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Energy and economic growth in a developing country:

The case of Peru to the year 2000

by

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TABLE OF CONTENTS

CHAPTER I. INTRODUCTION

The history of humanity can be seen through the use of energy. History reveals three primary energy eras: wood, coal, and oil and gas [145].

Wood was the natural fuel for cooking, space heating and manufacturing, the last specially associated with weaponry and ornaments.

The process of deforestation in some areas pushed the search for new sources, and coal was discovered. It was first mined on a large scale in England in the 16th Century.

Crude oil was first sold on a large scale in the 1860s, and at the beginning it did not compete with coal. Its time came with the development of the internal combustion engine in the first part of the 20th Century. Natural gas appeared as an important energy source in the 1930s.

The energy eras just described are associated with stages of industrial accomplishment. It has been noted that as an economy grows it demands more energy in more convenient forms. The way things have gone the increased economic activity in the industrialized world has produced a change from solid fuels to fluid fuels.

Wood and coal associated with the development of the steam generation technology permitted the substitution of physical labor with inanimate labor. The use of machines, made possible by the availability of energy, produced an unprecedented increase in output per worker, making output no longer constrained by the labor force [87].

The great industrialization era of this century is undoubtedly associated with the development of the internal combustion engine. It radically changed life styles, society values, and business attitudes.

The pattern just described is based on the industrial countries, such as the United States. In 1850, the United States derived 91% of its energy from wood and 9% from coal. By 1900, wood accounted for 20% and coal 75%. By the end of the 1940s, wood had diminished to 5%, coal was 51%, and oil and gas were 41%. In 1975, wood was only 1%, coal had diminished to 18%, oil had increased to 41%, natural gas accounted for 34%, and hydropower was 4% [131].

It is not surprising to find in the developing countries patterns of consumption that in a way reflect their stages of development. For example, Peru in 1976 derived from oil 49.5% of all energy consumed, but firewood still occupied a prominent place with a 25.7% share of the market.

Although we are not suggesting that Peru or any other developing country should follow the energy consumption pattern of the industrial countries, there is a relation between the rate of progress and the sources of energy utilized. This is due, in part, to the fact that non-commercial sources of energy cannot provide the forms of energy that the urban centers, manufacturing facilities, and agricultural equipment are geared to use at the present time. Therefore, to plan its general economic growth and development Peru needs an energy policy, which undoubtedly will reflect certain choices as to the future course [159].

The formulation of an energy policy depends upon expectations regarding future energy demand, energy supply, and the social choice for development. Assessing the future demand of energy contrasted against the expected supplies is the primary concern of this study.

The current and prospective energy situation is confounded with numerous conflicting and confusing elements. Estimation of demands and supplies becomes important when clarifying the issues involved in bringing supply and demand into equilibrium. Use of prices and/or controls to close the gap of demand and supply of energy have important implications for productivity and income distribution, and government intervention.

Confronted with these elements the general purpose of this study is to use an analytical framework for estimating future demand of energy in Peru to the year 2000.

Statement of Research Problem

The so-called oil crisis of 1973 has produced intense activity on research related to energy. Economics has been no exception. But it is in and for the developed countries that most of the studies have been done. One particular topic has drawn attention from researchers: the availability of energy in the future. The starting point of studies of that nature has been the forecast of demand and supply for certain numbers of years ahead.

The developing countries have been a lot less active in ascertaining their energy positions. Peru is among those countries. Peru had been importing oil since the early 1960s. Therefore, the 1973 oil crisis had a significant impact in the country's economy. New oil fields that had been discovered in the early 1970s started full production in 1978, turning Peru into a net oil exporter again. The preoccupation with energy matters that had developed in the years of the energy crunch subsided. But there is enough evidence that energy needs in the future may pose a burden, especially if it has to be imported, of such magnitude that strategies must be planned in advance if catastrophic occurrences are to be averted.

The planning and strategies to which we are referring here must be put together into a National Energy Plan, which has to be integrated into the general development plans of Peru.

The elaboration of such energy plans requires knowledge of present demand and supply of energy goods, and their estimated behavior in the future. The objective of any policy is to influence the estimated course of certain variables.

Peru's energy consumption pattern shows an increasing dependence on oil. This puts Peru in a delicate position, since the resource base does not seem to justify the encouragement of oil consumption. By projecting energy demand and supply to the year 2000, we intend to map the course that Peru is following at the present time. This information is the base for our policy implications.

Our underlying assumption is that increased consumption of commercial nonrenewable resources will place any country in a weak position as those resources become scarce and expensive. Peru, as well as other countries, must adapt to the new international circumstances, developing local resources to the fullest, taking into account all of the implications of such actions.

In searching for methods of energy demand estimation, we have had to be especially concerned with data availability in developing nations. A methodology must be used that would lend itself to immediate application. Although certain modifications must be made when the methodology adopted was developed for a country in a different stage of development, as the ones on which we intend to apply it; a method is also needed that has given good results. This is an important point in the study for our purpose is not the development of the method itself, but its application to the realities of developing nations and the energy policy recommendations that we may offer in their quest for general economic development and growth.

This author has not been able to find energy demand studies of the Latin American countries, except for projections of historical growth rates of all commercial resources put together. It is felt that such an approach is not satisfactory when we are confronted with the difficult decisions that governments must face to assure the availability of energy resources, constrained as they are by the financial, cultural, technological, and social realities of their countries.

Objectives of the Study

The general objective of this study is to utilize a methodology to forecast energy demand. This methodology is intended to be used in a number of developing countries in Latin America. We restrict ourselves to the case of Peru in this study to make the point as to the feasibility of the method and the type of results and recommendations that can be expected.

More specifically, the objectives are:

1. Describe and discuss different approaches to the problem of energy demand estimation.
2. Identify the major determinants of the demand for energy.
3. Quantify energy consumption levels for Peru in the year 2000.
4. Analyze the existing data on production and potential of Peru's energy resources, either presently utilized or not.
5. Establish the energy position of Peru in the year 2000, by integrating the demand and supply estimations.
6. Review the appropriate instruments of energy policy.
7. Infer the policy implications of the case of Peru, suggesting feasible options.

Organization of Study

Chapter II will discuss the concept of energy and its interaction with the economy. Chapter III concentrates on the demand for energy, beginning with the review of literature; to be followed by a detailed description of the methodology and its application. In Chapter IV, Peru's energy resources and their possible production levels in the year 2000 will be analyzed. Also, included will be resources that are not currently being used but that could be developed in the future. The interactions of demand and supply will be discussed in Chapter V. Chapter VI is devoted to energy policy. Finally, Chapter VII presents the summary and conclusions.

CHAPTER II. ENERGY AND THE ECONOMY

In this chapter, we will touch briefly upon the concept of energy and the forms in which it is found and transformed in our world today. We will also refer to the question of the relationship of energy and the economy, a topic that has caused extensive debate, and finally discuss energy use in Peru.

The Concept of Energy

Energy is a concept invented to account for the fact that when heat or work are put into or taken out of a system, and that system ends up in a different state, some property of the system has to account for the difference. The property is called the "energy content" and it is said that a given system under a given set of conditions has a certain energy content [139].

The same concept can be expressed as the amount of heat that must be transferred, exchanged or used up to effect a process or deliver a good to a particular point in the economic system.

The relationship between heat and work better expresses the idea behind energy. Heat and work are interchangeable. A major use of heat in our world is to carry out work. It is relatively easy to produce heat by work; but it is the converse that interests us, and which is more complicated to achieve. This last relationship: heat into work, is explained and studied in thermodynamics. The first law, also known as the Law of Conservation of Energy, states that energy can neither be created nor destroyed, but it is always conserved [43].

The second law of thermodynamics, empirically formulated by Carnot, states that the maximum amount of work we could get out of a quantity of heat depended only on the temperature of the heat and the temperature of the surroundings and had nothing to do with the technology or substances used [43]. In practical terms, it means that only a fraction of the initial energy can be converted into work, and the work of engineers and technologists have been concentrated in the improvement of efficiency.

The calculation of how much useful work one can extract from a given quantity of heat is rendered much easier by the use of entropy. Entropy is a measure of order. As order increases, entropy decreases. It is said that our world entropy is not decreasing, for in order to create order in one place, with loss of entropy, due to the inefficiencies inherent in the transfer of work and heat, there is a countervailing increase of entropy elsewhere, which is greater than the decline in the ordered system. Georgescu-Roegen [41, 42] has covered this topic, pointing out that the world's flow of negentropy (contrary to entropy) from stored sources will only just meet the world's need of it for maintenance, thereafter, further development will be impossible, and the entire system will be taken up with maintaining itself.

We can identify six distinct forms of energy [87]:

1. Mechanical energy
2. Heat energy

3. Electrical energy
4. Radiant energy
5. Chemical energy
6. Nuclear energy

Mechanical, heat, electrical, and radiant energy are examples of energy in motion, while chemical and nuclear energy comprise stored energy.

Mechanical energy is the kinetic energy of large bodies, of the size man can perceive. Heat energy is the kinetic energy of molecules in motion. Electrical energy is the energy at the subatomic level, is the energy of electrons. Radiant energy is the energy at the subelectronic level of the photon, it is the energy of vibrating photons. It is the energy which travels in the form of light, radio waves, ultraviolet, infra-red, X-rays, and gamma rays.

Chemical energy is the stored energy at molecular level. It is stored by the process of photosynthesis. We find this energy in fossil fuels: coal, oil, gas, tar sands, etc.

Nuclear energy is the energy stored at the subatomic level in the nucleus of atoms. It is the energy which normally holds protons and neutrons together in an atom's nucleus.

Sources of Energy

The forms of energy identified in the previous section do not give us but a clue as to the origin of the energy we utilize today. The only common denominator of the different forms of energy is that in order to use them a process of transformation or, at the least transportation, must take place. Electricity, for example, is one of the commonest forms of energy. To produce it there are several alternatives: a) one can utilize the kinetic energy of water, as it is done in hydroelectric power stations; b) one can use the stored chemical energy of fossil fuels and burn them in a thermal generating plant; c) one can use the stored energy of radioactive materials, as it is done in nuclear plants; d) one can use the kinetic energy of the wind, which traditionally produced mechanical energy in grain mills; or e) use the heat in the crust of the earth, i.e., geothermal energy. These are only examples.

Figure 1 shows the energy circuit from basic matter to waste heat.

Energy Resources

Energy can be extracted from a variety of resources. These resources have been classified in different ways, for example:

a) Primary and secondary

b) Commercial and noncommercial

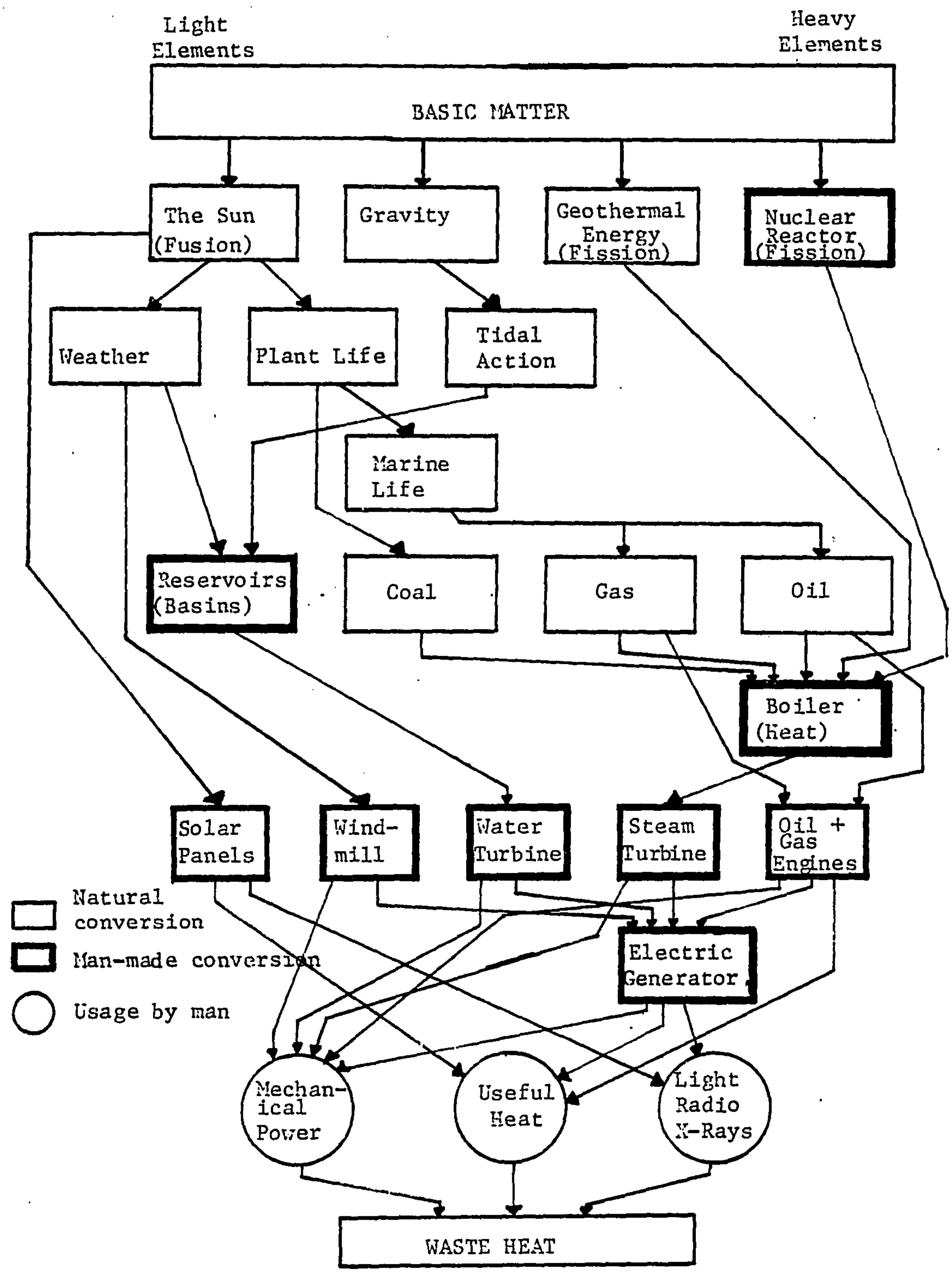
c) Conventional and nonconventional

d) Renewable and nonrenewable

e) Traditional and nontraditional

f) Primitive and modern

Figure 1. The energy circuit [87]



Light Elements
Heavy Elements
BASIC MATTER
The Sun (Fusion)
Gravity
Geothermal Energy (Fission)
Nuclear Reactor (Fission)
Weather
Plant Life
Tidal Action
Marine Life
Reservoirs (Basins)
Coal
Gas
Oil
Boiler (Heat)
Solar Panels
Wind-mill
Water Turbine
Steam Turbine
Oil + Gas Engines
Natural conversion
Man-made conversion
Usage by man
Electric Generator
Mechan-ical Power
Useful Heat
Light Radio X-Rays
WASTE HEAT

Each classification serves a purpose. In our case, and because of the statistics, we are going to use the commercial/noncommercial classification.

The following list tries to present the different resources available to mankind, without classifying them.

Available Resources

- Crude oil
- Oil shales
- Tar sands
- Liquid Natural Gas (LNG)
- Liquified Petroleum Gas (LPG)
- Coal
- Hydroelectric
- Lignites
- Nuclear minerals
    - Uranium
    - Deuterium
    - Radium
    - Thorium
    - Tritium
- Biomass
    - Phytomass (wood, peat)
    - Animal dung
    - Agricultural wastes
    - Charcoal
    - Agricultural crops
- Human power
- Animal power
- Ocean thermal
- Tidal
- Solar
    - Radiation
    - Photovoltaics
    - Photosynthesis
    - Flat-Plates collectors
- Water flows
- Hydromechanic
- Geothermal
- Wind power

This list is not exhaustive and does not reflect the technological constraints still existing to fully utilize some of the resources;

but it at least shows that in a general way it can be said that with proper technological development energy should always be available.

