India, Mexico, and Brazil), which contribute very little seasonality to the global totals. Table 5

Table 4. Monthly CO₂ emissions by fuel type for 21 countries (equal length months—30.417 days)

	Gases	Liquids	Solids	Total	% of annual
January	78.2	146.0	165.6	389.8	9.56
February	70.5	148.3	168.0	386.8	9.49
March	64.9	143.3	158.9	367.1	9.00
April	54.8	136.8	146.6	338.2	8.29
May	44.5	125.4	141.1	311.0	7.63
June	42.9	127.3	142.6	312.8	7.67
July	41.3	125.4	142.4	309.2	7.58
August	41.3	125.6	141.7	308.6	7.57
September	43.4	129.1	144.8	317.3	7.78
October	49.1	128.8	148.8	326.7	8.01
November	57.5	133.9	154.8	346.2	8.49
December	63.6	141.7	159.1	364.4	8.93
Totals	652	1611.6	1814.5	4078.1	

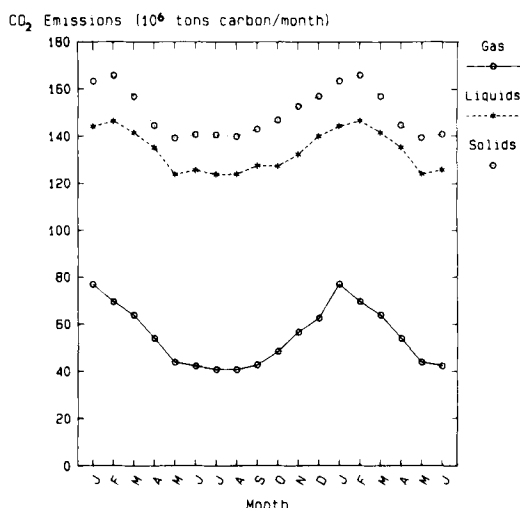


Fig. 4. Monthly emissions based on 30-day months for 21 countries by fuel type. Data include 92% of all CO₂ emissions from solids, 78% of all CO₂ emissions from liquids, and 90% of all CO₂ emissions from gases. Total represents 86% of CO₂ emissions assignable to countries (4749×10^6 tons C assignable in 1982; 4932×10^6 tons C total estimate for 1982).

provides a breakdown of the 21 countries into world geographical regions and gives percentages of the annual emissions from each region for each month. The Southern Hemisphere countries are at low latitudes and the seasonal effects are smaller than in the four Northern Hemisphere regions, although they are of opposite phase as expected. Most of the countries not included in the list of 21 are not only small users of energy, but also are low latitude countries that could affect the seasonal pattern very little.

Possible exceptions are the Scandinavian countries. The long winter periods and relatively high degree of industrialization suggest that consideration should be given to assessing the contribution these countries could make to the global totals. I was able to locate quarterly fuel consumption data in *Quarterly Oil and Gas Statistics*, published by the International Energy Agency (OECD, 1984). Considering the four countries, Denmark, Finland, Norway, and Sweden, as a group, I found that liquid fuels dominate and that solid fuels make a major contribution only in Denmark. The results of the separate analysis for

Table 5. Monthly CO₂ emissions by major world regions

Countries included:	North of 30° North Latitude					
	North America	Western Europe	Eastern Europe	Asia	30°N–30°S	Southern Hemisphere
	USA Canada	FRG, Italy UK, France Spain Belgium Netherlands	USSR Poland GDR Romania Czechoslovakia	Japan China	India Mexico Brazil	S. Africa Australia
1982 CO ₂ emissions from included countries (10 ⁶ tons C/year)	1243.5	639.6	1210.7	639.5	220.3	124.4
% emitted						
January	10.00	9.10	9.67	9.75	8.31	7.55
February	9.65	9.68	9.68	9.88	8.40	7.92
March	8.83	9.38	9.09	9.17	8.42	8.17
April	8.20	8.37	8.32	8.38	8.31	8.17
May	7.50	7.56	7.66	7.48	8.40	8.35
June	7.68	7.72	7.54	7.41	8.39	8.70
July	7.87	7.18	7.42	7.29	8.31	8.60
August	7.87	7.08	7.40	7.34	8.18	8.80
September	7.72	7.32	7.62	7.69	8.22	8.77
October	7.78	8.28	8.15	7.75	8.32	8.39
November	8.29	8.87	8.54	8.44	8.36	8.53
December	8.61	9.46	8.93	9.42	8.37	8.06

