UNITED NATIONS

ECONOMIC AND SOCIAL COUNCIL

LIMITED
ST/ECLA/CONF.7/L.1.13
7 December 1960
ORIGINAL: ENGLISH

LATIN AMERICAN ELECTRIC POWER SEMINAR

Held under the joint auspices of the Economic Commission for Latin America, the Bureau of Technical Assistance Operations and the Resources and Transport Economics Branch of the United Nations, with the collaboration of the Government of the United Mexican States

Mexico City, 31 July to 12 August 1961

THE HISTORICAL RELATIONSHIP BETWEEN ENERGY CONSUMPTION AND GROSS NATIONAL PRODUCT IN THE UNITED STATES

by Sam H. Schurr

NOTE: This text is subject to editorial revision.

CONTENTS

1. Introduction

The existence of a relatively stable relationship between the growth in a country's energy consumption and the growth in its total national output is often taken for granted, since on a commonsense basis it would seem apparent that the input of energy into an economy should grow at a rate which is more or less consistent with the expansion in its national product. Yet, an analysis of the historical record in the United States recently completed at Resources for the Future reveals that this is far from being the case.[1/] Instead, the long historical record between 1880 and 1955 reveals two distinct trends - a persistent increase in the input of energy per unit of GNP between 1880 and the decade of the First World War, and a persistent decline in energy consumption per unit of GNP since that time.

This paper deals with some of the factors which appear to lie behind these two diverse movements. It is offered at this meeting in the belief that the long record in the United States will be of interest to countries where future development may repeat in some measure the changes which have already been experienced in the industrialization of the United States.

2. The historical record

The basic information on the historical relationship between energy consumption and GNP is shown, for five-year intervals, in table 1 and figure I. These data, presented in index number form, were derived by dividing GNP (measured in constant dollars) by the Btu content of the

---

1/ Sam H. Schurr, Bruce C. Netschert, Vera F. Eliasberg, Joseph Lerner and Hans H. Landsberg, Energy in the American Economy, 1850-1975: An Economic Study of its History and Prospects, (Baltimore: John Hopkins Press, 1960). The historical analysis is contained in Part I, which was written jointly by Vera F. Eliasberg and the author of this paper. Chapter 4, from which this paper is adapted, presents a fuller treatment of the subject matter.

/commercial energy

commercial energy sources consumed.[2/]

The long movements in this record may be summarized briefly as follows: From 1880 to 1955, there occurred an increase of some 55 per cent in energy consumption per unit of GNP, which is equivalent to an average rate of about 0.6 per cent per year. However, this long-period rise of quite modest proportions is composed of the following diverse movements: an increase between 1880 and 1910 of 133 per cent, equivalent to an average rate of increase of 2.0 per cent per year; comparative stability between 1910 and 1920 (The decade 1910-20 marks both the culmination of the period of rise, and the transition to a new basic relationship between energy and national product); a decline between 1920 and 1955 of about 35 per cent, equivalent to an average rate of decline of about 1.2 per cent per year.

The discussion which follows focuses on the fundamental change in the relationship between energy and GNP which occurred following the First World War, the transition from a long-run tendency for energy consumption to rise relative to GNP to a trend in which the consumption of energy fell persistently relative to national output. The analysis is presented in terms of factors falling under two broad headings: changes in the total economy, which cover those influences originating outside of the energy sector, such as changes in the structure of the economy, and the over-all efficiency of its performance; and changes within the energy economy, such as changes in the thermal efficiency of energy use, and the rise of electrification.

2/ The total covers the so-called commercial sources of energy - coal, oil, natural gas, natural gas liquids and hydropower. The statistics measure apparent consumption, that is, production minus exports plus imports, and since 1920, including net stock changes in the mineral fuels. The basic physical statistics were converted to the common denominator of British thermal units (Btu's) by applying a representative conversion factor measuring the inherent Btu content of the physical unit. For hydropower the conversion was accomplished on the basis of the Btu equivalent of the fuel which would have been required to generate the same amount of electricity in the particular year. Fuel wood, which is excluded, accounted for more than one half of the total Btu content of the fuel supply in 1880. However, some 95 per cent of the wood was used for household purposes and was thus not consumed in the sectors of the economy whose output is measured in the gross national product. Direct water and windpower were already of relatively small importance in total energy by 1880.