Energy Demand and Economic Growth

In dealing with the question of energy in the economy, there is one question that cannot be avoided: What is the relationship between energy consumption and the rate of economic growth? This question has drawn considerable attention in the last few years, and although we will not try to address it directly, we will briefly refer to the arguments [5,31,65].

In modern growth theory limits to the rate of economic growth, are set by factors such as labor supply, technology, and capital accumulation. [152]. In classical theory, natural resources played a different role [88]. Adam Smith in "The Wealth of Nations" had no explicit statement about natural resources but his idea that the rent of land, considered as the price paid for the use of land, is naturally a monopoly price, implied that land and natural resources could be considered to be fixed in supply.

Malthus' "Essay on Population" may be credited with having established the belief that the scarcity of natural resources impairs economic growth.

Ricardo's view was that growth will be accompanied by increasing real costs, i.e., by diminishing returns to labor and capital.

J. S. Mill in his "Principles of Political Economy" elaborated upon the ideas of Malthus and Ricardo. He found that the Ricardian view, that resources underwent a persistent decline in economic quality as a consequence of growth, a more reasonable approach.

Marx addressed the question by indicating that the prevailing social system tended to press on the means of subsistence. He denied the existence of a natural law of population growth. For him, poverty was a consequence of unemployment, which in turn was basic to capitalism.

But we may say that the distribution of natural resources among nations in the world has no correlation with their rates and levels of economic activity. It is being considered that the exhaustion of natural resources does not put a limit on growth because of technological innovation [56]. Furthermore, Denison in his "Accounting for United States Economic Growth, 1929-1969," making the assumption that the quantity of land resources remained constant, ends up showing that the natural resource contribution to growth was zero.

What we have today in terms of one particular resource called energy is two points of view. One view is that the link between consumption and economic growth is significant and substantial, energy makes it possible for investment to be productive, technology to advance, and labor productivity to increase [71]. In the other view, energy consumption is perceived as a source of growth, and it is counted as just one among a number of growth determinants; therefore, economic growth will not slow down significantly if energy becomes difficult to get [54, 140].

The historical record indicates that there is an interaction between energy and the economy in which economic growth has promoted increased energy consumption, while energy consumption has, in turn, influenced the pace of economic growth [55, 90, 144].

Energy and Economic Development

Economic development must not be confused with economic growth. Although economic development encompasses growth it also means fundamentally transforming the economic structure through changes in technology, trade patterns, working conditions, and methods of resource allocation.

Favorable conditions of energy supply generally are perceived as contributing to economic growth. Conversely, unfavorable conditions will reduce the opportunities for resource shifts and work process changes, and this will, in turn, slow down the pace of economic growth [140].

Over the long run, economic development policies have produced a change in the composition of the labor force, from agriculture into industry and services.

Energy consumption is viewed as having contributed to the objectives of economic development policies by raising productivity in the industrial sector and, consequently, attracting resources to manufacturing; and also by increasing the mobility of people and goods, promoting at the same time the urbanization process.

There are still many elements of discussion in the measurement of economic development. The same is true for energy consumption. It cannot be simply postulated that more energy consumption will bring about growth and development.

Energy Inputs into the Peruvian Economy

Each of the sources of energy available is measured in its own units. To present and compare them a common unit must be adopted. In this study we are going to use the British Thermal Unit, or BTU, which has become widely used. Statistics are sometimes presented in gross values and sometimes in net quantities. The term "gross" signifies the inclusion of losses occurring when primary energy resources are converted into the secondary, or "net," energy forms that are delivered to ultimate consumers.

In 1976, Peru's gross energy consumption reached 509.7 trillion (10^{12}) BTU. Table 1 and Figure 2 summarize the composition of the primary resources that made up this total.

Table 1. Peru's gross energy inputs for 1976[a]

Source	Trillion BTU	Percentage Distribution
Hydropower	65.6	12.8
Oil	252.5	49.5
Coal	10.4	2.0
Gas	19.4	3.8
Biomass	167.7	31.9
	509.7	100.0

[a]SOURCE: [172].

Well over half of the energy consumption comes from fossil fuels. Water power contributes with 12.8% and noncommercial sources comprise a substantial part of the market with 32%. If we are to exclude the noncommercial sources, as is done commonly, the importance of fossil fuels is magnified, as shown in Table 2 and Figure 3. Fossil fuels provide for over 80% of the commercial market.

A broad picture of energy flows to the major consumption sectors of the economy appears in Table 3 and Figure 4.

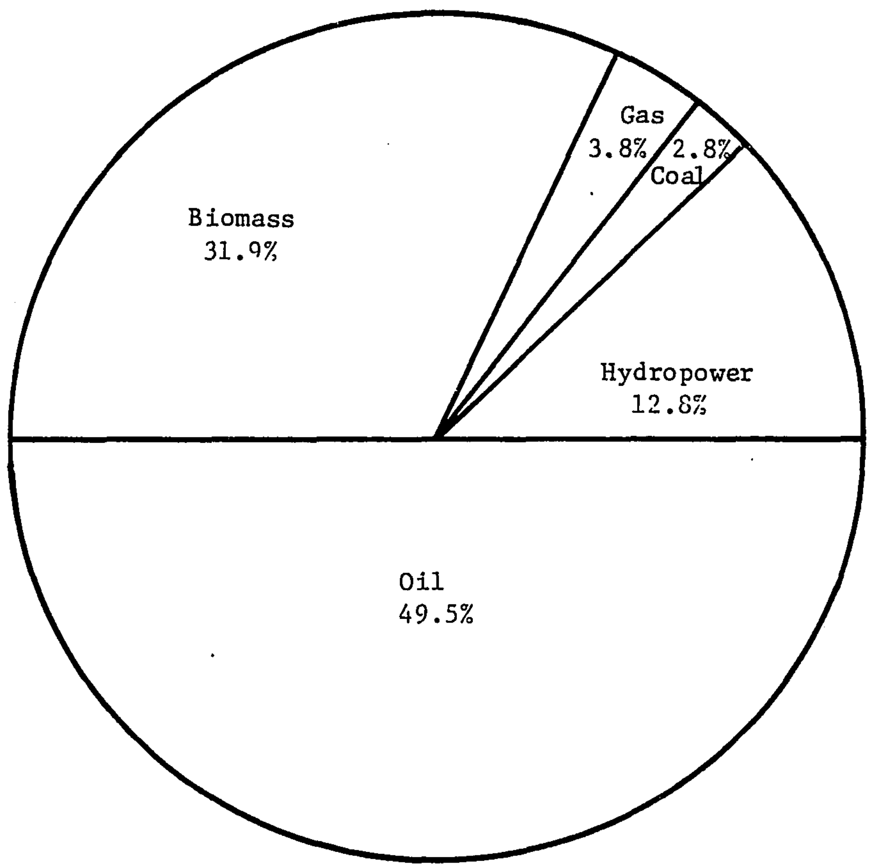


Figure 2. Distribution of Peru's gross energy inputs by source, 1976

Table 2. Commercial energy inputs for Peru, 1976[a]

Source	Trillion BTU	Percentage Distribution
Coal	10.4	3.0
Oil	252.5	72.6
Gas	19.4	5.6
Hydropower	65.6	18.8
Total	347.9	100.0

[a]SOURCE: [172].

Table 3. Peru's gross and net commercial energy inputs for 1976, by source and consuming sector[a]

Consuming Sector	Fossil Fuels	Electricity	Net	Electrical Losses	Gross Energy Consumption	
					BTU	%
		(in 10^{12} BTU)				
Households-commercial	31.8	8.9	40.7	25.2	65.9	18.9
Industry	104.7	14.0	118.7	39.6	158.3	45.5
Transportation	111.2	---	111.2	---	111.2	31.9
Agriculture	8.0	1.0	9.0	3.5	12.5	3.7
Total in 10^{12} BTU	255.7	23.9	279.6	68.3	347.9	100.0
Total percent	73.5	6.9	80.4	19.6	100.0	

[a]SOURCE: [172].

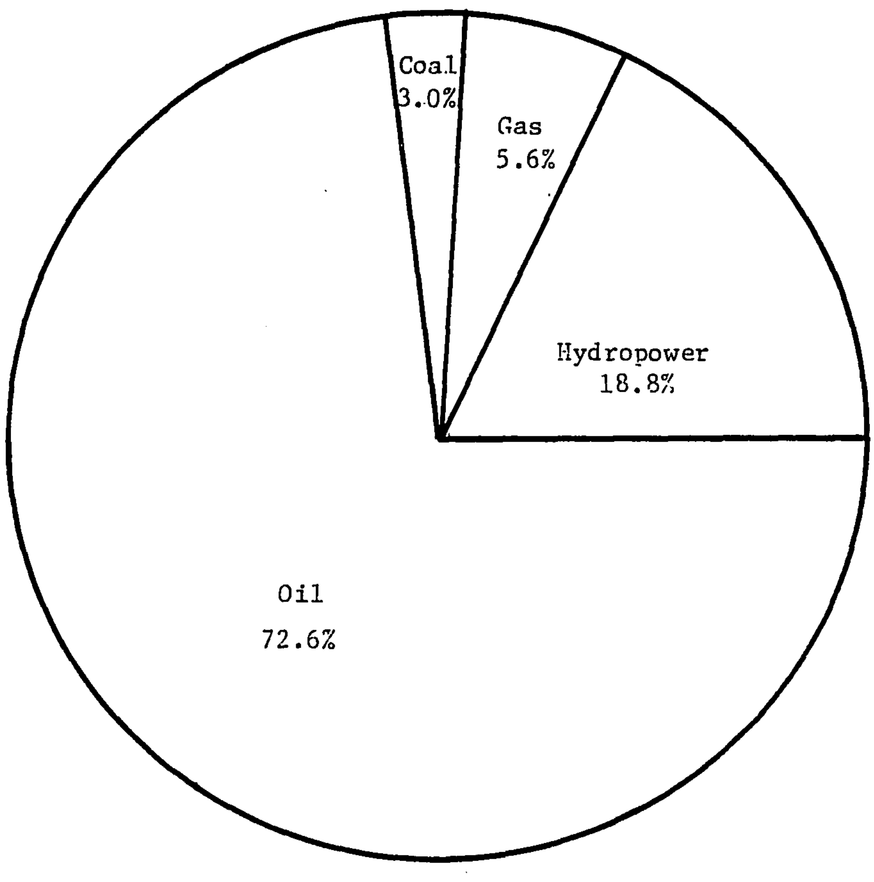


Figure 3. Distribution of Peru's gross energy inputs of commercial energy by source, 1976

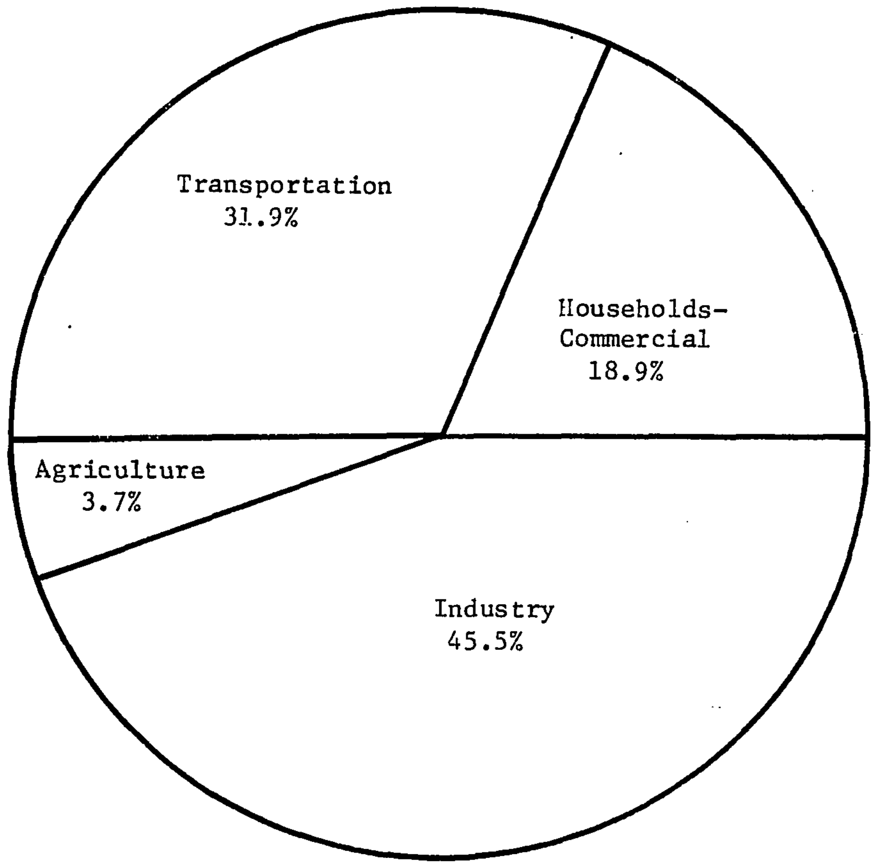


Figure 4. Distribution of Peru's gross commercial inputs by consuming sector, 1976

Noncommercial resources are more difficult to analyze, in part, because there are no good statistics on consumption. It has been estimated that around 161.8 trillion BTU of these resources were used in Peru in 1976. They are mainly firewood, charcoal, animal dung, and other agricultural wastes. Table 4 presents these estimates.

Table 4. Noncommercial[a] gross energy inputs, 1976[b]

Consuming Sector	Firewood	Bagasse	Other	Total	Percent
Households (cooking-heating)	130.8		22.8	153.6	95.0
Agriculture (process heat/electricity)		8.2		8.2	5.0
Total	130.8	8.2	22.8	161.8	100.0
Percentage distribution	80.8	5.1	14.1	100.0	

[a]The name noncommercial energy is a misnomer. It has been adopted here because of its wide use in the literature.

[b]SOURCE: [172].

Energy losses in noncommercial fuels are quite large. It is estimated that they deliver only 10% of the gross input.

The net-gross relationship is sometimes used as a very crude kind of overall efficiency measure reflecting the efficiency of a country's system. In our Table 3, such a figure is around 80% for Peru in 1976. In Schurr et al. [130], calculations for the U.S. economy show a similar figure. The breakdown that has been presented is broad. In Table 5, it has been attempted to specify purposes for which energy is used in Peru.

In looking at Table 5, one can observe that more than half of the households' consumption of energy is for cooking, which is a basic activity. In the transportation sector, automobiles and trucks dominate the sector with 57% of the total. Note, notwithstanding, the relative importance of the public transportation systems with 13% of the sector total.

Table 5. Gross energy consumption, estimated distribution by sector and detailed end use--commercial resources only, 1976[a]

Sector	Trillion BTU	Percentage Distribution
Households	56.0	16.1
Cooking/Heating	29.2	
Lighting	8.4	
Other	18.4	
Commercial	9.9	2.8
Lighting/Appliances	9.9	
Agriculture	12.6	3.6
Electricity/Process Heat	12.6	
Transportation	111.2	32.0
Bus	14.2	
Ship	12.8	
Air	12.9	
Automobile	20.9	
Truck	41.9	
Rail	1.8	
Armed Forces	6.7	
Industry	158.2	45.5
Process heat and steam	73.2	
Electrolysis	22.1	
Electric drive	38.9	
Feedstock	14.1	
Other	9.9	
Total	347.9	100.0

[a]SOURCE: Prepared from data in [172].

This reflects a rather low number of automobiles in the country as a whole. In industry, the bulk of the energy goes to process heat and steam.