the Scandinavian four are shown in Fig. 5. Significant seasonal effects appear in the CO₂ emissions from liquid fuels with variations from a low of 2.6×10^6 tons C/30.417 days in the summer months to a high of 3.8×10^6 tons C/30.417 days in the winter. However, this is only 2.5% of the winter month emissions from the 21 country total from liquid fuels and just over 1% of the global winter time CO₂ emissions from all fuels. The impact the Scandinavian four have on the world totals is negligible as seen by comparing Table 6 with Table 4. This supports the

conclusion that the seasonality of global CO₂ emissions is adequately captured by including the countries considered here. Including additional countries (for which reliable data could be very difficult to obtain) could not increase the seasonal amplitude and could only serve to slightly weaken the contrast between the winter peak and summer valley by spreading the additional emissions more uniformly throughout the year. Data for the 21 countries plus the Scandinavian four include 87% of the world total CO₂ emissions and any additions can only have a very small effect.

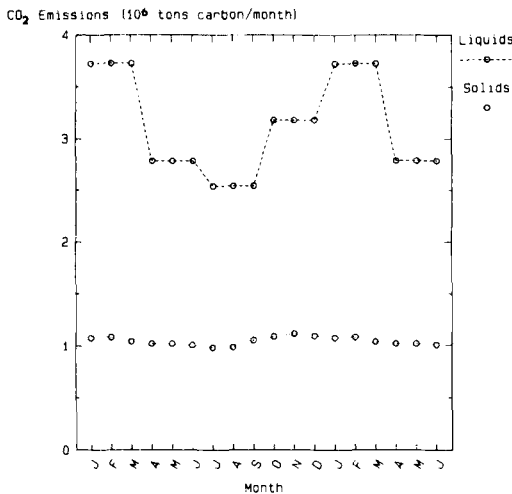


Fig. 5. Monthly emissions based on 30-day months for Scandinavia by fuel type.

6. Regional differences

To examine the regional differences in the seasonal pattern of CO₂ emissions, I divided the 21 countries into the 6 regions tabulated in Table 5. In Fig. 6, data for North America, Western Europe, Eastern Europe (including the USSR), and the Southern Hemisphere countries are plotted. The respective curves are based on 100% of the emissions from North America, 77% of the emissions from Western Europe, and 96% of the emissions from Eastern Europe, and hence the curves are quite representative of these regions of the world. The Southern Hemisphere curve is the composite of South Africa and Australia and represents only about 3% of the world's total CO₂ emissions.

The primary difference between the pattern in North America and Europe is the increase in

Table 6. Monthly CO₂ emissions by fuel type for 21 countries plus the Scandinavian four (equal length months—30.417 days)

	Gases	Liquids	Solids	Total	% of annual
January	78.3	149.7	166.6	394.6	9.56
February	70.7	152.0	169.2	391.9	9.49
March	65.0	147.1	160.0	372.1	9.01
April	54.8	139.8	147.6	342.2	8.29
May	44.5	128.3	142.1	314.9	7.63
June	43.0	130.1	143.6	316.7	7.67
July	41.5	127.9	143.4	312.8	7.58
August	41.4	128.1	142.7	312.2	7.56
September	43.4	131.7	146.0	321.1	7.78
October	49.2	132.1	149.8	331.1	8.02
November	57.6	137.2	155.8	350.6	8.49
December	63.6	144.9	160.2	368.7	8.93
Totals	653.0	1648.9	1827.0	4128.9	

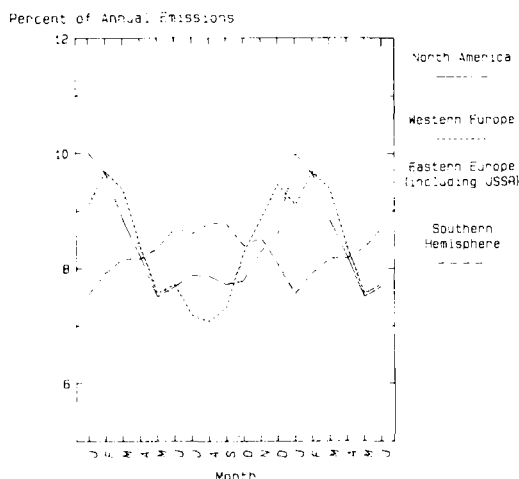


Fig. 6. Regional differences in monthly CO₂ emissions patterns.