Table 1

ENERGY CONSUMPTION PER UNIT OF GROSS NATIONAL PRODUCT, 1880-1955

(Five-year intervals)

Year	Index of GNP (1900 = 100; dollars at 1929 prices)	Indexes of energy consumption per unit of GNP (1900 = 100)		Percentage change	Average annual percentage rate of change
	(1)	(2)		(3)	(4)
1880	50.0	56.8			
			1880-1885	+20.1	+3.7
1885	57.3	68.2			
			1885-1890	+27.0	+4.9
1890	68.6	86.6			
			1890-1895	+0.3	+0.1
1895	81.4	86.9			
			1895-1900	+15.1	+2.9
1900	100.0	100.0			
			1900-1905	+19.8	+3.7
1905	125.3	119.8			
			1905-1910	+10.4	+2.0
1910	147.9	132.2			
			1910-1915	+1.5	+0.3
1915	158.2	134.2			
			1915-1920	+1.3	+0.3
1920	191.9	136.0			
			1920-1925	-14.5	-3.1
1925	237.0	116.3			
			1925-1930	+1.5	+0.3
1930	249.1	118.0			
			1930-1935	-10.8	-2.3
1935	239.4	105.2			
			1935-1940	-5.4	-1.1
1940	316.8	99.5			
			1940-1945	-11.9	-0.25
1945	473.7	87.7			
			1945-1950	+4.3	+0.9
1950	490.6	91.5			
			1950-1955	-4.0	-0.8
1955	597.6	87.8			
			1880-1920	+139.4	+2.2
			1920-1955	-35.4	-1.2

Source: Energy in the American Economy, 1850-1975, Appendix, tables IX and XIII. The authors thank John W. Kendrick who made available his estimates of GNP (Department of Commerce concept) which are derived from estimates of Simon Kuznets for the period prior to 1929. These will be published in the forthcoming National Bureau of Economic Research volume, Productivity Trends in the United States. Kendrick's estimates of GNP in 1929 dollars were shifted to an index with 1900 = 100.

/Of course,

Of course, the distinction between two classes of factors is not clear-cut. Thus, improvements in the over-all efficiency of the economy's performance are obviously related to the manner and form in which energy is consumed: for example, the rise of electrification - a change within the energy economy - appears to be an important factor in explaining the growth of over-all productivity in the economy. Nevertheless, the distinction provides a useful framework for distinguishing between what may be viewed as essentially different classes of factors.

3. Changes in the total economy

(a) Structural changes It is to be expected that the more rapid the growth of manufacturing and mining in relation to the total economy, the greater will be the consumption of commercial fuels relative to the growth of the nation's total output of goods and services. It is therefore reasonable to begin with the hypothesis that the upward trend in consumption of mineral fuels and hydropower per unit of national product between 1880 and the 1910-20 decade and the downward trend between 1920 and 1955 are connected with differences in the rate of expansion of the industrial sector compared with that of the total economy during these periods.

This hypothesis is partly borne out by the facts. In 1920, manufacturing and mining, measured by the index of output, was nearly five times greater than in 1885. This expansion was considerably faster than that for the economy as a whole, which in terms of GNP rose to three and a third times the former level (see table 2). It is not surprising that in a period of such rapid industrialization the consumption of energy per unit of national output would rise. In the second period, from 1920 to 1955, when the consumption of energy fell relative to GNP, the industrial sector again expanded faster than the economy as a whole, even though mining lagged behind. While GNP rose from 100 in 1920 to 311 in 1955, manufacturing output expanded to 350, mining output to 234, and total industrial production to 339. However, during this period, the faster growth of industry was not nearly so pronounced as previously; barely 10 per cent more than total national output as compared to nearly 50 per cent more in the earliest period.

/Table 2

Table 2

COMPARATIVE GROWTH: GROSS NATIONAL PRODUCT AND INDUSTRIAL OUTPUT
1885-1920 AND 1920-1955

Year	Indexes				Ratio of increase compared to GNP (GNP = 1.00)		
	GNP	Manufacturing output	Mining output	Total industrial output	Manufacturing	Mining	Total industrial
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1885	100	100	100	...			
1920	335	479	540	...	1.43	1.61	...
1920	100	100	100	100			
1955	311	359	234	339	1.15	0.75	1.09

Sources:
Column 1: Energy in the American Economy, 1850-1975, Appendix, table XIII.
Column 2: Figures for 1885-1920 from United States Bureau of the Census, Historical Statistics of the United States, 1789-1945 (Washington, D.C.: Government Printing Office), Series J 13 and J 14, index of physical production of manufacturing (Warren M. Persons) linked to index of physical output of all manufacturing industries (National Bureau of Economic Research). Figures for 1920-55 from Federal Reserve Board Index of Manufacturing Production.
Column 3: Index of Physical Volume of Mineral Production, Bureau of Mines, Minerals Yearbook, 1956, (Washington, D.C.: Government Printing Office), Vol I, pp. 3-4.
Column 4: Federal Reserve Board Index of Industrial Production (manufactures and minerals combined).

/(b) Overall

(b) Overall changes in national productivity. Partial explanation of the reversal in the trend of energy relative to GNP which occurred after 1920 may be found in another force affecting the total economy - the efficiency with which input factors generally were transformed into the final products constituting the nation's output of goods and services. There are definite indications that the American economy's efficiency in this regard, as measured by the national product relative to the input of labor and capital, underwent a change in trend at about the same time.