The categories listed in Table 5 refer to functions for which energy is consumed. For the industrial sector, it is possible also to identify the particular industrial groups accounting for the bulk of the sector's energy inputs. To be specific, six manufacturing groups accounted for nearly two-thirds of total industrial energy consumption in 1976: oil refining (6.3%), mining and nonferrous metals (29.1%), iron and steel (6.2%), cement (7.5%), fertilizers (5.6%), and fishing (5.4%).

A useful differentiation can be made between the energy consumed in the final demand sector of the domestic economy and that consumed in the intermediate economic activities. By final demand, we mean direct purchases of fuels or power by ultimate consumers. Unlike the energy used by the business sector in production of goods and services, these are direct energy purchases in so far as they are not subject to further processing and not embodied in other commodities. Their consumption, of course, is closely tied to other expenditures, such as those in cars, appliances, etc. By contrast, intermediate energy consumption occurs at a prior stage of economic flow where energy, along with other resources, contributes an input into the production of goods and services, either destined for still further processing or for subsequent delivery to ultimate consumers.

For 1976, it can be estimated that gross energy inputs into the economy can be broken down approximately as shown in Table 6. The gross total shows a distribution of 43% to household and 57% to intermediate sectors. But when adjusted for energy losses during conversion, it shows 19.5% for households and 80.5% for intermediate factors, which is more in line with the commercial resources distribution.

Table 6. Gross energy inputs (by percentage)

Consumption Sector	Gross Commercial	Gross Noncommercial	Gross Total
Households	19	95	43
Intermediate sector	81	5	57
	100	100	100

The importance of this distinction lies in the nature of the energy utilized in the final demand as opposed to the intermediate sectors. It is similar to comparing personal consumption and capital investment. The latter is needed to generate the former. Energy in the intermediate sector is a factor of production, along with labor, capital, land, materials, etc.

The importance of energy consumption in the national economy is not completely captured when expressed in physical units or caloric terms. To get a better idea of energy importance, we have tried to give it a money value, then energy can be expressed as a percentage of the GDP. Table 7 shows that the estimated value of gross energy inputs into the economy came to about 30 billion in soles in 1976 (some US $ 460 million at the exchange rate of 1976). This means that it is about 3.7% of the GDP of 1976 which is calculated to be 830.5 billion of soles (some US $12.8 billion). For the different primary energy sources combined, this works out to be about $58.85 soles per million BTU (about US $0.81 per million BTU).

Table 7. Value of gross commercial energy inputs, 1976

Source	Quantity Consumed	Average Price (in soles)	Total in 1976 Soles (in billions)
Hydropower	7.911×10^9 Wh[a]	0.72 per kWh[b]	5.7[c]
Oil	42.726×10^6 barrels[a]	527.15 per barrel[d]	22.5
Coal	253,500 metric tons[a]	6,088 per metric ton[a]	1.5
Gas	26.22×10^9 cubic feet[a]	62.50 per 1,000 cubic feet[a]	1.6
Total			31.3

[a]SOURCE: [172].

[b]Obtained by dividing total income of electric sector by the production [98].

[c]SOURCE: [98].

[d]The international price of oil in 1976 has been used, US $8.11 per barrel [167].

In the process of valuation of energy inputs, noncommercial resources, which constitutes about one third of all energy consumed. Prices for these noncommercial resources are not available, although some of them, like firewood, have a very active market. Bagasse is used by the sugar mills and, therefore, is not traded. The lack of information may underestimate the importance of energy in relation to the GDP.

A crude correlation between energy consumption and the gross domestic product (GDP) can be established by examining historical data. Table 8 shows a rather constant relationship. From 543 BTU per sol of output in 1950, it grew to 668 BTU per sol in 1974, an increase of 23%, which indicates a greater energy intensity most probably the result of industrialization and urbanization.

Table 8. Historic energy to GDP ratio[a]

Year	GDP	Commercial Energy Consumption	BTU per Sol
	(10^9 in 1973 soles)	(10^{12} BTU)	
1950	126.3	68.6	543
1951	136.1	73.9	542
1952	143.5	76.0	529
1953	151.2	86.2	570
1954	160.2	94.8	591
1955	166.9	93.6	561
1956	173.2	96.9	560
1957	184.5	105.0	569
1958	185.1	112.4	607
1959	193.8	111.8	577
1960	215.8	125.9	583
1961	230.8	130.8	642
1962	249.7	145.0	581
1963	360.0	159.6	614
1964	279.1	174.4	625
1965	293.5	176.3	601
1966	312.4	219.1	701
1967	322.8	221.7	687
1968	322.1	225.2	699
1969	334.5	226.9	678
1970	352.6	237.3	673
1971	370.3	247.1	668
1972	376.5	245.8	653
1973	392.6	259.9	662
1974	421.9	281.9	668

[a]SOURCE: [172, 190].

Just for comparison, in 1970 the United States consumed 62,400 BTU per one dollar of GNP. Peru, in 1970, consumed 673 BTU per one sol of GDP. Using the rate of exchange at that time (US $1 = 40 soles), it was discovered that Peru was using 22,431 BTU to produce $1 of GDP. While the tendency in the United States is to decrease the BTUs per $1 worth of output, the tendency in Peru is to increase it, although moderately.

CHAPTER III. THE DEMAND FOR ENERGY

The main purpose of this section is to arrive at estimates of energy consumption for Peru to the year 2000. In proceeding with this objective, the review of literature will be presented concentrating on the period 1950-1980; then the methodology selected will be presented, followed by its application.

Review of the Literature

The purpose of the projection, the time available for its preparation, and the sophistication and personal preference of the author cause the many differences in methods of estimating energy requirements. No one method can be said, a priori, to be more accurate than others, but as it was said elsewhere ". . . while sound methodology does not insure a better forecast any more than good form in sport assures a winning team, good form and sound methodology increase the probability of superior performance" [8].

In order to cover as briefly as possible the different approaches, this section will be divided into two groups: a) energy modeling and b) statistical projections. Since this study does not fall into the energy modeling category, this group will be discussed first.

Energy modeling

An energy model may be defined as a set of mathematical relations expressing economic theory about energy [4, 47, 50].

The decade of the 1970s has seen a tremendous increase in energy modeling. In a seminar in 1973 [134] it was reported that 94 energy modeling efforts were being carried out in the United States alone. In 1978, the Energy Modeling Forum [64] reported 146 models worldwide; they also indicated that at least 15 more models were in preparation at that time. The popularity of models does not apply only to energy. The following paragraph may summarize the situation:

> "When the history of economic policy-making in the turbulent late 1970s is written, an important part of the story will be about the ever-widening impact of econometric models on federal policy decisions. The wondrous computarized models--and the economists who run them--have become new rages on the Washington scene. These days, it seems, every spending and tax bill is played into mathematical simulations inside a computer. The model managers themselves are star witnesses before congressional committees whose members seek to devise the future. And what these machines and their operators have to say has come to have a significant bearing on what Washington decides to do" [38].

It has been said elsewhere [147] that major models since 1973 have given predictions about the U.S. energy situation that have been consistently more optimistic than the reality proved to be, especially in regard to energy supplies.

To fit the complexities of the real world into the variables that can be handled in a model, a number of simplifying assumptions are made that can lead to inaccuracies [158]. Five of these assumptions include:

1. Exclusion. The influence of any factor not included in the model is assumed to be unimportant in affecting the conclusion.
2. Aggregation. Data are often combined or aggregated in order to reduce the number of variables to manageable proportions,

or because it is not possible or convenient to measure them separately.

3. Range. The data put into an equation used to make forecasts are calculated from observations made within a range of prior experience. This is especially important in the case of elasticities.

4. Reversibility. For example, if the elasticities used to make forecasts are derived during a demand process in which reduced prices are accompanied by increased consumption, then, under the reversibility assumption, it is assumed that forecasts can also be made using these elasticities for periods when increased prices are expected to be followed by reduced consumption.

5. Time lag. Data are seldom available to enable modelers to make an accurate estimate of the time lag required for the change in one variable, such as price, to achieve any given effect.

The calculation of the response of energy demand to changes in energy prices is the central point of the energy demand models. A recent study [30] produced the following table, based on 16 detailed models (Table 9).

Another comparison was performed on the base of different indexes. Table 10 summarizes the results for individual models.

Kuz and Smil [66] made a study of elasticities in European countries and found a variety of patterns. More importantly, they found that elasticities for the same country varied widely for extended periods. Table 11 presents that information.

Table 9. Twenty-five year secondary demand elasticities estimates[a]

Sectors	Parameter Estimation Methodology Statistical	Other
All sectors	0.3–0.7	0.1–0.6
Residential	0.5–1.0	0.4
Commercial	0.5	0.3–0.4
Industrial	0.2–0.5	0.2–0.4
All transportation	0.2–0.5	0.4

[a]SOURCE: Adapted from Energy Modeling Forum [30].

Table 10. Comparison of 25-year secondary demand elasticity estimates based on selected indexes[a]

Model	Reference Number	Tornquist	Paasche	Laspeyres	BTU-Weighted
ETA-MACRO (1976)	[70]	0.19	0.18	0.20	0.35
FOSSIL1 (1977)	[22]	0.08	0.08	0.08	0.14
BECOM (1978)	[14]	0.54	0.51	0.57	1.00
Jackson et al. (1978)	[63]	0.38	0.37	0.38	0.33
Sweeney (1978)	[151]	0.46	0.46	0.46	0.46
Baughman et al. (1979)	[9]	0.61	0.61	0.61	0.59
EPM (1979)	[2A]	0.57	0.57	0.57	0.59
Griffin (1979)	[45]	0.56	0.55	0.57	0.68
Hirst (1979)	[51]	0.45	0.44	0.45	0.37
ISTUM (1979)	[29]	0.24	0.24	0.24	0.01
Parikh (1979)	[89]	0.09	0.10	0.09	0.10
Pindyck (1979)	[125]	0.71	0.70	0.71	0.66

[a]SOURCE: Adapted from Energy Modeling Forum [30].

Table 11. European energy elasticities estimates[a]

Country	1950-1971	1950-1960	1960-1970
Spain	0.65	0.99	0.97
Poland	0.67	0.85	0.83
USSR	0.66	0.79	0.88
West Germany	0.71	0.74	0.96
France	0.88	0.88	1.01
Norway	1.27	1.10	1.09
Bulgaria	2.47	1.73	1.49
Italy	3.01	2.00	1.45

[a]SOURCE: Adapted from Kuz and Smil [66] and Medina [76].

Energy models have been built for a variety of purposes. The National Research Council examined six models and looked at the implications for future consumption, which are presented in Table 12.

Table 12. Forecasts of U.S. energy consumption of selected models[a]

Model	Reference	1990[b]	2010[b]
		(in 10^{15} BTU)	
DRI (1976)	[23]	107.9	---
DESOM (1975)	[73]	113.0	186.0
SRI (1976)	[142]	108.9	175.0
FEA (1976)	[34]	114.5	---
ETA (1976)	[72]	103.9	162.0
WN (1976)	[83]	88.3	123.0
EPRI (1978)[c]	[186]	---	167.0

[a]SOURCE: National Research Council [81].

[b]When more than one estimate is given the average has been taken.

[c]Not originally included in National Research Council study.

Statistical projections

The interest in forecasting energy demand seems to be associated in the early stages with the political realities of the post-World War II era: a concern in the United States for the availability of raw materials, especially those that had to be acquired outside. Losing the sources of these materials in the changing political patterns of the era, in the face of the growing importance of communism in the world, was a real threat. A major study, appropriately named Resources for Freedom [179] led the efforts to keep an eye on the energy situation of the United States.

In the studies reviewed, three aspects were analyzed: a) method of estimation, b) construction of final demand and c) projected energy consumption figures.

For the method of estimation, three procedures were identified: time trends analysis, multi-regression analysis and judgment [166, 171].

Time trends analysis Time trends analysis calculates historical trends in energy consumption by determining a statistical relationship or correlation between energy consumption and time. By the very nature of time trend analysis, projections of its calculated trends will yield accurate forecasts of the future if the projected historical relationships between energy consumption and time continues into the future.

Multi-regression analysis Multi-regression analysis calculates the historical trends in the relationship between energy consumption and various selected economic variables, and uses them as forecasting relationships to project future energy consumption. An equation of this type is represented by:

$$C_t = a + bX_t + cY_t$$

where:

C_t = total energy consumption at time t;

X_t = population at time t;

Y_t = Gross National Product (GNP) at time t; and

a = constant.

While the forecasting relationship calculated by regression analysis may be good for predictive purposes, it does not necessarily represent causal relationships or even economic relationships [40].

Judgment Even when time trends or multi-regression analysis is used, judgment is used in choosing the sources of data, the time period of the data, and the type of forecasting relationship to be fitted to the data.

As to the construction of the final demand, two methods have been used.

Building blocks When forecasts of each major energy source or use are made and added together to project total energy consumption, these are building blocks.

Subdivision When the total energy forecasts constrain the sum of its various components, subdivision results.

In Table 13 the forecast of total energy demand by all the works reviewed are presented. This author feels that the presentation of each of these studies would serve no purpose, thus, only several have been selected to be included here to add depth and information of some interest to the study. In passing, it should be noted that we have rejected the method of extrapolation of historical trends. There are three indicators that have been used in the past: total energy consumption, total energy consumption per capita and total energy consumption per unit of GNP. But in Schurr et al. [131] a detailed analysis of each shows that over the period 1850-1955 their behavior for the United States was so erratic that it would be unsound to make predictions of their future behavior.

In this study, Schurr et al. [131] start by assuming a rate of growth of GNP, based on projection of size of the labor force, annual average hours of work, and output per man-hour. A separate and careful projection of population was made using the historical trends available. The next variable to be estimated was the number of households, derived from the population estimate. Labor force, work hours, and productivity were estimated following the estimates of the Census Bureau.

The heart of the projection method lies in the estimation of future energy consumption in specific energy-consuming activities, many of which in one way or the other are, of course, related to either population or

Table 13. Energy demand forecasts of U.S. studies, 1950-1980 (in 10^{15} BTU)

Study	Reference	1970	1975	1980	1985	1990	2000	2010
Paley, MPC (1952)	[179]		62.2					
Putnam (1953)	[127]			87.6			150.0	
B and N (1955)[a]	[6]			60.0				
B of M (1956)	[164]			72.5				
U.S. Congress (1956)	[170]			87.5				
Teitelbaum (1958)	[153]			80.9				
Sporn (1968)	[141]		72.0				105.0	
Lamb (1959)	[67]			78.0				
Schurr et al. (1960)	[131]		74.5					
Weeks (1960)	[184]			90.0			180.0	
Searl (1960)	[135]		73.0	86.2			170.0	
Texas (1961)	[154]			82.6				
U.S. Congress (1962)	[169]			82.0				
Hubbert (1962)	[57]			67.2			101.0	
AEC (1962)	[160]			82.0			135.0	
B of M (1962)	[165]			85.9				
Landsberg et al. (1963)	[68A]	60.2		79.2		101.9	135.2	
Cambel (1964)	[13]		70.2	80.8			136.0	
AEC (1967)	[161]			80.0			130.0	
Cook (1967)	[20A]	60.8	79.9	93.3	118.1			
Texas (1968)	[155]	64.4	79.6	97.8	119.5			
B of M (1968)	[162]	64.3	75.6	88.1			168.0	
Chase (1968)	[17]			97.0				
D of I (1968)	[178]			88.1				
Nathan et al. (1968)	[78]			91.0				
Strout (1967)	[148]			90.3			155.0	
SRI (1970)	[143]		47.2	57.5			174.0	
Morrison (1970)	[77]			95.1		134.7	168.5	
Ebasco (1977)	[28]	68.2	83.1	100.0	120.0			
Darmstadter (1971)	[21]			95.1		134.7	190.1	
B of M (1971)	[163]						165.9	
NPC (1971)	[79]	67.8	83.2	102.5	124.9			
FPC (1971)	[36]			105.0		143.0		

D of I (1971)	[176]		84.8	103.5	127.7			
Schurr and Homan (1971)	[132]			90.9				
Steele (1971)	[144]		86.2	105.3	128.5			
Gamb (1971)	[39]			110.0		195.0	337.0	
Haydinger (1971)	[49]			101.6				
FEA (1974)	[35]				105.0			
Ford (1974)	[37]				98.5		136.9	
D of I (1975)	[177]				103.5		163.4	
Shell (1976)	[136]				96.5	110.0		
IEA (1976)	[62A]				85.0		113.5	138.5
U.S. Congress (1977)	[168]				94.8	108.9		
Exxon (1977)	[33]				93.0	108.0		
NEP (1977)	[185]				97.0			
CIA (1977)	[16]				98.6			
NRC (1978)	[80]						94.0	136.0
D of E (1978)	[173]				91.6		117.3	
D of E (1978)	[175]				94.0	105.1		
Shell (1978)	[137]				90.4	101.2		
Schurr et al. (1979)	[130]						114.7	
NRC (1978)	[19]							108.9
Allen (1979)	[1]				85.0		113.5	
ACTUAL FIGURES	[167, 174]	66.8	70.7	76.3				

[a] B and N stands for authors Batchelder and Nelson.