North American values in July and August reflecting the use of more energy for air conditioning. The other feature that stands out is the earlier rise in emissions in Western Europe during the autumn months. This may be partially a consequence of equating fuel "sales" with consumption for some countries in Western Europe, or it may be a real indicator of earlier response to cooler or damper weather.

The regional patterns of Fig. 6 are reassuring in the sense that for countries where data were sparse and proxy information was used, the results are consistent with those for an area (e.g., North America) where fuel consumption data are thought to be reliable.

7. Discussion of the results

The 21 leading fuel consuming countries plus the Scandinavian four account for 87% of the world's CO₂ emissions. I consider these the best estimate of the seasonal pattern of CO₂ emissions. In Figs. 7 and 8 the quantities plotted are for 30-day months; for normalized monthly values that will sum to the annual totals, the percentages given in the lower part of the figure should be used, or the values obtained from Table 6. Fig. 9 shows the monthly fractions of the annual CO₂ production for each fuel type. Gas is clearly the fuel type with demand most sensitive

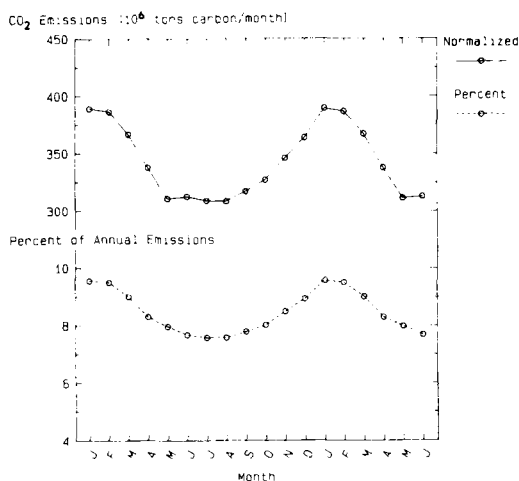


Fig. 7. Seasonal CO₂ emissions based on 30-day months (upper curve) and monthly % of annual emissions (lower curve) for 21 countries plus Scandinavia. Data include 93% of all CO emissions from solids, 80% of all CO₂ emissions from liquids, and 90% of all CO₂ emissions from gases. Total represents 87% of CO₂ emissions assignable to countries (4749×10^6 tons C assignable in 1982; 4932×10^6 tons C total estimate for 1982).

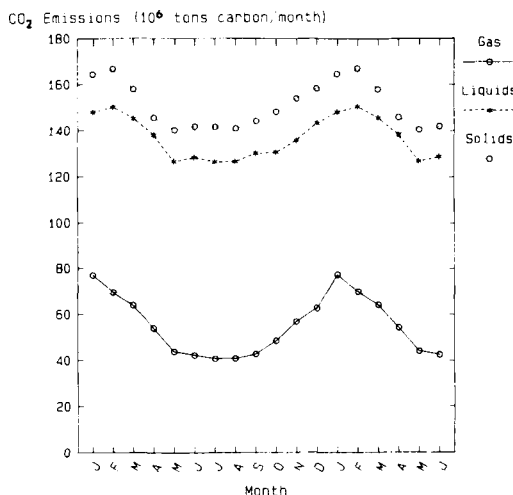


Fig. 8. Seasonal emissions based on 30-day months by fuel type for 21 countries plus Scandinavia. Data include 93% of all CO₂ emissions from solids, 80% of all CO₂ emissions from liquids, and 90% of all CO₂ emissions from gases. Total represents 87% of CO₂ emissions assignable to countries (4749×10^6 tons C assignable in 1982; 4932×10^6 tons C total estimate for 1982).