The detailed studies of the National Bureau of Economic Research dealing with the productivity of the United States economy indicate that a distinct acceleration in the rate of productivity increase of labor and capital began shortly after the First World War. The historical course of energy relative to GNP does not parallel that of labor and capital, as disclosed in the studies of the National Bureau. The turning point in the energy-GNP relationship involved a reversal in trend, whereas that in labor and capital productivity involved not a reversal, but a marked increase in rate in what has been a single persistent direction of change. However, what is significant for the purposes of this analysis is that national output after 1919 grew much faster relative to the input of labor and capital than it had in the earlier period. There is no apparent reason to believe that the same broad influences which operated to accelerate the growth in national output after the First World War, in relation to the input of labor and capital, should not also have increased, in some measure, the rate of growth of national output relative to the input of energy.

It is well known that the increasing use of inanimate energy per worker plays an important part in raising the over-all productivity of the economy, but the foregoing assumes that the factors which produced the post-1920 acceleration in the growth of national output relative to capital and labor inputs were of a sort that could also increase the "productivity" of energy inputs relative to national output. Can such an assumption be supported? The National Bureau's studies have suggested

/that the

that the post-First World War acceleration in labor and capital productivity is explained by the growth of society's "intangible capital," i.e., "all the improvements in basic science, technology, business administration, and education and training, that aid in production" and other such broad influences affecting the efficiency of production. These factors appear, in part, to be of a sort which could serve to increase the productivity of energy, although some of them (for example, basic science and technology) might also depend for their effectiveness on substantial increases in energy input per unit of national product. The composition of intangible capital thus leaves the question unresolved.

There is, however, some statistical indication of the fact that the post-1920 acceleration in the increase in productivity within manufacturing has not been the result of a comparable acceleration in mechanization. The relevant data, covering the period 1879-1954, comparing output per man-hour with horsepower installed per man-hour, are assembled in table 3.

This table shows that between 1879 and 1954 output per man-hour (labor productivity) grew continously. Over the same period, the number of horsepower installed per man-hour also increased uninterruptedly. However, while the number of horsepower installed per man-hour grew by about 160 per cent between 1879 and 1919, labor productivity increased only 86 per cent. The increase of 196 per cent in horsepower per man-hour in the years after 1919 went along with a growth of 190 per cent in labor productivity. Thus, the acceleration in the growth of labor productivity in manufacturing in the period following 1919 did not depend on a similar acceleration in the growth of horsepower installed per man-hour. Although changes in the degree of mechanization do not yield a direct measure of the input of energy, these comparisons establish a prima-facie case for the proposition that the productivity of energy, at least in manufacturing, grew at a substantially faster rate after 1920 than before. This was apparently in response to general forces increasing productivity throughout the economy, in which, as will be argued later, a change in the form of energy application - the rise of electricity - played an important part.

/Table 3

Table 3

MAN-HOURS, OUTPUT PER MAN-HOUR, AND HORSEPOWER RATING OF INSTALLED EQUIPMENT PER MAN-HOUR IN MANUFACTURING INDUSTRIES FOR SELECTED YEARS, 1879-1954

Year	Man-hours worked	Output per man-hour	Horsepower installed per man-hour
	(1)	(2)	(3)
Index numbers (1899 = 100)			
1879	54.2	68.4	64.2
1889	76.7	86.6	78.9
1899	100.0	100.0	100.0
1909	138.5	113.8	132.9
1919	173.7	127.5	166.6
1929	165.3	219.8	253.5
1939	134.7	276.5	389.1
1954	223.8	370.3	493.5
Percentage increases:			
1879 - 1919	220	86	160
1919 - 1954	29	190	196

Sources: Columns 1 and 2: John W. Kendrick, Productivity Trends in the United States (New York: National Bureau of Economic Research, forthcoming), shifted to 1899 = 100. Column 3: based on horsepower figures shown in Energy in the American Economy, 1850-1975, table 56.

/To summarize

To summarize the effects of changes in the total economy on the energy-GNP ratio, the following hypothesis is broadly consistent with the facts examined: Prior to the 1910-20 decade, the fast growth of industrial output relative to the total national output resulted in a rising trend of energy consumption relative to gross national product. After 1920, although industrial output continued to grow faster than total national output, energy consumption per unit of GNP declined. This was because the growth of industrial output relative to total national product was slower than before 1920; and because general factors which resulted in a higher rate of output relative to both labor and capital inputs apparently had a similar effect in raising national product relative to the input of energy.

4. Changes in the energy economy

(a) Thermal efficiency of energy utilization The energy input totals basic to this analysis measure the inherent Btu values of the primary energy materials consumed in the United States. It is well known that the efficiency of converting these materials into useful heat and mechanical work has changed considerably during the historical period studied. On the whole, these changes have been in the direction of fuller utilization of the inherent energy contained in the primary materials. Indeed, the explanation most frequently advanced for the downward trend in the ratio of energy input of GNP in recent decades runs in terms of such improvements in the efficiency of energy use. However, as already shown, the increasing efficiency of energy utilization, as measured by the relationship between the economy's energy inputs and its output of goods and services, is explained by more than just the higher effective rate of converting raw energy materials into useful energy.