GNP. The year 1955 was selected as the data base. Two steps were followed: 1) projection of future output levels for the specific industries and activities represented in the energy-use pattern and 2) estimation of possible future changes in the relationships between the energy these industries or activities consume and their levels of output. As it can be seen from Table 13 the projection of energy consumption for the United States for 1975 is 74.5 x 10^{15} BTU, which comes very close to the actual figure of 70.7 x 10^{15} BTU. Table 14 takes a closer look.

Table 14. Comparison of predictions of Schurr et al. study with actual figures, 1975

Sources	Schurr et al.[a]	Actual[b]	Percent Difference
	(10^{15} BTU)		
Coal	19.0	12.8	+48.0
Natural gas	19.7	19.9	--
Oil	29.9	32.7	- 9.0
Hydropower	2.4	3.2	-25.0
Other	3.5	1.97	+75.0
Total	74.5	70.7	+ 5.4

[a]SOURCE: [131].

[b]SOURCE: [167].

The work of Schurr et al. was followed by Landsberg et al. [68A], who included other types of resources as well. They used a building block approach starting with a 1960 base for the various end-use sectors and forward projection of the base. These projected demand figures were then disaggregated (subdivided) into the different sources of energy categories based on estimates of future sharing. Compared to the actual consumption this study underestimated U.S. consumption for 1970 by 10% and overestimated for 1980 by 3.8%.

In 1979, Schurr et al. [130] directed another study using basically the same methodology as before and analyzing the major changes of the U.S. economy since the study of 1960.

The final study discussed will be that of Allen [1] which followed the report of the Institute for Energy Analysis [62A], in which Allen was a coordinator.

In Allen's study, the U.S. energy demands are divided into four broad sectors--households, commercial space, the transportation of persons and goods, and industry. The future growth of energy demands in each sector is determined by combining demographic-economic assumptions with attainable technical efficiencies in specific energy consuming devices and calculating the rates for the introduction of these newer technologies. The specific energy demands obtained from an analysis of each sector are then summed to obtain the total energy demand. To arrive at these estimates of energy demand four steps are taken:

1) estimation of GNP which also requires the estimation of population and labor participation rates;
2) estimation of labor productivity by extrapolation of historical trends;
3) Derivation of other information such as number and type of household, square feet of commercial space needed to support the households, etc., from projection of GNP and population; and

4) estimation of the corresponding end-use energy demand taken from the information obtained in the previous three steps—the total energy demand is the sum of the energy demands in each end-use category.

An important feature of this study is the introduction of efficiency as a key variable in determining energy consumption. Factors such as conservation, government restrictions, saturation of energy-consuming devices, and the impact of an aging population, enter the analysis specifically.

Methodology

The review of literature provided a look at the possible approaches to energy demand estimation. In order to select one way or another, the ultimate goal must be kept in mind. We are interested in assessing energy demands for the developing countries of Latin America.

This goal puts certain restrictions on the real avenues open in choosing a methodology. We have to work with an approach that will not require excessive amounts of data, compiled over a number of years. This author's experience with the developing countries of the area is that energy statistics are about the poorest of them all. The case on noncommercial resources is dramatic because these resources are usually consumed within the producing unit; therefore, we do not have either a quantity or a value for them. Ignoring noncommercial resources is a serious mistake in countries where they represent a substantial part of all energy consumed.

The methodology that has been selected starts with the estimation of key demographic and economic variables. These are a) Population and b) Gross Domestic Product (GDP).

The parameters and variables that affect our two demographic-economic variables can be divided in turn into two: i) inputs and ii) intermediate factors. The inputs are: the fertility rate, the labor participation rate, and labor productivity.

These three inputs must be estimated bearing in mind their historical trends. Once they are estimated the estimates of population, the labor force and GDP can be derived.

The intermediate factors are:

i) households,

ii) services,

iii) transportation (private),

iv) industry and agriculture,

v) transportation of goods and services.

Figure 5 presents a representation of the relationships of the variables, inputs and intermediate factors.

The estimation procedures for each of the mentioned variables are discussed in the following paragraphs.

Population

In this study, we are going to use the estimations of the Peruvian Census Bureau. Their study of 1975 projects population to the year 2000 under four alternatives. Each of the alternatives assumes a different

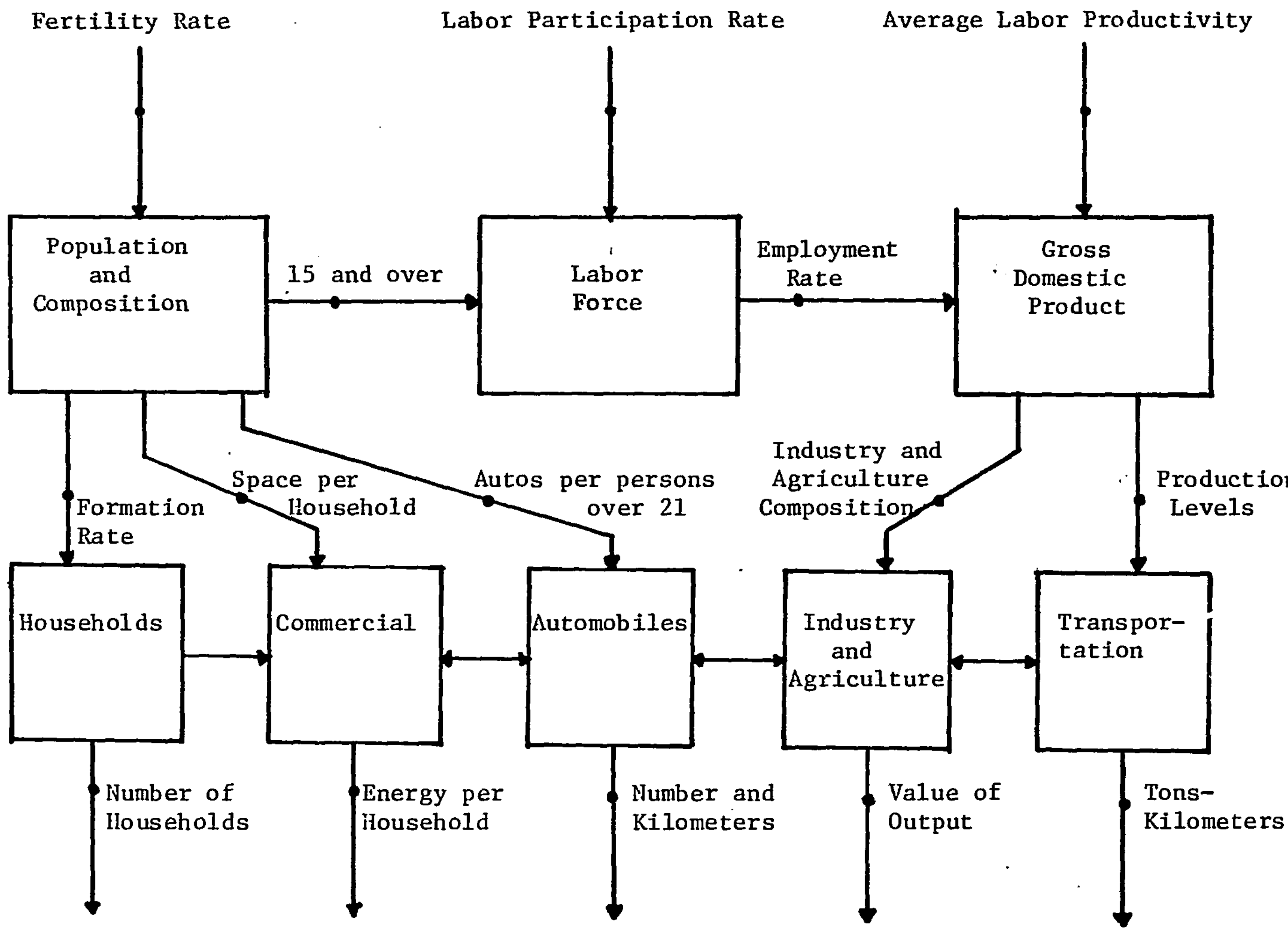


Figure 5. Variables, inputs and intermediate factors

change in fertility rates, but all assume the same changes in death rates. One of the reasons to follow the Bureau's study is that population estimates that require the composition of the population by age and sex needs laborious calculations that are beyond the scope of this work. Updated information on Peru's fertility rates allows us to choose among the four alternatives with a certain degree of confidence.

Labor force

The size of the labor force at any given time depends on the total population and on the labor participation rate. The latter is defined as the percentage of persons 15 years of age and over who are either employed or actively seeking employment.

We have obtained the population figures from the Census Bureau study previously mentioned, along with the estimations of labor participation rates which are based on historical trends.

Labor productivity

Labor productivity can be measured in different ways. In this study, we use the ratio of GDP to Labor Force to derive a time series from which we can observe the behavior of productivity. It is very difficult to make predictions of change in productivity. Since it is such an important determinant of Gross Domestic Product, a gross distortion in its predicted value will undermine the results that will be obtained for energy consumption.

Based on the historical record of labor productivity in Peru, we will use a reasonable rate that will reflect a possibility for the

Peruvian economy to recover from the crisis that started in 1975. In cases where there are no distortions of the magnitude that afflicts the Peruvian economy, we would suggest a projection of historical values to avoid the difficulties mentioned above.

Gross Domestic Product

For the purposes of this study GDP is defined as labor force multiplied by labor productivity. This is the conclusion of previous estimates. The rate of growth of GDP is not assumed but derived from our estimate of 2000 and the actual figures for 1979.

The GDP and population estimates provide us the possibility to calculate other factors that affect energy consumption. These have been identified as:

i) households and their structure/commercial sector,

ii) agriculture,

iii) transportation (private),

iv) industrial production,

v) transportation of goods and services, and

vi) energy sector.

Each of these individual sectors will now be referred to, along with their estimations.

Households

Households numbers are important for projecting future energy consumption because they are the starting point for estimating residential consumption of energy. The starting point is the estimated population for the year 2000. In order to derive the number of units from the population figures, we will use an independent study that established the average number of persons forming a household in urban and rural areas.

Once we have the number of households, we multiply by the energy use in our base year. Energy consumption per household may increase in the future but data for commercial fuels in urban areas show little change over the years.

The fuel mix is assumed to be constant. This may not be the best alternative possible, because price differentials will produce shifts in fuel consumption. However, the investments required to shift fuels indicate that the extent of the shifts cannot be very significant.

Commercial sector

The energy consumption of the commercial sector has usually been derived by estimating the space, in square feet, per household at any given time (in other words, the number of square feet dedicated to office buildings, shopping centers, schools, etc.) and dividing it by the number of households. The projected number of households multiplied by the historical space relationship gives an estimation of the size of the commercial sector, from which the energy use is obtained.

In our case study, we were not able to do this because no information on commercial space in Peru has been found.

We propose to find an alternate route. An approximation that may be perfectly acceptable is to start with the energy consumed by the commercial sector in our base year. Divide this amount by the number of households in the same base year. Thus, we obtain an estimation of the energy that could be attributed to each household. The commercial sector performs services for the households and it expands or contracts as population increases or decreases.

The next step is to use the household numbers projection to multiply it by the energy attributed to each unit to obtain our estimate in the year 2000.

Automobiles

We have separated automobiles from transportation because the use of the private car is associated with population and growth of urban centers; while the transportation sector itself is mostly associated with the production of goods and services.

The estimate of automotive fuel consumption in 2000 combines two factors: the estimated number of automobiles in that year and the estimated fuel or energy per automobile. The estimated number of vehicles in 2000 is going to be based on the existing relationship of number of vehicles per persons 21 years old and over. The number of vehicles has been increasing in a way that the relationship with population has just been maintained. We feel that it is safe to assume a constancy of the ratios to the year 2000.

The average number of kilometers per vehicle and the average efficiency have been estimated by the Ministry of Transportation. Since Peru's automobile fleet is made up of mostly small cars, reduced gasoline consumption will have to come from less kilometers driven and/or better efficiencies embodied in the new automobile generation.

We will include motorcycles in the automobile sector since they are becoming a very popular means of private transportation. The number of motorcycles and the energy consumption will be calculated basically the same as for automobiles, except that in this case we will allow the number of units per 1,000 people to increase to reflect the tendency of the last decade.

Transportation

It is important to identify transportation as a consuming sector because of its share of the total energy used. The classification system used in projecting energy consumption in transportation divides all transportation into major categories which essentially are different media: railroads, marine transport, aviation, and road transport. Each will be looked at independently.

Railroads The consumption of energy by railroads is divided between freight and passengers. Both are expected to rise over the years. We will use the estimations of the Ministry of Transportation which are focused in the year 2000. Since railroads in Peru consume only oil, it is relatively simple to derive the energy intensities by ton-kilometers and passenger-kilometers; and from there to obtain energy consumption levels in 2000.

Air transport Air transport could also be divided between freight and passengers, but for the specific case of Peru there is practically no internal cargo service independent of passenger service.

In general terms, air transport is not a popular means of intercity travel. Prices and the short distances between the major urban centers are the explanations for this lack of usage. We expect that some growth in air transport will take place, but not at historical trends.

Maritime fleet The maritime fleet in Peru is solely dedicated to cargo transport. The sector is composed of large ships serving the coast and smaller vessels in the rivers of the Amazon region and Lake Titicaca.

It is expected that this subsector will take a bigger share of the market as mineral and oil production tend to increase. The base of our prediction is a study of the Ministry of Transportation of Peru. The energy intensity per ton-kilometer is obtained from 1976 data and applied to the estimated level of activity in 2000.

Road vehicles Other than the automobiles and motorcycles, this subsector includes buses, trucks and vans.

The number of buses and the number of passengers are associated with the growth of population and urban areas. We will use as the base of our analysis a rate of growth of passengers in line with our population estimates. The underlying assumption here is that the bus fleet will expand to satisfy the needs. The energy consumption is obtained by using the average number of kilometers per passenger per year and then multiplying it by the energy intensity from our base year.

In the case of trucks, we start with the number of ton-kilometers performed in 1976. We apply a rate of growth in line with our rate of growth of general economic activity and use the energy intensity of the base year to obtain the level of consumption in 2000.