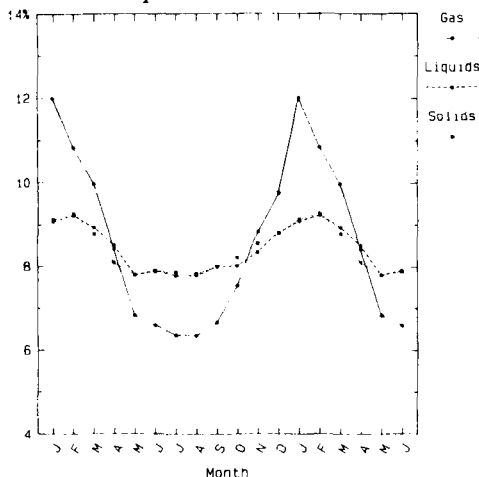
Percent of Annual CO₂ Emissions

Fig. 9. Monthly fractions of annual CO₂ production for each fuel type.

to seasonal conditions. The seasonal pattern for solids in these figures is mostly due to the electrical peak demand in winter months and the assumption that much of the electricity is generated with coal. The similar pattern for liquids is a consequence of demand for refined heating oil.

These results account for the emission of 4129×10^6 tons C, or 87% of the total of the fossil fuel emissions assignable to individual countries (4749×10^6 tons C). An additional 183×10^6 tons C are a result of fuel burning in international shipping and the flaring of natural gas and are not considered here.

To relate these results to the annual cycle of CO₂ in the atmosphere, I have plotted in Fig. 10 the month-to-month changes in atmospheric CO₂ concentration (a crude step derivative of the annual cycle in Fig. 1). When the pattern of the monthly changes in atmospheric CO₂ is compared with the monthly percentages of the emissions from fossil fuels a phase agreement is clear (Fig. 10). It should be noted, however, that the seasonal variation in the fossil fuel source is only about 82×10^6 tons more in January than in August.

An amplitude in the curve of seasonal emissions (January–August) of only 82×10^6 tons C represents only 2.0% of the annual emission of 4129×10^6 tons C emitted by the countries

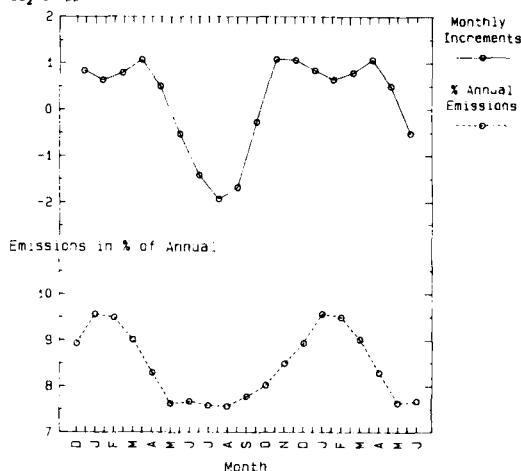
CO₂ in ppm

Fig. 10. Monthly increments in observed atmospheric CO₂ (upper curve) and monthly %s of annual CO₂ emissions (lower curve).

considered. Most of the countries not included are not only ones that inject much smaller amounts of CO₂ into the atmosphere, but are also ones that should have small seasonal variations in their emissions. In contrast, a change from one month to the next in the global average CO₂ concentration of 1 ppm requires 2128×10^6 tons of C be added to (or removed from) the CO₂ stored in the atmosphere. The contribution from seasonal changes in CO₂ from fossil fuels is far less than is required to account for the annual cycle in atmospheric CO₂ but is perhaps sufficient to be considered in careful analyses of the seasonal carbon cycle.

8. Acknowledgement

This work was conducted under contract number DE-AC05-76OR00033 between the US Department of Energy, Office of Energy Research, and Oak Ridge Associated Universities. I acknowledge with special thanks the help given by William Clive and Christine Kronauer, and their staff of the Energy Statistics Branch of the United Nations Department of International Economic and Social Affairs.

9. Appendix

Table A. Estimates of 1982 CO₂ emissions from fossil fuels by month (10⁶ tons C)