Nonetheless, changes in thermal efficiency have played an important part in decreasing raw energy input in relation to national output. Some estimates have been made of long-run changes in the thermal efficiency of converting fuels into useful heat and mechanical work in the United States. Although the data and concepts on which they are based are very

/crude, the

crude, the broad picture they convey is one of greater and more rapid increases in efficiency in the twentieth century than in the latter half of the nineteenth century. Putnam estimates that the average thermal efficiency of energy use for all purpose rose from 8 per cent in 1850 to 11 or 12 per cent in 1900, and to 30 per cent in 1947.3/ Dewhurst assumes a rise in the efficiency of converting fuels and hydropower (direct water-power in 1850) into mechanical work from 1.8 to 3.2 per cent between the middle and the end of the nineteenth century, and an increase to 13.6 per cent by 1950.4/

Improvements in thermal efficiency are related also to the radical transformation which has taken place in the nation's fuel consumption pattern. The relative decline in the use of coal and the rise in oil and gas consumption is very well known; statistics summarizing this change are shown in table 4. It has been estimated that in transforming fuel into heat for industrial process purposes, typical thermal efficiency rates are 55 per cent for coal, 60 per cent for oil, and 80 per cent for gas.5/ Similarly, in residental and commercial space heating, it has been estimated that coal has a thermal efficiency of from 40 to 60 per cent, oil from 60 to 65 per cent, and gas 70 per cent and over.6/

An outstanding example of improvement in thermal efficiency associated with change in energy source is, of course, provided by railroads. In 1955, railroad freight service consumed:

8,594,000 tons of coal = 225 million million BTU
53,428,000 barrels of diesel oil = 305 million million BTU

3/ Palmer C. Putnam, Energy in the Future (New York, Van Nostrand, 1953), pp. 89-90, 95, 416.

4/ J.F. Dewhurst and Associates, America's Needs and Resources, A New Survey (New York, The twentieth Century Fund, 1955), Appendix 25-3, table I, p.1113.

5/ Nathaniel B. Guyol, "U.S. Energy Resources for the Future," Standard Oil Company of California, San Francisco, California, 1956, Appendix, p. 1.

6/ Ibid., and W.M. Holaday, et al., "Fuels - Their Present and Future Utilization," Proceedings, Twenty-Ninth Annual Meeting, American Petroleum Institute, Section III, Refining (Chicago 1, 1949), pp. 29-30.

/Table 4

Table 4

SPECIFIC MINERAL FUELS AS PERCENTAGES OF TOTAL CONSUMPTION OF MINERAL FUELS, 1900-1955, FIVE-YEARS INTERVALS

(Based on BTU values)

Year	Coal			Liquid and gaseous fuels				Total mineral fuels
	Bituminous	Anthracite	Total	Crude petroleum[a]/	Natural gas	Natural gas liquids	Total	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1900	74.2	19.3	93.4	3.1	3.4		6.6	100.0
1905	73.7	17.4	91.1	5.6	3.4		8.9	100.0
1910	74.7	14.4	89.2	7.1	3.8		10.8	100.0
1915	72.4	14.0	86.4	9.2	4.4	b/	13.6	100.0
1920	70.2	11.5	81.6	13.9	4.3	0.2	18.4	100.0
1925	64.8	8.1	72.9	20.6	5.9	0.6	27.1	100.0
1930	55.5	8.0	63.5	26.3	9.0	1.1	36.5	100.0
1935	51.2	7.1	58.3	30.2	10.5	1.0	41.7	100.0
1940	49.2	5.4	54.6	32.6	11.6	1.2	45.4	100.0
1945	48.9	4.4	53.3	32.1	12.9	1.6	46.7	100.0
1950	36.8	3.1	39.9	39.3	18.4	2.4	60.1	100.0
1955	29.0	1.6	30.6	42.7	23.6	3.1	69.4	100.0

Source: Energy in the American Economy, 1850-1975, Appendix, table VII.

a/ Including net trade in oil products.
b/ Less than 0.1 per cent.

/Since, per

Since, per unit of freight service, diesel oil was utilized about 5.8 times as efficiently as coal,[7/] the above quantity of diesel oil replaced 1,766 million million coal BTU, or 67,405,000 tons of bituminous coal. The difference between 1,766 million million and the 305 million million actually used in the form of diesel oil, amounts to 1,461 million million BTU, or nearly 4 per cent of the aggregate 1955 energy consumption of the economy. Similar savings, but on a much smaller scale, were achieved in passenger service and in yard-switching service.

The foregoing materials are only illustrative. Without doubt, improvements in thermal efficiency have been an important factor contributing to the decline in the energy input-GNP ratio in the post-First World War period; and the acceleration in the rate of increase in thermal efficiency in the present century, as compared to the nineteenth century, doubtless contributed to the change in the trend in the energy-GNP ratio experienced after the 1910-20 decade. Unfortunately, however, the information available does not provide a basis for measuring the impact of changes in thermal efficiency in the innumerable different applications of energy in a precise manner.