Light vans are associated with commercial and service activities in urban areas. Since we have the estimation of population and urban areas, we derive the number of vans by calculating the density in our base year, applying it to the year 2000 population estimates, and finally, multiplying by the energy intensity per vehicle-kilometer.

Armed Forces The military uses oil for road, air and aquatic transportation of personnel and military hardware. They also perform civilian tasks in the border towns, in the jungle region and patrol the sea limits. There is no breakdown of activity level reported. We suggest the use of the rate of growth of general economic activity to avoid the underestimation of military use of energy. The historical trend is for the defense budget to increase, as well as the size of the armed forces, so this estimation is not felt to be far off the mark.

Agriculture

The agricultural sector is one of the most difficult to treat when it comes to data. Energy data are no exceptions. We have to identify the energy uses of agriculture as oil for tractors and to process raw materials in the sugar mills.

Part of the sector's requirements are satisfied by using residues, since the residues ultimately depend on the crops themselves. We will focus on them for our estimates.

Due to the unsatisfactory data on tractors, we suggest that a rate of growth of 1% be used to reflect the possibility of agriculture to slowly recover. This rate of growth is applied on the energy consumption of our base year and projected to 2000. Noncommercial resources will be treated separately.

Industry

There are several alternatives open to us for treating the industrial sector. We will include four subsectors in industry: manufacturing, mining, fishing, and construction.

Industrial activities encompass diverse energy uses and different fuels. Since no detailed data of energy use by industry for a number of years is found, we will use a different approach.

We will assume that each subsector will participate in the GDP of 2000 in the same percentage as it did in 1976. We will derive the energy intensity per sol of output of the base year and use it with the estimated value of output obtained.

Electricity sector

To complete our calculations we must include the electricity sector. This is because electricity is produced by using oil, gas, coal, and other materials, which have not been counted in any of the other sectors.

In the specific case of Peru, only oil and gas are used to produce electricity other than water. We base our projections on government plans for expansion of thermal generation throughout the country and estimates of industry self-produced electricity needs.

Estimation of Demographic and Economic Variables

In this section, we will refer to the main determinants of economic activity: population and gross domestic product, the inputs that determine their size and behavior, and the factors that will be derived from their estimation.

Population

Population growth determines the size of the labor force and serves as a guide in what concerns energy demand, since everyone consumes energy directly or indirectly.

Population trends in Peru can be divided into three phases: 1) rapid depopulation, 2) moderate recovery and 3) accelerated growth. Table 15 presents available information on population for selected years since 1523. It can be noted that from 1523 and 1796 population rates decreased considerably. There are several estimates of population of the Inca Empire, but no matter what the numbers are the size of the empire indicates that the total population was in the millions. Up to the end of the 19th century there was a recovery, although a modest one. In this century Peru has had three censuses, which of course, provide a more reliable data collection. It can be observed that since 1940 the rate of growth has been consistently above 2% per year (Table 16).

Table 15. Population of Peru

Year	Population	Rate of Change
	(millions)	(percent)
1523[a]	32.0	
1530	16.0	-7.1
1548	8.3	-2.6
1570	2.7	-3.0
1650	3.0	+0.1
1796	1.1	-0.5
1825	2.5	+4.5
1836	1.4	-3.9
1850	2.0	+3.2
1862	2.5	+2.0
1876	2.7	+0.5
1940	6.2	+2.0
1961	9.9	+2.2
1970[b]	13.5	+4.0
1972	14.2	+2.6
1974	15.0	+2.8
1976	15.9	+3.0
1977	16.2	-1.9
1978	16.8	+3.7
1979	17.3	+3.0
1980	17.8	+2.9

[a]For years 1523 to 1960 data are taken from [25].

[b]For years 1970 to 1980 data are taken from [98, 102].

Table 16. Average growth rate per year in Peru[a]

Period	Rate (Percent)
1750-1876	1.0
1876-1940	1.5
1940-1961	2.1
1961-1972	2.9
1972-1980[b]	2.8

[a]SOURCE: [190].

[b]Derived from estimates of 1980 population.

The rapid fall in mortality rates during this century has been the principal cause for the acceleration of population growth (Table 17 with a significant reduction in infant mortality, as reported by the Census Bureau [103].

Table 17. Mortality rate in Peru[a]

Year	Rate Per Thousand
1876	33
1940	27
1975	14

[a]SOURCE: [190].

Tables 18 and 19 and Figure 6 present the information on fertility rates in Peru. The fertility rates have been diminishing since 1962. This is considered a consequence of the shift of the population from rural to urban centers. It has been noted [126], in general, that urban populations tend to have less children than rural. This is also true in the case of Peru (Table 19).

Table 18. Fertility rates in Peru[a]

Years	Fertility Rate
1962-64	6.0
1965-67	6.2
1968-70	6.3
1971-73	5.9
1974-76	5.5
1976-78	5.0

[a]SOURCE: [104].

Table 19. Fertility and number of births by geographic areas, 1975[a]

Region	Annual Rate of Births (per 1,000 inhabitants)	Annual Rate of Fertility (per 1,000 women)	Rate of Fertility (by women)
Coast	31.0	124.5	4.2
Coast (excluding Lima)	36.0	157.9	5.4
Sierra	44.6	202.3	7.0
Selva	44.9	220.0	7.3
Urban Areas	31.9	128.1	4.4
Coast	29.9	117.1	4.0
Coast (excluding Lima)	34.7	146.6	5.4
Sierra	35.3	149.1	5.2
Selva	39.8	168.8	5.8
Rural Areas	48.7	236.4	8.1
Coast	39.4	196.0	6.7
Sierra	50.5	239.5	8.3
Selva	48.8	269.0	8.9
Total	38.2	164.1	5.6

[a]SOURCE: [104].

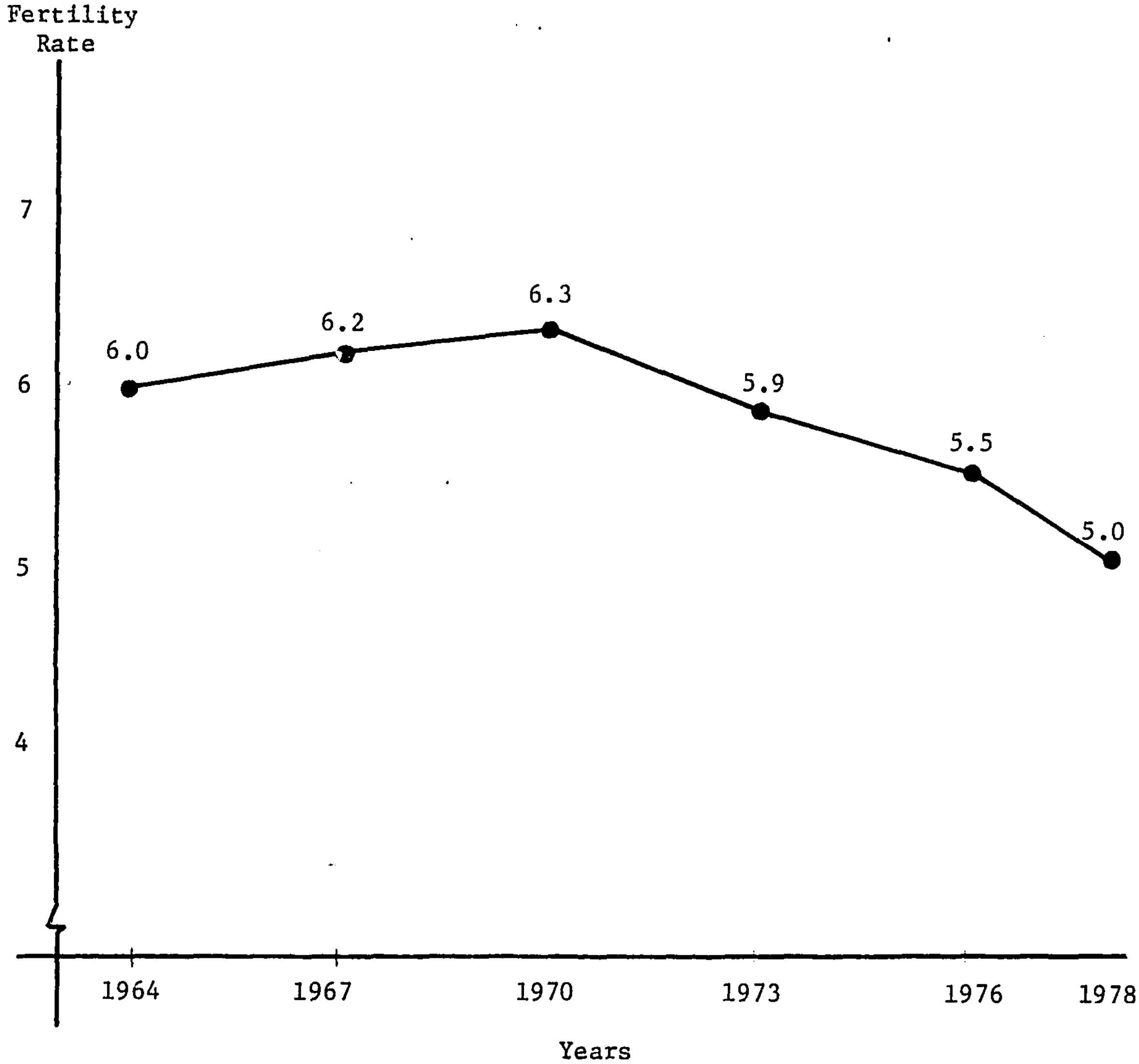


Figure 6. Fertility rates pattern [102, 106, 107, 108]

In 1975, the Peruvian Census Bureau, made projections of population growth for the 1975-2000 period under several alternatives [116]. Figure 7 and Table 20 summarize the information gained from this study.

Analyzing the projections of the Peruvian Census Bureau, we observe that Alternative II could be eliminated because a constant fertility rate is assumed, which is much higher than the actual estimation of the first projected period 1975-80. The Alternatives I, III and IV do assume a decline in fertility rates but I and III are still too high when compared to the latest estimation. Therefore, for the purposes of our study, we will use Alternative IV which seems to depict the phenomenon of rapidly declining fertility rates more accurately. Tables 21 through 26 summarize the projections under Alternative IV. From this accumulated data, a total population for the year 2000 is estimated at 29,684,929.

Table 20. Peruvian Bureau of Census population projections (10^6 people)[a,b]

	1970-75	1975-80	1985-90	1995-2000
Alternative I				
Population (10^6)	15.6	18.1	23.6	31.9
Fertility rate	6.33	6.00	5.33	4.68
Alternative II				
Population (10^6)	15.6	18.3	25.5	36.0
Fertility rate	6.33	6.33	6.33	6.33
Alternative III				
Population (10^6)	15.6	18.2	25.0	34.3
Fertility rate	6.33	6.19	5.91	5.62
Alternative IV				
Population (10^6)	15.6	18.0	23.6	29.7
Fertility rate	6.33	5.82	4.79	3.75

[a]SOURCE: [116].

[b]Each alternative assumes a different fertility rate, but all assume the same change in death rates.

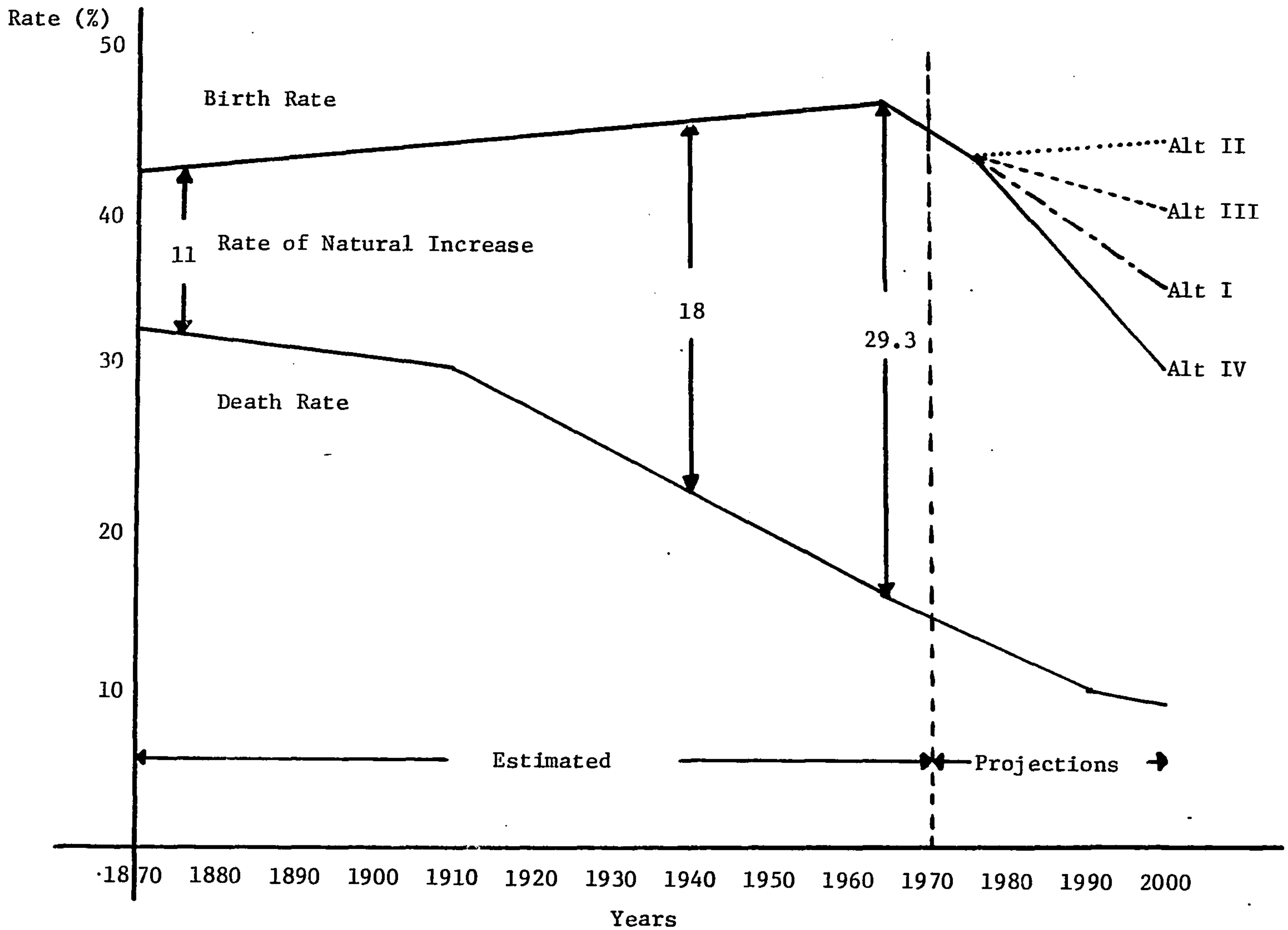


Figure 7. Rate of natural increase of population, 1870–2000

Table 21. Estimated demographic indicators for 1980-2000 under Alternative IV[a]

	1980-85	1985-90	1990-95	1995-2000
Fertility				
Number of births (10^3)	3,426.00	3,984.00	4,160.00	4,244.00
Gross birth rate (0/00)	38.46	35.97	33.15	30.15
fertility rate	5.29	4.79	4.26	3.75
Gross reproduction rate	2.58	2.33	2.08	1.83
Net reproduction rate	2.14	1.88	1.80	1.62
Mortality				
Number of deaths (10^3)	1,059.00	1,101.00	1,137.00	1,173.00
Gross death rate (0/00)	10.94	9.94	9,06	8.34
Life expectancy at birth	58.12	59.60	61.06	62.46
Natural Growth				
Natural growth rate	27.53	26.03	24.09	21.82
Dependency Index				
Age dependency ratio	88.61	84.86	80.21	75.19

[a]SOURCE: [116].