Country	Fuel type	Annual total	January	February	March	April	May	June	July	August	September	October	November	December
USA	gas	245.394	32.711	27.042	25.055	20.245	15.484	15.190	15.607	15.681	15.533	17.865	21.251	23.705
	liquid	501.936	44.923	40.255	43.367	43.267	41.359	40.456	41.309	41.359	40.506	41.410	40.456	43.166
	solid	387.963	37.710	32.783	31.968	29.214	30.106	30.688	35.033	34.878	31.115	30.184	31.192	33.054
USSR	gas	205.620	22.289	19.904	19.554	17.724	15.792	14.578	14.661	14.661	14.743	15.730	16.717	19.369
	liquid	335.583	35.572	31.813	28.793	28.793	26.041	24.162	24.397	24.397	24.430	25.974	27.283	31.276
	solid	359.669	33.233	30.032	33.233	27.587	28.486	27.587	27.910	27.910	27.011	32.586	31.543	32.586
China	gas	6.233	0.529	0.478	0.529	0.512	0.529	0.512	0.529	0.529	0.512	0.529	0.512	0.529
	liquid	66.288	5.628	5.084	5.628	5.449	5.628	5.449	5.628	5.628	5.449	5.628	5.449	5.628
	solid	340.610	37.365	33.584	32.971	29.531	25.920	23.809	23.706	22.821	24.183	25.920	27.589	32.358
Japan	gas	13.572	1.323	1.192	1.291	0.999	1.038	1.098	0.985	1.033	1.086	1.098	1.132	1.297
	liquid	148.478	13.333	13.378	13.987	11.344	10.379	10.601	11.344	11.819	11.878	11.819	12.843	15.768
	solid	64.308	5.325	4.437	5.350	4.997	5.241	5.228	5.338	6.000	5.402	5.505	5.685	5.801
FRG	gas	23.914	3.171	2.635	2.609	2.025	1.574	1.294	1.179	1.196	1.322	1.863	2.315	2.733
	liquid	71.472	5.789	6.025	6.954	6.082	5.253	6.025	5.753	6.240	5.825	5.689	5.789	6.047
	solid	85.985	7.670	6.982	7.214	6.758	6.973	6.578	6.457	6.509	7.128	7.859	7.928	7.928
UK	gas	25.468	3.257	2.794	2.840	2.083	1.666	1.250	1.172	1.210	1.363	2.104	2.567	3.166
	liquid	47.887	4.252	4.032	4.750	3.955	3.687	3.764	3.764	3.558	3.802	3.970	4.166	4.195
	solid	67.646	3.883	6.156	6.217	5.243	5.574	6.420	4.553	5.216	6.453	5.973	5.588	6.365
Canada	gas	26.235	3.476	3.140	3.476	1.650	1.705	1.650	1.291	1.291	1.249	2.463	2.385	2.463
	liquid	56.756	5.301	4.790	5.301	4.421	4.569	4.421	4.733	4.733	4.580	4.688	4.541	4.688
	solid	25.192	2.753	2.486	2.753	1.814	1.874	1.814	1.874	1.874	1.814	2.068	2.000	2.068
France	gas	13.812	1.716	1.462	1.425	1.029	0.921	0.617	0.655	0.569	0.662	1.107	1.347	1.673
	liquid	68.880	5.986	5.602	6.132	5.692	4.976	4.829	4.868	4.222	4.836	5.360	5.321	6.056
	solid	33.670	3.091	2.707	3.098	2.630	2.771	2.249	2.670	2.306	2.721	3.141	3.013	3.276
Poland	gas	4.833	0.567	0.505	0.424	0.424	0.357	0.321	0.320	0.320	0.327	0.355	0.391	0.473
	liquid	10.813	0.918	0.829	0.918	0.889	0.918	0.889	0.918	0.918	0.889	0.918	0.889	0.918
	solid	96.337	8.516	8.352	8.796	7.765	6.975	7.004	7.668	7.322	8.054	8.314	8.497	8.352
Italy	gas	14.339	1.758	1.633	1.506	1.078	0.964	0.872	0.789	0.672	0.946	1.042	1.420	1.659
	liquid	60.175	5.693	5.121	5.711	4.772	4.248	4.652	4.652	4.477	4.982	4.910	5.049	5.909
	solid	13.257	0.976	1.038	1.047	1.071	1.261	1.192	1.486	0.829	0.928	1.119	1.106	1.205