(b) <u>The rise of electricity</u> An adequate statistical record for electricity begins in 1902, although commercial production and distribution started some 20 years earlier. Even in 1902, when the first nation-wide census was taken, the figures on total electricity generated were based largely on estimates. In any event, the industry was young at the turn of the century, and its growth as a significant force in the American economy is confined essentially to the subsequent period.

The rise of electricity is important among the factors underlying the behavior of the energy-GNP relationship for two main reasons: The efficiency with which fuels have been converted to electric energy has improved considerably during the past half century; and the application of electricity in production has grown rapidly. The latter is an aspect

---

7/ Based on Interstate Commerce Commission statistics, which show that in 1955 railroads consumed 101 pounds of coal (equivalent to 1,323,000 BTU) per thousand gross ton miles of road freight service, and 1.68 gallons of diesel fuel (228,480 BTU) to perform the same work.

/of the

of the shifting composition of energy consumption, and in particular of the trend away from primary to secondary energy forms, but it merits special consideration because of its implications for the organization of industrial production.

The growth of electricity production between 1902 and 1955 is summarized in table 5, which also includes for comparative purposes the data on total energy consumption. Both electricity generation and total energy consumption are shown also in index numbers, with 1902 as a base to indicate the comparative growth of the two series. The fact that electricity grew much more rapidly than total energy consumption is clearly evident; between 1902 and 1955 electricity's growth was over twenty times that of the total.

This rapidly growing element within the energy total was characterized by marked advances in thermal efficiency. In the generation of electricity, the amount of fuel required by thermal utility stations to produce one kilowatt hour declined from an average of 6.85 pounds of coal or coal equivalent in 1900, to 3 pounds in 1920 and 0.95 pounds in 1955. This represents an increase in thermal efficiency of more than seven times since 1900. What have been the effects of this increase in efficiency on the energy-GNP relationship?

Between 1920 and 1955, energy consumption per unit of gross national product dropped by about 35 per cent (see again table 1). Assume, however, that the consumption of energy for non-electric purposes per unit of GNP had declined to the extent that it actually did over this period, but that the electricity actually produced in 1955 would have required the same amount of fuel BTU per kilowatt hour as in 1920. This is the situation as it developed, with the exception that there were no improvements in the thermal efficiency of converting primary energy sources into electricity. 8/ Under this assumption (treating the total electricity production, including hydro, as if it had been thermally generated) the consumption of energy in 1955 and its relation to the

8/ It is, of course, clear that in the absence of these improvements in thermal efficiency the cost of electricity would have been higher and, consequently, the growth of electric power consumption would not have been as great as it actually was.

/Table 5

Table 5

GENERATION OF ELECTRICITY COMPARED WITH TOTAL ENERGY CONSUMPTION FOR SELECTED YEARS, 1902-1955

Year	Electricity		Total energy consumption (mineral fuels and hydropower)	
	Millions of kilowatt hours	Index (1902 = 100)	Millions of millions of BTU	Index (1902 = 100)
	(1)	(2)	(3)	(4)
1902	5 969	100	8 715	100
1907	14 121	237	13 831	159
1912	24 752	415	15 708	180
1917	43 429	728	19 597	225
1920	56 559	948	19 768	227
1925	84 666	1 418	20 878	240
1930	114 637	1 921	22 253	255
1935	118 935	1 993	19 059	219
1940	179 907	3 014	23 877	274
1945	271 255	4 544	31 439	361
1950	388 674	6 512	33 972	390
1955	629 010	10 538	39 729	456

Sources:

Column 1: Figures for 1902-17: Census of Electric Light and Power Statistics as quoted in Bureau of the Census, Historical Statistics of the United States, 1789-1945 (Washington, D.C., Government Printing Office), Series G 171. 1920-55 based on Federal Power Commission, Production of Electric Energy and Capacity of Generating Plants as quoted in Edison Electric Institute, "Electric Utility Industry in the United States", Statistical Bulletin for the Year 1957 (New York: 1958), p. 13. Excludes small net imports of hydro, which are included in the electricity consumption shown in Energy in the American Economy, 1850-1975, table 58.

Column 3: Energy in the American Economy, 1850-1975, Appendix, table VII.

/expansion of

expansion of the economy as a whole since 1920 would have been the following:

Item	1955 consumption of energy (millions of millions of BTU)
Energy in all uses other than electricity generation, actual consumption (excl. wood)	32,179
Electricity, kilowatt hours actually produced in 1955 at 1920 fuel equivalent required per kWh	24,811*
Total	56,990
Index of energy input per unit of GNP (1900=100)..	92.6

* Fuel or fuel equivalents actually required for the total electricity generation in 1955 amounted to 7,550 million million BTU.

The drop in the energy input-GNP ratio would then have been only about 7.5 per cent instead of the actual decline of about 35 per cent. This would seem to indicate that almost all of the decline in the ratio of energy consumption to the output of the economy as a whole during the post-First World War period may be explained by improvements in the thermal efficiency of generating electricity.