Table 22. Population to June 30 each year under Alternative IV, 1980-2000[a]

Year	Population	Rate of Growth (%)
1980	18,041,153	
1981	18,554,967	2.8
1982	19,078,310	2.8
1983	19,611,714	2.8
1984	20,155,147	2.7
1985	20,708,299	2.7
1986	21,270,564	2.7
1987	21,841,021	2.7
1988	22,418,628	2.6
1989	23,002,274	2.6
1990	23,591,039	2.6
1991	24,184,402	2.5
1992	24,782,432	2.5
1993	25,385,874	2.4
1994	25,996,023	2.4
1995	26,614,253	2.4
1996	27,041,063	1.6
1997	27,874,298	3.1
1998	28,506,476	2.7
1999	29,120,710	2.2
2000	29,684,929	1.9

[a]SOURCE: [116].

Table 23. Structure of population in year 2000 under Alternative IV[a] (in percentage)

Age Group	Male	Female	Total
0- 4	6.62	6.48	13.10
5- 9	6.29	6.19	12.49
10-14	5.90	5.81	11.71
15-19	5.38	5.30	10.68
20-24	4.84	4.78	9.61
25-29	4.26	4.22	8.47
30-34	3.62	3.59	7.22
35-39	3.06	3.04	6.10
40-44	2.54	2.54	5.07
45-49	2.03	2.05	4.08
50-54	1.60	1.61	3.21
55-59	1.23	1.26	2.49
60-64	0.98	1.00	1.98
65-69	0.74	0.77	1.52
70-74	0.52	0.55	1.08
75-79	0.33	0.35	0.68
80+	0.24	0.27	0.50
Total	50.19	49.81	100.00

[a]SOURCE: [116].

Table 24. Male population projection by age for selected years, 1980-2000[a] (in thousands)

Age Group	1980	1985	1990	1995	2000
0- 4	1,516	1,664	1,802	1,905	1,966
5-14	2,457	2,781	3,083	3,373	3,620
15-59	4,629	5,424	6,340	7,612	8,473
60-64	160	190	221	254	289
70-74	83	95	111	133	155
75+	88	103	119	140	166
Total	9,061	10,402	11,849	13,362	14,897

[a]SOURCE: [116].

Table 25. Female population projection by age for selected years, 1980-2000[a] (in thousands)

Age Group	1980	1985	1990	1995	2000
0- 4	1,480	1,625	1,762	1,864	1,923
5-14	2,410	2,732	3,030	3,317	3,561
15-59	4,600	5,385	6,294	7,307	8,421
60-64	165	195	227	260	297
70-74	89	102	118	140	164
75+	103	117	134	155	184
Total	8,980	10,306	11,741	13,251	14,787

[a]SOURCE: [116].

Table 26. Population projection by age for selected years, 1980-2000[a] (in thousands)

Age Group	1980	1985	1990	1995	2000
0- 4	2,997	3,289	3,564	3,769	3,889
5- 9	2,615	2,919	3,215	3,495	3,706
10-14	2,253	2,595	2,899	3,196	3,477
15-19	1,929	2,226	2,567	2,872	3,170
20-24	1,637	1,910	2,206	2,548	2,853
25-29	1,345	1,608	1,879	2,175	2,515
30-34	1,091	1,318	1,578	1,847	2,141
35-39	886	1,065	1,289	1,545	1,812
40-44	753	860	1,035	1,254	1,506
45-49	639	725	828	998	1,211
50-54	530	606	689	789	952
55-59	426	494	566	644	739
60-64	325	386	448	515	587
65-69	243	283	336	391	450
70-74	173	197	229	274	320
75+	192	220	254	295	350
Total	18,041	20,708	23,591	26,614	29,684

[a]SOURCE: [116].

Labor force and participation rates

The three censuses of this century provide information on the labor force. One word of caution regarding the definitions over the years of labor force and participation. In 1940, the economically active population included only those with gainful employment at the moment of the census. In 1961 and 1972, the unemployed were also included. The economically active population--EAP--grew at a rate of 1.3% for the period 1940-61 and at 2.0% from 1961 to 1972 (Table 27).

The important question to answer now is whether the labor participation rates are going to change drastically to the end of this century. From Tables 28 and 29, we observe that there has been a decrease over time in the rate of labor participation. This has been associated mainly with the expansion of the educational system, therefore postponing the entrance into the labor force of the younger people; also the expansion of social security allows a larger number of persons to retire earlier.

The size of the labor force in the case of Peru shall be analyzed through the workings of demographic and nondemographic factors. The demographic factor affects the size of the population in working ages. The nondemographic factors affect the rate of labor participation.

The labor participation rates have been declining in recent years. In Tables 29 and 30, we observe the assumed labor participation rates. From these data, we derive our estimates of the size of the labor force in the year 2000 (Table 31). These estimates produced annual compound rates of growth of EAP of about 2.07%. This rate is in line with the one observed since 1960.

Table 27. Size of the labor force--economically active population (by thousands)

Age Groups	1940	1961	1972
Total 6 and older	n.a.	3,124.6	3,871.6
Total 15 and older	2,313.5	3,045.1	3,786.1
Total 15-64	n.a.	2,896.2	3,608.8
6-14	n.a.	79.5	85.4
15-24	n.a.	907.1	1,016.0
25-29	n.a.	1,581.7	2,084.8
50 and older	n.a.	556.3	685.4
Total 6 and Older	n.a.	3,164.6	3,871.6
Urban	n.a.	1,554.9	2,388.8
Rural	n.a.	1,569.7	1,482.8

[a]SOURCE: [116].

Table 28. Labor participation rates (in percent) [116]

Age Group	1940	1961	1972
Total 6 and older	n.a.	39.42	35.49
Total 15 and older	64.25	54.31	49.81
Total 15-64	n.a.	55.31	50.98
6-14	n.a.	3.43	2.58
15-24	n.a.	49.76	39.53
25-49	n.a.	59.14	58.82
50 and older	n.a.	50.14	46.14
Total 6 and Over	n.a.	39.42	35.49
Urban	n.a.	n.a.	36.18
Rural	n.a.	n.a.	34.43

Table 29. Assumed labor participation rate[a] (in percent)

	1990	2000
Total 6 and older	32.34	31.91
Total 15 and older	44.97	43.75
Total 15-64	46.09	44.99
6-14	1.53	1.21
15-24	28.75	24.37
25-49	57.79	58.62
50 and older	42.10	39.64

[a]SOURCE: [116].

Table 30. Labor participation rates by sex[a] (in percent)

	Male			Female		
	1940	1961	1972	1940	1961	1972
Total 6 and older	n.a.	62.24	56.27	n.a.	16.99	14.68
Total 15 and older	87.30	87.66	80.19	42.88	22.36	19.92
Total 15-64	n.a.	89.74	81.31	n.a.	22.87	20.79
6-14	n.a.	3.46	2.69	n.a.	3.40	2.29
15-24	n.a.	71.85	57.77	n.a.	27.19	21.23
25-49	n.a.	98.39	85.71	n.a.	21.59	22.17
50 and older	n.a.	88.75	82.20	n.a.	16.86	9.22
<u>Total 6 and Older</u>	n.a.	62.24	56.27	n.a.	16.99	14.68
Urban	n.a.	n.a.	54.42	n.a.	n.a.	18.00
Rural	n.a.	n.a.	59.03	n.a.	n.a.	9.56

[a]SOURCE: [116].

Table 31. Labor force projections (in thousands)

	Total	Labor Participation Rate	Labor Force
15 and Older	18.606	44.97	8.367

Labor productivity

Labor productivity is a very important variable since it determines, along with other variables, the size of the GDP, and is the main source of increasing living standards. In Table 32, we have obtained an estimate of labor productivity by dividing GDP by the labor force. Such a procedure gives us a yearly growth from 1961 to 1979 of 0.6% per year. In Table 33, we have extracted information from the National Productivity Council of Peru, obtaining an estimate of labor productivity change between 1970 to 1977 of 0.53%, which confirms our findings.

As can be observed in Table 32, labor productivity in Peru has been growing very slowly. We do not have any reason to believe that there will be any crucial change in productivity in Peru in the next 20 years. Nevertheless, we may expect a certain improvement due to the efforts in education [86]. Therefore, we will assume an average increase in labor productivity of 1% to the year 2000.

A study of the Peruvian economy [133] made predictions of future labor productivity, reaching the conclusion that labor productivity will increase at a rate of 0.5% per year up to year 1990. Our estimate may seem too optimistic, but since we are projecting to the year 2000, we have allowed for certain recovery of the economy.

Table 32. Measure of labor productivity, 1961-79[a]

Year	Gross Domestic Product	Labor Force	Productivity Index (GDP/L)	Rate of Change of Productivity
	(billions of 1973 soles)	(millions)	(in soles)	(percent)
1961	230.837	3.045	75,808	
1962	249.693	3.145	79,394	+4.7
1963	260.047	3.249	80,039	+0.8
1964	279.140	3.356	83,176	+3.9
1965	293.544	3.467	84,668	+1.8
1966	312.377	3.581	87,231	+3.0
1967	322.866	3.699	87,285	+0.05
1968	322.046	3.822	84,261	-3.6
1969	334.486	3.948	84,723	+0.5
1970	352.596	4.188	84,192	-0.6
1971	370.336	4.291	86,305	+2.5
1972	376.501	4.398	85,607	-0.8
1973	392.559	4.528	86,696	+1.3
1974	421.933	4.666	90,427	+4.3
1975	441.073	4.809	91,718	+1.4
1976	449.987	4.957	90,778	-1.1
1977	449.738	5.112	87,977	-3.2
1978	446.740	5.273	84,722	-3.8
1979	461.831	5.440	84,895	+0.2

[a]SOURCE: [98].

Table 33. Change in gross domestic product and labor productivity by sector, 1970-77[a] (percentage)

	1971	1972	1973	1974	1975	1976	1977	1970-77
Agriculture and Fishing								
GDP of sector	0.09	-7.39	-1.42	5.37	-1.06	3.03	-1.13	0.36
Labor productivity	4.70	-6.70	-8.00	-3.50	-3.60	4.70	-0.90	-1.90
Mining and Oil								
GDP of sector	-0.60	7.60	1.00	3.80	-6.10	7.20	31.10	6.30
Labor productivity	-11.30	-4.60	-6.30	-3.90	-6.10	5.70	-1.40	-3.90
Manufacturing								
GDP of sector	7.23	7.03	7.35	9.50	4.76	5.20	-2.50	5.50
Labor productivity	-0.80	-1.17	-2.37	-0.40	1.62	0.80	0.00	-0.33
Construction								
GDP of sector	13.70	11.90	15.70	24.80	9.60	-3.30	-9.20	9.10
Labor productivity	6.70	1.30	6.90	14.80	3.20	-4.75	2.00	4.31
Commercial								
GDP of sector	10.77	4.68	6.84	10.14	7.46	-1.13	-4.31	4.92
Labor productivity	2.20	-0.50	-5.90	1.70	6.70	-3.70	1.60	0.30
Utilities								
GDP of sector	10.98	8.35	12.78	8.59	7.64	12.43	2.85	9.10
Labor productivity	1.40	4.10	4.00	10.20	5.80	-2.70	-0.60	3.17
Transportation and Communication								
GDP of sector	5.51	6.79	9.45	11.42	9.16	7.01	-3.81	6.50
Labor productivity	1.25	1.23	4.87	12.20	12.85	-11.52	6.25	3.80

<u>Financial Sector</u>								
GDP of sector	4.22	4.38	5.26	5.38	4.53	4.68	0.93	4.25
Labor productivity	2.06	-2.12	-0.39	-2.17	7.07	-2.73	n.a.	0.28
<u>Government</u>								
GDP of sector	3.60	4.34	6.70	3.84	8.89	3.29	1.47	4.60
Labor productivity	-3.84	-2.4	0.81	7.31	3.78	-5.83	3.10	0.42
<u>Other</u>								
GDP of sector	5.36	5.06	5.88	6.53	7.40	7.55	4.99	6.11
Labor productivity	-4.50	-3.77	-4.90	5.15	2.94	-2.85	1.96	-0.85
<u>Average Change in Productivity in All Sectors</u>	-0.21	-1.46	-1.13	4.14	3.44	-2.34	1.33	0.53

[a]SOURCE: [109, 113, 114, 120, 121].

With our assumed rate of growth, labor productivity in soles of 1973 will grow from $84,895 in 1979 to $103,588 in 2000.

Gross Domestic Product

Using the definition of Gross Domestic Product (GDP) = Labor Force x Productivity, we are now able to reach a specific figure for GDP in the year 2000. Since labor force has been estimated to be 8.367 million and productivity 103,588 (in soles of 1973), therefore GDP, in soles of 1973, would be around 867 billion (a sum equal to US $22 billion, using the 1973 exchange rate)--an increase of 88% over the GDP in 1979.

The rate of growth obtained from the estimate is 3% per year. This is a rather modest increase and implies that the per capita income will not change substantially unless productivity increases dramatically, which we cannot assume at this time. GDP from 1965 to 1975 increased at an annual rate of 5.5%, but after that time it diminished and was even negative. Table 34 presents the summary of the estimations of main demographic and economic variables.

Table 34. Summary of estimations

	Estimation Year 2000	Rate of Change
Gross Domestic Product	867[a]	3.0%
Population	29.685[b]	2.7%
Labor Force	8.367[b]	2.1%
Labor Productivity	103,588[c]	1.0%
Labor Participation Rate	44.97[d]	-0.1%

[a] In 10^9 of 1973 soles.

[b] In 10^6.

[c] In 1973 soles.

[d] In percentage.

Estimation of Energy Consumption

Energy sources covered

The projection encompasses all of the sources currently used in Peru, i.e., oil, natural gas, coal, hydropower, and biomass. The question of substitution does not seem to be of extreme concern in this case. The reason for this is the nature of energy consumption in a country like Peru where most of it goes to satisfy basic needs. The case is usually one of no alternative sources. Price enters the picture but in a different way than it does in developed economies [124].

Studies on Peru's energy consumption shows that there are regions where biomass must be used because other sources could not reach these areas in the face of lack of communications. In other areas, even if a fuel could be delivered, it cannot be utilized unless an investment is made on the purchase of a device, such as a gas stove. In depressed rural areas, such an expenditure may be difficult to make.

Transportation is one example of an extreme case where practically no substitution can be expected in future years. It is known that alcohol can be used in combination with gasoline, but the extreme needs of foodstuffs production will certainly prevent a significant program to dedicate land for energy-related crops.

The best possibilities are perhaps in the production of heat in the industrial sector. It can be achieved by several methods and different raw materials. This is also true of electricity, but it should be noted that in Peru, hydropower does not compete with thermal generation. Thermal generators have been installed whenever hydro-electricity cannot be made available. We feel that this is not a heroic assumption because Peru is not engaged in energy research beyond some small scale intermediate technology projects for rural areas. Peru will certainly benefit from advances in other countries such as greater automobile fuel efficiencies in developed countries, but there is always a time gap which in some cases has been rather extended.

Derivation of the estimates

For the purpose of our projections total energy consumption in Peru has been classified into six major consuming sectors as shown in Table 35.

Table 35. Relative importance of energy-consuming sectors in Peruvian economy, 1976[a]

Sector	Percentage Energy Consumed
Industry	25.8
Automobiles	4.1
Households/Commercial	39.8
Transportation	17.7
Agriculture	3.6
Electric Sector	9.0
	100.0
Consumed in the Form of Electricity	17.7

[a]SOURCE: [172].

In this table, commercial and noncommercial sources have been included. The relative importance of the household/commercial sector is due to the inefficiencies of noncommercial sources, therefore, the resource base consumed per BTU produced is very large. One can also observe from Table 35 that despite the vast hydroelectricity potential of Peru, only 17.7% of the total is consumed in the form of electricity.