Table A—continued

Country	Fuel type	Annual total	January	February	March	April	May	June	July	August	September	October	November	December
Mexico	gas	12.931	1.098	0.992	1.098	1.063	1.098	1.063	1.098	1.098	1.063	1.098	1.063	1.098
	liquid	56.296	4.780	4.318	4.780	4.628	4.780	4.628	4.780	4.780	4.628	4.780	4.628	4.780
	solid	4.466	0.379	0.343	0.379	0.367	0.379	0.367	0.379	0.379	0.367	0.379	0.367	0.379
India	gas	1.190	0.101	0.091	0.101	0.098	0.101	0.098	0.101	0.101	0.098	0.101	0.098	0.101
	liquid	25.455	2.161	1.952	2.161	2.092	2.161	2.092	2.161	2.161	2.092	2.161	2.092	2.161
	solid	78.432	6.671	6.133	6.910	6.533	6.714	6.486	6.471	6.377	6.133	6.478	6.494	6.933
GDR	gas	4.409	0.585	0.486	0.481	0.373	0.290	0.239	0.217	0.220	0.244	0.343	0.427	0.504
	liquid	14.413	1.224	1.106	1.224	1.185	1.224	1.185	1.224	1.224	1.185	1.224	1.185	1.224
	solid	64.183	5.648	5.103	5.648	5.070	5.244	5.070	5.237	5.237	5.064	5.687	5.494	5.687
Romania	gas	21.619	2.882	2.382	2.207	1.784	1.364	1.338	1.375	1.381	1.368	1.574	1.872	2.088
	liquid	12.460	1.058	0.956	1.058	1.024	1.058	1.024	1.058	1.058	1.024	1.058	1.024	1.058
	solid	16.836	1.429	1.291	1.429	1.384	1.429	1.384	1.429	1.429	1.384	1.429	1.384	1.429
Czechoslovakia	gas	3.847	0.452	0.402	0.381	0.337	0.284	0.256	0.255	0.255	0.260	0.282	0.311	0.376
	liquid	12.946	1.099	0.993	1.099	1.064	1.099	1.064	1.099	1.099	1.064	1.099	1.064	1.099
	solid	47.118	3.981	3.765	4.113	3.944	3.953	3.963	3.765	3.883	3.958	4.066	3.920	3.812
Spain	gas	1.307	0.131	0.119	0.131	0.099	0.102	0.099	0.100	0.100	0.096	0.111	0.107	0.111
	liquid	34.069	2.991	2.702	2.991	2.661	2.749	2.661	2.783	2.783	2.695	3.053	2.954	3.053
	solid	18.541	1.574	1.422	1.574	1.524	1.574	1.524	1.574	1.574	1.524	1.574	1.524	1.574
Brazil	gas	0.576	0.049	0.044	0.049	0.047	0.049	0.047	0.049	0.049	0.047	0.049	0.047	0.049
	liquid	34.270	2.769	2.639	2.868	2.670	3.009	2.896	3.057	2.862	2.879	3.064	2.834	2.728
	solid	6.647	0.564	0.510	0.564	0.546	0.564	0.546	0.564	0.564	0.546	0.564	0.546	0.564
Australia	gas	6.149	0.397	0.398	0.439	0.469	0.529	0.567	0.646	0.638	0.565	0.546	0.492	0.462
	liquid	22.051	1.872	1.691	1.872	1.813	1.872	1.813	1.872	1.872	1.813	1.872	1.813	1.872
	solid	29.648	2.262	2.167	2.363	2.262	2.603	2.591	2.808	2.814	2.529	2.502	2.381	2.348
Netherlands	gas	17.104	2.372	1.952	1.820	1.391	1.040	0.855	0.795	0.802	0.884	1.327	1.692	2.172
	liquid	15.011	1.325	1.381	1.537	1.492	1.198	1.298	1.139	1.157	1.181	1.031	1.154	1.115
	solid	3.380	0.233	0.331	0.320	0.368	0.256	0.192	0.287	0.403	0.303	0.230	0.176	0.280
South Africa	gas	—	—	—	—	—	—	—	—	—	—	—	—	—
	liquid	7.261	0.616	0.557	0.616	0.597	0.616	0.597	0.616	0.616	0.597	0.616	0.597	0.616
	solid	59.267	4.415	4.255	5.061	4.878	4.967	5.097	4.961	5.210	5.245	5.091	5.174	4.913
Belgium	gas	4.237	0.581	0.461	0.462	0.378	0.292	0.229	0.173	0.188	0.230	0.316	0.401	0.527
	liquid	13.983	1.554	1.393	1.576	1.196	1.060	1.060	0.744	1.011	1.089	1.056	1.093	1.152
	solid	11.094	0.983	0.763	0.918	0.973	0.876	0.790	0.979	0.862	0.951	0.866	0.956	1.177

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