But there is another side to the picture. In spite of the large gains in the efficiency of transforming primary fuels into electric power, some 12,000 BTU were required in 1955 to produce one kilowatt hour which has an inherent energy content of 3,412 BTU. Thus, some 72 per cent of the raw BTU input was lost in the conversion process and never entered the economy beyond the energy sector proper. Since the electric power ultimately utilized in the production of goods and services does not consist of the changing BTU equivalents of the fuels required to generate it, but of actual kilowatt hours, the production and consumption of electricity may just as reasonably be measured by the constant inherent BTU value of the kilowatt hour.[9/]

9/ Indeed, this is the practice in some countries, in which electricity obtained from waterpower is a significant component of total energy. It is also the approach used in the United Nations publications dealing with energy. While production of energy is measured in United Nations statistics by the full, inherent BTU - or calorific - values of the primary energy materials, their consumption statistics generally count all electricity, including that generated from fuels, at its actual BTU equivalent of 3,412 BTU per kilowatt hour.

/Using this

Using this basis of measurement, the aggregate energy input per unit of GNP dropped by nearly two-fifths between 1920 and 1955 - which is not far from the total decline of 35 per cent derived above. The reason for this is that no matter which method of measurement is used, the BTU of electric energy constitute a comparatively small percentage of the energy total, so that the aggregate is dominated by the movement of the BTU of energy consumed for non-electric purposes, as shown in the following figures:

Item	Energy Consumption (Millions of millions of BTU) 1920	1955
1. MEASURING ELECTRICITY AT DIRECT CALORIFIC EQUIVALENT:		
Energy in all uses other than electricity generation	17,535	32,179
Electricity (kilowatt hours generated at 3,412 BTU)	193	2,146
Total	17,728	34,325
1955 index of BTU input per unit of GNP (1920= 100)		62.2
2. MEASURING ELECTRICITY AT FUEL EQUIVALENTS REQUIRED IN ITS GENERATION:		
Energy in all uses other than electricity generation	17,535	32,179
Electricity (fuel equivalent required in its generation at the prevailing conversion rate)	2,233	7,550
Total	19,768	39,729
1955 index of BTU input per unit of GNP (1920=100)		64.5

Thus, we are again faced with the same phenomenon, namely that the amount of energy (measured in BTU) consumed decreased by some 38 per cent relative to the over-all performance of the economy. 10/ Consistent with the calculations just presented, the following hypothesis may be advanced to explain this phenomenon. Despite the comparatively small share of electricity in BTU terms, the relative growth of electric power may still

10/ It should be noted that in the above calculations energy other than for electricity generation is measured before conversion into heat or power ultimately utilized. Thus, changes in the thermal efficiency outside of the electricity sector are not taken into account.

/be important

be important in explaining the decline in the energy-GNP ratio after 1920, if (1) electricity has been substituting for other energy sources in a manner in which BTU in the form of electricity replace substantially greater numbers of non-electric BTU; and (2) the use of electricity permits industrial production to be organized more efficiently, thereby increasing over-all economic productivity, which is reflected in a rising trend of national output relative to all input factors including raw energy consumed. Some data bearing on this hypothesis are presented in the following paragraphs.

The first thing to examine is the growth of electricity relative to the growth of total energy consumption. As noted earlier, over the entire period covered by the statistics, electricity has grown substantially faster than all energy. If the record is examined in terms of the periods of rise and decline in the total energy-GNP relationship, the following pattern is found:

	Rising energy-GNP ratio: 1920 index (1902=100)	Declining energy-GNP ratio: 1955 index (1920=100)
Consumption of all energy (BTU).....	226.8	201.0
Electricity generated (kWh)	947.5	1,112.1
Ratio of growth in electricity generation to growth of total energy consumption	4.2	5.5

Thus, electricity grew faster relative to all energy in the period when the over-all ratio of energy to GNP declined than in the period when the ratio rose.

More significant than the general increase in the relative importance of electricity in the later period was its increasing use in manufacturing operations. This is depicted in table 6 which shows the horsepower of electric motors in relation to total mechanical horsepower used in manufacturing. Since 1899, there has been a rise in the relative importance of electric motors from 5 per cent of total manufacturing horsepower to between 85 per cent and 90 per cent in recent years. By 1909, electric motors constituted one-quarter of all manufacturing horsepower; between

1909 and 1919, their relative importance grew to more than one-half; and, from 1919 to 1939, the horsepower of electric motors had grown to about 90 per cent of total horsepower. Thus, the growth in the relative importance of electric motors was concentrated in the period between 1910 and 1939.

The dominant position achieved by electric motors in manufacturing is a factor of prime importance for several reasons. First, it is apparent that the relatively small share in total energy consumption of BTU's in the form of electricity is a poor guide to the importance of electrical machinery in the industrial sector of the economy.