Households

We have estimated the population to be around 29.685 million by the year 2000. According to the three censuses of this century more than 50% of the population forms a household at any particular year. The precise rates are shown in Table 36.

Table 36. Distribution of population 15 years or older by marriage status[a] (by percentage)

	1940	1961	1972
Total	100.0	100.0	100.0
Single	38.4	36.3	35.4
Married	34.8	43.2	41.1
Consensual	17.8	13.6	15.0
Other	9.0	6.9	8.5
Households	52.6	56.8	56.1

[a]SOURCE: [105].

The number of units, (i.e., of households) is an important intermediate factor in our derivation of the final demand. A study of Peru's population and structure [111] concludes that the number of households in urban centers can be estimated by using the ratio of 4.7 persons per household. In rural areas, the ratio is 4.2.

From Alternative IV of the Peruvian Census Bureau an independent study [190] has estimated urban and rural populations as shown in Table 37. From the information in Table 37 and the persons per household figure, we derive Table 38.

Table 37. Projections of urban and rural populations to year 2000[a]

	1972	2000	Rate of Growth (percent)	Percentage Structure in 2000
Total	14,273	29,685	2.7	100.0
Urban	7,593	21,788	3.8	73.4
Rural	6,678	7,897	0.6	26.6

[a]SOURCE: [190].

Table 38. Households projections in year 2000 (in thousands)

Urban households	4,636
Rural households	1,880
Total	6,516

Because of fundamental differences in urban and rural populations in terms of energy consumption we will discuss them separately.

Urban households In Table 39, energy uses and sources for urban populations have been specified. A total of 56 x 10^{12} BTU were used by urban households whose number in 1976 were estimated to have been 2.191 million. Therefore, the consumption per household is about 25.6 million BTU for 1976.

Table 39. Energy consumption of urban households by use and source, 1976[a]

	Oil	Coal	Gas	Electricity	Total
			(10^{12} BTU)		
Cooking/Heat	26.5			2.7	29.2
Lighting	5.3			3.1	8.4
Other				18.4	18.4
Total	31.8			24.2	56.0

[a]SOURCE: [172].

It has been observed that energy consumption has remained stable for the household sector. Since the projections of Gross Domestic Product (GDP) and labor productivity do not consider a major improvement in personal income, it makes sense to project household energy consumption in urban areas at the same consumption ratio found in 1976. Our estimate of urban households in the year 2000 is 4.636 million, a consumption pattern of 25.6 million per household yields a total figure of 118.7 x 10^{12} BTU. In Table 40, is presented the breakdown of the estimate by source. The breakdown has been constructed under the assumption that energy consumption patterns of urban households will continue unchanged into the future. This assumption, as others that have been made in this study, are based on documentation that shows that only basic needs are being covered by most of the Peruvian population [172]. It cannot be assumed that there will be large savings in energy consumption because this would be tantamount to assuming a deterioration of living conditions--which are already bad.

Table 40. Urban households energy consumption in year 2000 by sources and uses

Uses \ Sources	Oil	Gas	Electricity	Total
			(10^{12} BTU)	
Cooking/Heating	56.2		5.8	62.0
Lighting	11.2		6.6	17.8
Other			38.9	38.9
Total	67.4		51.3	118.7

An increase could be a more reasonable assumption, but it would be preferable not to assume this because in our estimation of economic growth only a modest rate of increase for the 20-year period under consideration was found.

Rural households Households located in the rural areas of Peru practically do not consume commercial forms of energy. There is evidence [172] that in certain areas a penetration of fuels for cooking, such as kerosene, may be occurring because of the decline in availability of local resources, mainly firewood. Nevertheless, we have not been able to determine the size of such demand. Sales of petroleum products reported by Petroleos del Peru would seem to indicate that they could only be extremely small. A problem associated with the consumption of commercial resources is the investment to purchase a device that will use the fuel. Because such an investment is out of the question in rural Peru, the only product that could penetrate the rural market is kerosene, a by-product of petroleum. The use of kerosene is made possible by the purchase of a stove that, in Peru, is called "primus" which is the cheapest to be found and is locally manufactured.

The rate of substitution of noncommercial resources for commercial resources cannot be forecast, in part because no regional data on noncommercial resource availability and potential has been found. Therefore, the following is proposed for this study. The household energy consumption in rural areas will be assumed to remain constant to the year 2000.

It will be assumed that because of deterioration of the resource base, commercial resources may have to be utilized increasingly. A proportion of 10% in the year 2000 will be used, in order to make room for this possibility, and enhance the prediction of commercial resource needs.

The total rural consumption in 1976 has been estimated to be 153.6 x 10^{12} BTU for a total of 1.333 million households [172]. The per household consumption is then 115.2 million BTU.

In the year 2000, we estimate that there will be 1.880 million rural households. They will require a total of 216.6 x 10^{12} BTU to satisfy their energy needs. We have suggested that a penetration of 10% be considered in order to account for some degree of market penetration for commercial fuels. However, before proceeding with the estimation we must point out that the energy needs in this case were measured at the resource base. In other words, we estimate that rural households will need 21.66 x 10^{12} BTU, but because of the efficiency factor of 10% they will have to utilize an equivalent of 216.6 x 10^{12} BTU of biomass.

To include kerosene in the energy consumption picture, this 10% will be deducted from 21.66 x 10^{12} BTU. In effect, we are stating that about 2.2 x 10^{12} BTU of rural consumption may be satisfied by kerosene. The difference of 19.46 x 10^{12} BTU represents 194.6 x 10^{12} BTU at the resource base. For kerosene the efficiency reported in [172] is 45%, therefore the need for kerosene could be estimated at 4.9 x 10^{12} BTU.

Commercial sector

The estimation of commercial sector energy consumption is tied in with the consumption in the household sector. This is because the increase in population increases the need for more commercial space, such as office buildings, shopping centers, etc. One way to look into the consumption of energy in the future will be to calculate the number of square feet of commercial space per household existing at a given time. Assuming the ratio remains constant the total square feet needed in the future could be estimated. This figure will then be multiplied by an estimated BTU per square feet based on historical data.

However, at this time it is not possible to follow up on this line of reasoning as a result of lack of information from Peru's First and Second Economic Census [94, 96, 119]. Thus, it is not possible to estimate commercial space.

As a result of this lack of information, a different way to deal with this problem has been prepared. Commercial space is linked to urban areas. We will derive a BTU per urban household of commercial space, i.e., divide the total BTU consumption of the commercial sector by the number of urban households in 1976. That figure comes to 4.518 million BTU per urban household. Therefore, in the year 2000 the 4.636 million urban households will require an expansion of the commercial sector that will make them use 20.9×10^{12} BTU of energy. This energy is entirely consumed in the form of electricity.

Table 41 presents the final figures of the Household/Commercial sector.

Table 41. Households and commercial sector energy consumption in 2000

	Oil	Electricity	Biomass	Total
		(10^{12} BTU)		
Urban Households				
Cooking/Heating	56.2	5.8		62.0
Lighting	11.2	6.6		17.8
Other		38.9		38.9
Rural Households				
Cooking/Heating	4.9		194.9	199.8
Commercial		20.9		20.9
Total	72.3	72.2	194.9	339.4

Automobiles

It has been decided to separate the use of the private automobile from the transportation sector; which in this case refers to the transportation of goods and services and is, therefore, associated more with commercial and industrial activities.

In 1976, it was reported that Peru had an automobile stock of 271,000 units [97]. In per capita terms, this means 17 automobiles per 1,000 persons. It is a rather low ratio in our modern times, but it is a reflection of the distribution of income where only a very small fraction of the population can afford a private vehicle. Prices have gone up considerably not only in monetary terms but in real terms.

If only the population age 21 years or older is taken into account as potential buyers of vehicles, the proportion changes to 33 vehicles per 1,000 inhabitants 21 years or older.

In this section, automobiles dedicated to public transportation are included. Also, included in the analysis of private transportation is the number of motorcycles--47,000 in 1976 [97]. It is reported that the average motorcycle travels 10,950 kilometers (km) (6,800 miles) per year and has an energy intensity of 891 BTU per km [172]. The motorcycle density in 1976 was 3 per 1,000 inhabitants. However, if only the adult population is considered the ratio is 6 per 1,000 inhabitants.

In order to estimate the number of vehicles and motorcycles expected in the year 2000 we will use our population projections and the densities, as explained below.

Since it will not be possible to forecast extremely better economic conditions for Peru in the years ahead, it will be better to assume that additions to the automobile stock will just keep pace with population increase and urban growth. At 33 vehicles per 1,000 inhabitants, over the age of 21, the projected stock is 484,400 vehicles. This is a rate of growth of 2.5% per year which is well within what can be expected in Peru.

A Ministry of Transportation publication [97] estimated that each vehicle travels 12,000 km (7,450 miles) per year, mostly on urban roads, with an average efficiency of 20 km per gallon (12.5 miles per gallon). Peru's fleet is made up mostly of small cars with higher rated efficiencies, but it is noted that traffic congestions in urban areas and poor maintenance lowers the efficiency considerably.

In 1976, private automobiles used 20.9 x 10^{12} BTU of energy in the form of gasoline, which means that each car consumed 6,425 BTU per km traveled, using the average figures just quoted.

If the efficiency were to be maintained, the 488,400 cars of the year 2000 will need 37.7 x 10^{12} BTU to run the same average number of km. There is enough evidence in the press today that one of the efforts in energy conservation most likely to proceed at good speed is in the automobile efficiency area. This will undoubtedly benefit Peru as a receiver of foreign technology. The new vehicles to enter the fleet either as replacements of old cars or as net additions to the stock may do better by the gallon. At this time, however, there is no way to include such technological innovations in this analysis. It could be suggested that a modest percentage be deducted from the total consumption, but it is preferable to leave well enough alone since it is felt that better efficiences coupled with the expansion of roads and growth of urban areas may increase the number of kilometers driven per year offsetting the efficiency effect.

In regard to the motorcycle sector, an increase should be allowed in the ratio because it is becoming an increasingly popular means of transporation in the face of a very deficient public service and skyrocketing automobile prices. To keep the same density in 2000, there should be 88,880 motorcycles, which represents a rate of growth of 2.7% per year. It is suggested that a modest increase in the ratio to 7 motorcycles per 1,000 inhabitants over 21 years of age be used. Such an increase will yield an estimate of 103,600 motorcycles in 2000. This gives a rate of growth of around 3.5% per year, also within the expected limits.

The total energy consumption of the motorcycle stock would then be its total number multiplied by the average number of kilometers driven times the efficiency factor. The total energy consumption is $103.6 \times 10^3 \times 10.95 \times 10^3 \times 891 = 1.1 \times 10^{12}$ BTU. It is then concluded that the private transportation sector would require a total of 38.8×10^{12} BTU of energy, all of it from oil.

Transportation

In dealing with the transportation sector, we must first refer to the state of the infrastructure.

Roads The road system of Peru covers 56,940 kilometers (35,360 miles) of which about 10% is paved [97].

Railroads There are 2,545 kilometers (1,580 miles) of tracks. About 76% is owned by the state. Although passengers are transported, the main railroad activity is associated with mining [97].

Airports In 1975, there were 244 registered airports. However, only three were capable of handling aircrafts of the 707 class and eight capable of handling 727s [97].

Seaports There are 28 seaports in the country each differing in their facilities. Only 12 of these ports allow ships to tie up alongside a wharf [97].

Urban transport Lima is the most important urban area of the country with a population that surpasses several times the populations of any other cities in Peru. Passengers and freight are moved by road.

There are no alternative ways, such as subways or tramways, for passenger transportation. Compared to the more developed countries

Peru relies more on public transportation. With the expected growth of urban areas, public services will have to be expanded to accommodate increasing numbers. Private means of transportation as a possibility for taking a greater share of the market has been ruled out.

Having already covered the private transportation, we now turn to road vehicles other than cars and motorcycles.

Buses Buses are divided between omnibus and microbus. There were 13,000 omnibuses in 1976 and 10,000 microbuses [97]. The microbus is used mostly in urban areas with about 75% of them based in Lima [97]. The omnibus is used both in urban transportation and intercity travel. Half of the omnibuses are registered in Lima.

The estimation of kilometers driven is 30,000 (18,630 miles) per year for urban use and 12,000 (7,450 miles) per year for rural and intercity travel [97]. Table 81 shows the passenger movements by road for 1976. Once again the total domination of the central region where Lima is located is observed.

For the purposes of this study, an attempt must be made to infer what the activity will be in the future. From Table 5, we know that buses consumed 14.2×10^{12} BTU of energy in 1976 to move approximately 8.3 million passengers, nationally and internationally (Table 42). This service was performed by a fleet of about 13,700 buses [117].

It is rather difficult to estimate the number of buses that will be in service in 2000. To generate more confidence, in our analysis the estimates will be tied up with population projections. The population of Peru in 1976 was 15.9 million and produced a total of 8.3 million intercity passengers, a relation close to 52%. With this study's population estimate of 29.7 million in 2000, it is expected to have traffic involving 15.4 million, which means a rate of growth of passenger traffic of 2.6% per year within acceptable limits. With an average of 483.5 kilometers (300 miles) per passenger the total activity for the year 2000 may reach 7.5 x 10^9 passenger/kilometers.

Table 42. Intercity passenger movements by road, 1976[a]

Intra-Region	Passengers (10^3)	Passengers/ Kilometers (10^9)	Kilometers/ Passengers	Road[b] Percent of All Modes Passengers
North	1,657.9	0.487	293.8	99.2
Center	2,516.0	1.477	587.1	85.5
South	1,227.0	0.497	405.5	54.3
East	----	---	---	--
Subtotal	5,400.9	2.461	455.7	79.7
International				
Center-North	2,060.9	1.453	705.0	87.9
Center-South	886.9	0.355	400.3	65.9
Subtotal	2,947.8	1.808	613.3	74.7
Total	8,348.7	4.369	511.3	76.6

[a]SOURCE: [117].

[b]National traffic only.

Before getting our estimate of energy consumption, we must refer to urban transportation. In [172], a reference is made to a study in support of the construction of a subway in the city of Lima. Table 43 was derived from this study.

Table 43. Urban passengers forecasts: Lima, 1972-1992[a]

Year	Annual Journeys	Length of Each Journey	Annual Passengers/kilometers
	(10^9)	(kilometers)	(10^9)
1972	0.914	6.7	6.124
1976	1.234	7.8	9.625
1980	1.555	8.9	13.840
1984	1.901	9.8	18.630
1988	2.246	10.7	24.032
1992	2.592	11.6	30.067
Average Annual Growth (percent)	3.35	2.78	8.25

[a]SOURCE: [172].

Table 43 presents information for Lima only. Based on the ratio of buses in other urban centers to those for Lima and taking the same amount of passenger-kilometers per vehicle per year for those centers as for Lima, it is estimated that public transport in other urban centers amounted to 1.64×10^9 passenger-kilometers in 1976. The total for 1976 is then 15.54×10^9 passenger-kilometers. However, this figure includes the passenger-kilometers by automobiles, the so-called "colectivos" that are part of the public transportation system.

In order to deduct the passenger-kilometers that are associated with automobiles, we suggest a 10% deduction. (This is to avoid double counting since "colectivos" were included in the automobile sector and it is known that about 10% of public transport vehicles are "colectivos.") This brings the final count for 1976 to 14×10^9 passenger-kilometers.

The energy intensity has been estimated elsewhere to be 947.8 BTU per passenger-kilometer [172].