In addition, the shift from other sources of power - mainly steam - to electric energy involves the substitution of a more efficient source of power in the sense that a larger percentage of the energy consumed in the factory is converted into mechanical work. The over-all thermal efficiency of a system of machines within a factory, belt-driven by a steam-powered prime mover, was less than 10 per cent,[11/] whereas with the electric motor mounted on the machine, some 70 to 90 per cent of the power may be effectively transmitted from the plant substation to the machine.[12/] Thus, in thermal efficiency terms, an "electric BTU" can be considered as worth several times as much as a BTU formerly used for steam-based mechanical power in manufacturing. But perhaps more important, with the individual

---

11/ Assuming the efficiency of the average stationary steam engine to be in the neighborhood of 15 per cent and losses in the belt-drive system of roughly 50 per cent. For discussions of comparative efficiencies at the time of transition, see: A.D. Dubois, "Will It Pay to Electrify the Shops?" Industrial Engineering and the Engineering Digest, Vol. XI, No. 1 (January 1912), pp. 6-7; A.P. Haslam, Electricity in Factories and Workshops (London: Lockwood, 1909), p. 9; and D. C. Jackson, "The Applicability of Electrical Power to Industrial Establishments", Transaction, American Institute of Electrical Engineers, Vol. XXIX, Part I (February 16, 1910), pp. 111-12.

12/ Further losses between the utility central station and the plant substation would range up to 10 per cent. The figures in this whole comparison are merely illustrative. The number of variables and their wide ranges preclude the use of a statistical average as representative of the two sets of conditions.

/Table 6

Table 6

ELECTRIC MOTOR USE IN RELATION TO TOTAL MECHANICAL HORSEPOWER IN MANUFACTURING FOR SELECTED YEARS, 1899-1954

Year	Total horsepower (thousands)	Electric motors[a/] (thousands of HP)	Electric motors as percent of total horsepower
	(1)	(2)	(3)
1899	9 811	475	4.8
1904	13 033	1 517	11.6
1909	18 062	4 582	25.4
1914	21 565	8 392	38.9
1919	28 397	15 612	55.0
1925	34 359	25 092	73.0
1929	41 122	33 844	82.3
1939	49 893	44 827	89.8
1954	108 362	91 821	84.7

Source: Bureau of the Census, U.S.Census of Manufactures: 1954, (Washington, D.C.: U.S. Government Printing Office, 1957), Vol. I, p. 207-2, table 1.

a/ Represents electric motors driven by purchased electricity and by electric power generated at the establishment.

/electric motor

electric motor drive each machine requires an energy supply only when it is being used; in the old mechanical drive, shafts and belting (miles of such apparatus in a large establishment) were idling continuously between periods of use. Clearly a large decline in "steam BTU" could have been achieved through a much smaller increase in the use of "electric BTU."

Finally, the growing use of electric motors in manufacturing and the improvements in electrical control equipment brought with them a flexibility in industrial operations previously impossible to achieve. Before the advent of the electric motor, mechanical power, where needed, had to be obtained from the single prime mover in the plant no matter how small the needs might be. Manufacturing operations thus had to be designed to accommodate the location of the machines to that of the prime mover (the larger power demands had to be established close to the prime mover) rather than to the sequence of the production process. The introduction of the unit drive, in which each machine has its own motor or motors, changed all this: power was available in completely flexible form, and could be distributed throughout the factory in accord with other criteria of efficient organization and with very little energy loss between the plant substation and the machine.

It seems probable, therefore, that the greatest impact of electricity on the efficiency of industrial operations was achieved not as a result of the replacement of BTU which were less efficient thermally than more efficient ones, but the terms of electricity's impact on the total economics of industrial operations. The release from the restrictions of internal mechanical energy transmission systems opened up wholly new possibilities for applying modern techniques of industrial and business management. It is, therefore, not far-fetched to speculate that the marked acceleration in labor and capital productivity after the First World War is attributable in some degree to the new methods of organizing production made possible through the growing electrification of industrial operations.

All of the foregoing seem to support the hypothesis stated earlier: that despite the comparatively small share of BTU of energy consumed in the

/form of

form of electricity, even in recent years, the rise of electricity may be a factor of considerable importance in explaining the decline in the energy-GNP ratio since the end of the First World War. Although more research is needed to establish the validity of this proposition, it does seem consistent with the facts presently available.

/SUMMARY

SUMMARY

The statistics examined reveal a persistent increase in energy consumption relative to GNP between 1880 and 1910, comparative stability between 1910 and 1920, and a persistent decline between 1920 and 1955.

Two groups of explanatory factors were examined: changes in the total economy and changes in the energy economy. The former include structural changes in total output and over-all changes in efficiency reflected in general productivity increases; the latter include changes in thermal efficiency, and the rise of electrification.

Structural changes in the direction of the increasing importance of the industrial sector were found to be a continuing trend during the entire historical period. However, the relative importance of industry grew faster before 1920 than after. General productivity increases in the economy yielding greater national output in relation to the input of labor and capital - which, by the same token, could also increase national output relative to gross energy input - were found to be a persistent factor, but growing faster after 1920 than before. Increases in thermal efficiency of energy utilization were at work throughout the entire period examined, but were stronger in the twentieth century than in the second half of the nineteenth. The rise of electricity - which was found to involve major increases in thermal efficiency and, more important, was probably a significant factor in increasing the over-all productivity of the economy - is confined to the twentieth century, with an acceleration in the period following the First World War.

Changing economic structure in the direction of greater industrialization, which should lead to greater energy consumption per unit of national product, was apparently a dominant factor at work in the period until about World War I. Following 1920, changing economic structure still worked in the same direction, but with greatly reduced force. The other factors examined - increases in the thermal efficiency of energy utilization, the growth of electrification, and the acceleration in the rise of over-all economic productivity - all of which worked on balance in the direction of less energy input per unit of national output, were dominant.

/FIGURE I

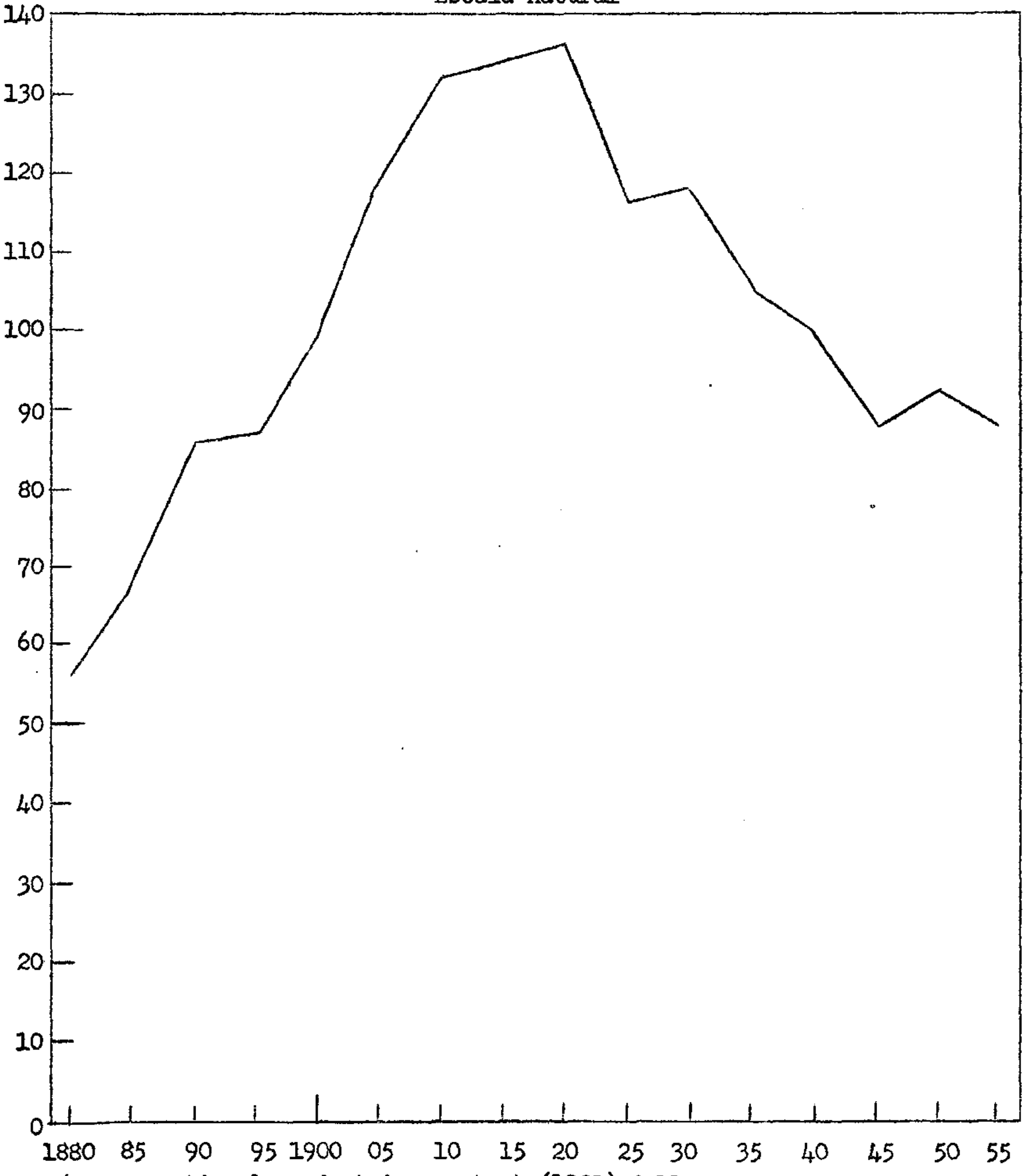
FIGURE I

ENERGY CONSUMPTION PER UNIT OF GROSS NATIONAL PRODUCT a/
1880-1955 (Five-years intervals)
(Index numbers 1900 = 100)

GRAFICO I

CONSUMO DE ENERGIA POR UNIDAD DE PRODUCTO NACIONAL BRUTO a/
1880-1955 (Intervalos de cinco años)
(Indices 1900 = 100)

Natural scale
Escala natural



a/ Gross national product in constant (1929) dollars.
Producto nacional bruto en dólares constantes (1929).