Now this study will attempt to derive some figures for urban transportation. For Lima, the rate of growth of 8.4% will be used (as indicated in Table 43). This will yield an activity of 56.7×10^9 annual passenger-kilometers in urban Lima in 2000. Other urban areas cannot be estimated at the same growth rate as that of Lima. In lieu of any other evidence, a proposed rate of 3% per year will be used which is suggested by the Ministry of Transportation [117]. This will give a total of 3.3×10^9 passenger-kilometers.

Adding the three forms of transportation a figure of 67.5×10^9 passenger-kilometers in 2000 is estimated. By using the energy intensity just defined, the energy consumption is estimated to be 63.9×10^{12} BTU, all coming from oil.

Trucks and vans In 1976, the truck stock was estimated at 61,000 [97]; about 40% was registered in Lima. The average number of kilometers in this case is 15,000 (9,000 miles).

Light vans, mostly on service functions, totaled 62,000 [97]. About 55% of these were registered in Lima. The same average number of kilometers per year as that of trucks is used for light vans. In this case ton-kilometers as a unit of measure will be used.

The Ministry of Transportation [117] estimates road freight in 1976 at 5.6×10^9 ton-kilometers (Table 44).

Table 44. Intercity road freight, 1976[a]

	Ton-Kilometers (10^9)	Percentage of Sector by Road	Percentage of All Road Freight
Agriculture	2.4	94.8	42.7
Industry	2.9	83.7	51.5
Mining	0.1	9.5	1.7
Hydrocarbons	0.2	5.2	4.1
Total	5.6	49.9	100.0

[a]SOURCE: [117].

It is estimated that road traffic accounts for almost 50% of all domestic freight in terms of ton-kilometers [117]. Road is especially important for agricultural products. It accounts for 94.8% of ton-kilometers of agricultural products and 83.7% of ton-kilometers of industrial products.

Since the road freight is associated with productive activities, it is suggested that the rate of growth of general economic activity be used to account for the fact the two are tied together to some degree. The ton-kilometers expected in 2000 are then 11.4 x 10^9 ton-kilometers. The efficiency cited in [172] is 6, 824 BTU per ton-kilometer. The demand in 2000 is then 77.8 x 10^{12} BTU. However, this figure refers only to trucks in intercity travel. The light vans are assumed to serve only urban areas, hence their numbers are related to the growth of cities.

Number of light vans will be estimated first for Lima and then for all other urban areas. Population for Lima and other urban areas is presented in Table 45.

Table 45. Population in urban areas, 1976 and 2000[a]

	1976	2000
	(10^6)	(10^6)
Lima	3.8	8.7
All Others	6.5	13.1

[a]SOURCE: [111, 122, 190].

Using Table 45, the light van density for Lima and other urban areas is deducted. For Lima, it is 9 vehicles per 1,000 inhabitants. For all other urban areas, the density is 4 vehicles per 1,000 inhabitants. The number of vehicles in 2000 is derived by using the ratio and the population from Table 45. Lima is expected to be served by 69,600 light vans in 2000. The rest of the urban areas would have 52,400 light vans which makes a fleet of 122,000 vehicles. This represents a rate of growth of approximately 2.8% annually.

Since service vehicles operate in urban areas, the Ministry of Transportation estimates they run 15,000 kilometers (9,315 miles) per year with an energy intensity of 2,047 BTU per vehicle-kilometer [117].

This study's estimated fleet in 2000 will travel 1,830 x 10^6 kilometers and consume 3.8 x 10^{12} BTU of energy in the form of oil. The final figure of the road freight sector is estimated to be 81.6 x 10^{12} BTU.

<u>Railroads</u> In 1976, the two main railroads had a total of 107 locomotives of which 74 were diesel electric. Rolling stock included

2,008 freight and 190 passenger cars. Table 46 summarizes the rail freight of 1976 and Table 47 summarizes the passenger service.

Table 46. Intercity rail freight, 1976[a]

	Ton-Kilometers (10^6)	Percentage of Sector by Rail	Percentage of All Rail Freight
Agriculture	102.7	4.1	10.0
Industry	389.7	11.4	37.5
Mining	354.4	35.8	34.3
Hydrocarbons	185.1	4.2	17.9
Total	1,031.9	9.1	100.0

[a]SOURCE: [117].

Table 47. Intercity passenger movements by rail, 1976[a]

	Passengers (10^3)	Passenger/ Kilometers (10^6)	Kilometers Per Passenger	Rail Passengers Percentage of Total
Central Region	249.1	83	333.2	8.5
Southern Region	989.2	363	367.0	43.8
Total	1,238.3	446	360.2	11.4

[a]SOURCE: [117].

The estimation of ton-kilometers for 1976 is 1.03×10^9. The Ministry of Transportation estimates that rail freight shall increase at a rate of 3.5% per year for the next 20 years [117]. Since that estimate is based on a number of considerations, including addition to the number of train tracks, freight and passenger cars, it will be used as a base for our calculations. It is also felt that this rate fits with the general overview of relatively modest increases in the general economic activity held by our study.

The estimated number of ton-kilometers in 2000 will be 2.4×10^9. In [172], an energy intensity of 1,042 BTU per ton-kilometer is estimated for railroads. This will yield a total of 2.5×10^{12} BTU of energy, all in the form of oil.

For passengers using railroads we will also use the rate of growth predicted in the same study [117], which is 4% annually. This rate of growth means 3.17 million passengers in 2000; using the average of 360.2 kilometers per passenger (224 miles). The total passenger kilometers will be 1.1×10^9. The energy intensity is estimated to be 1,488 BTU per passenger kilometer [172], therefore, the energy needed to satisfy the demand for passenger transportation is 1.6×10^{12} BTU. This study's total estimate for the railroads sector is 4.1×10^{12} BTU.

Air transport Of the 145 aircraft registered in Peru in 1976, 15 were jet-propelled, 6 were turbo-propelled and 124 were propeller planes. Twenty-seven aircraft were maintained on regularly scheduled flights and 14 of these were jet-propelled [172].

This sector also has two kinds of services--cargo and passenger--but as reported in [117] cargo is carried in passenger flights, so only passenger activity will be examined. The passenger activity is reported at the level of 1.3 million in 1976, with an estimated 644.2 kilometers per passenger (400 miles) so we get 844 x 10^6 passenger-kilometers. Detailed information is provided in Table 48.

Table 48. Intercity passenger movements by air, 1976[a]

	Passengers (10^3	Passenger Kilometers (10^6)	Kilometers per Passenger	Air Passengers Percentage of Total
Region				
North	13.1	2	152.7	0.8
Center	177.1	76	429.1	6.0
South	43.3	10	231.0	1.9
East	75.8	34	448.6	100.0
Interregional				
Center-North	283.7	188	662.7	12.1
North-East	34.3	11	320.7	100.0
Center-South	459.7	315	685.2	34.1
Center-East	223.1	206	923.4	100.0
Total	1,310.1	844	644.2	12.0

[a]SOURCE: [117].

The estimation of air passengers in 2000 poses a problem. The cost of aircraft and the increasing price of aviation fuels will probably deter a significant growth in air passengers. Comparatively speaking, air transport is more expensive in Peru. An expansion in air traffic would also require the modernization of provincial airports. In consideration of these elements, it is felt that air transport will have the lower rate of growth than all the other means. Thus, a rate of 2% growth per year will be estimated to allow for some increases to occur. This

2% rate is just estimated and has no historical support. But it is felt to be justified within the limits previously explained. With a 2% yearly increase, 2.1 million passengers will be carried in 2000, practically doubling the 1976 figure.

In 1976, the air transportation sector consumed 12.9 x 10^{12} BTU of energy. It has not been possible to obtain estimates of energy intensities so this study suggests that a doubling of the 1976 level be used. This may seem inadequate, as more passengers can be accommodated in the same number of flights; but since the main airport (in Lima) provides jet fuel to foreign carriers, this apparent overestimation may be offset by these sales, which cannot be forecasted at this time. Therefore, we will use 25.8 x 10^{12} BTU as the estimate of air transport consumption in 2000.

Maritime fleet In 1976, Peru had 39 vessels in its ocean-going merchant fleet. The State owned 24 of these. A measure of the carrying capacity of a vessel is the deadweight. In Table 49, the capacity of the fleet is presented exclusive of lake and river vessels.

The most important lake in Peru is the Titicaca where it is reported six vessels are registered [117]. The Amazon system, which comprises the ports of Iquitos, Pucallpa and Yurimaguas, reported 6,088 vessels registered, all of small size.

Only cargo is moved by the maritime fleet. It moves minerals and petroleum products. Table 50 presents the activity levels for cabotage and Table 51 presents activity levels for river freight.

Table 49. Peru's merchant fleet, 1976[a]

Type	Number of Vessels	Deadweight Tonnage	Average Deadweight Per Vessels
General cargo	22	251,735	11,443
Bulk cargo	9	258,215	28,691
Tankers	8	116,699	14,587
Total	29	626,649	16,068

[a]SOURCE: [117].

Table 50. Cabotage freight, 1976[a]

	Ton/Kilometers	Percent of Sector by Sea	Percent of All Sea Freight
Mining	541.6	54.7	12.1
Hydrocarbons	3,921.5	89.5	87.9
Total	4,462.9	39.5	100.0

[a]SOURCE: [117].

A total of 4.7 x 10^9 ton-kilometers of coastal and river shipping was performed in Peru in 1976. The rates of growth are expected to be higher than the other modes because increases in the production of oil and minerals [117, 172]; and the possible introduction of new products in the cabotage freight. Such rate is 6% and will be used in this study. Thus, the maritime movements in 2000 are projected to be 19.0 x 10^9

ton-kilometers. With the energy intensity of 436 BTU per ton-kilometer [172], the estimation of fuel needs comes to 8.3×10^{12} BTU, all coming from oil.

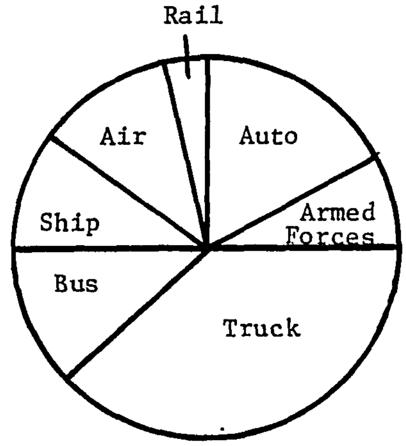
Table 51. River freight, 1976[a]

	Ton-Kilometers (10^6)	Percent of Sector by River	Percent of All River Freight
Agriculture	27.5	1.1	11.3
Industry	167.5	4.9	69.1
Hydrocarbons	47.5	1.1	19.6
Total	242.5	2.2	100.0

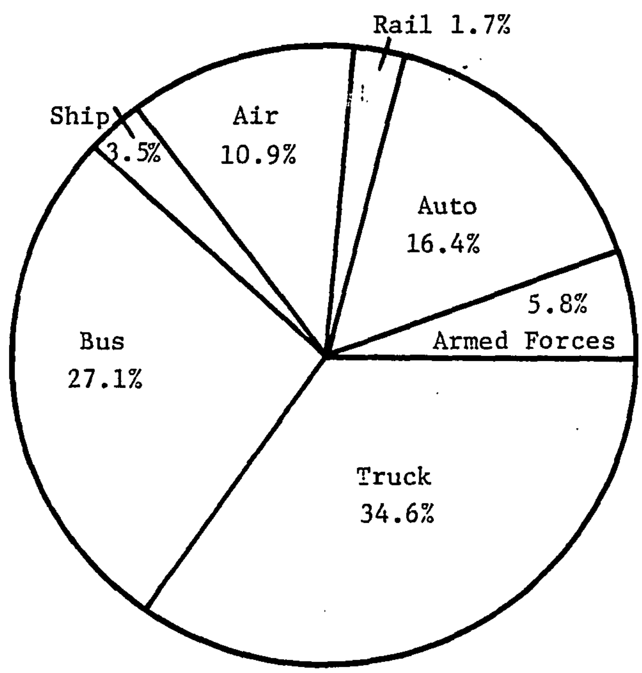
[a]SOURCE: [117].

The Armed Forces used 6.7×10^{12} BTU in 1976 for transportation purposes. We have no basis on which to evaluate what the level of activity will be in the future. Considering the importance of the military in the country, not only from the political point of view but also its geographical distribution along the national territory and their services to civilians in isolated areas (especially jungle areas), a rate of 3% increase per year is suggested to be included in the estimate. This assumption will give a figure of 13.6×10^{12} BTU for the Armed Forces in 2000.

The transportation sector is now completed. Table 52 presents a summary of the findings and Figure 8 compares this study's estimations with actual distribution of the various modes in 1976.



1976



2000

Figure 8. Comparison of 1976 and 2000 energy inputs of transportation sector by mode

Table 52. Energy in the transportation sector

	Unit of Measure	Estimation	Energy Inputs (10^{12} BTU)
Bus	Passenger/kilometer	67.5×10^9	63.9
Truck	Ton/kilometer	11.4×10^9	77.8
Truck (light)	Vehicle/kilometer	$1,830 \times 10^6$	3.8
Rail (freight)	Ton/kilometer	2.4×10^9	2.5
Rail (passenger)	Passenger/kilometer	11.0×10^9	1.6
Air	Passengers	2.1×10^6	25.8
Ship	Ton/kilometers	19.0×10^9	8.3
Armed Forces	-----	-----	13.6

Agriculture

The agricultural sector is not energy intensive. In 1976, it consumed about 3.6% of all commercial resources and about 5% of the non-commercial.

The commercial resources consumed were 89% derived from oil and 11% in the form of electricity. With respect to all oil consumption, agriculture used only 3.1% of the total and used only 4.2% of all electricity produced in 1976.

Table 53 presents the GDP of Peru and the contribution of agriculture. The average rate of growth for the period 1974-79 is 0.5%. The slow growth of agricultural production reflects the land reform initiated in 1969. The overall performance of agriculture from 1950-79 shows a rate of growth of 2.5%, reflecting the higher rate of expansion of the pre-reform years.

Table 53. GDP and agricultural sector of Peru, 1974-79[a]

	GDP	Agricultural Product	Percentage of Total	Rate of Growth
	(billions of 1973 soles)		(percent)	
1974	392.6	53.6	13.7	
1975	421.9	53.6	12.7	0.0
1976	441.1	54.4	12.3	1.5
1977	449.9	54.3	12.1	-0.2%
1978	446.7	53.4	12.0	-1.7
1979	461.8	54.9	11.9	2.8

[a]SOURCE: [98].

There has been a reduction in the cultivated area and stagnation of yields. In addition the drought of recent years must be included in the problems facing the agricultural sector in Peru. This study's concern is to derive a level of energy consumption of the agricultural sector. The energy utilization is practically associated with the Costa agriculture only, where energy is needed for tractors and for the sugar mills.

An increase in agriculture production would mean an increase in productivity and yields and/or an increase in land utilization, or a combination of all. With respect to productivity and yields, there is little hope for better performance in the years to come. This is in part due to the drain of human resources--engineers and managers--from the sector. This drain occurred early in the agrarian reform, following disputes with the peasants on important issues such as long-term development policies. Time has shown that the professionals were right, as the sugar cooperatives have seen in recent years the collapse of the industry, and the increased importation of sugar in a country that has traditionally supplied the product to world markets.

The second point is the discontinuation of agrarian extension services in the early 1970s. During 1969, the Institute de Reforma y Promocion Agraria (IRPA) was integrated into the Ministry of Agriculture and assigned to different tasks, putting an end to 26 years of work. All supporting services to the agricultural sector were reduced. This reduction occurred in spite of the fact that a new organization was created, which seemed to end up involved in bureaucratic matters and not in field work [191].

Agricultural research is mostly conducted by the Institute Nacional de Investigacion Agraria (INIA) along different lines in crops, livestock, forestry, and agro-industry. However, the work of INIA is very general while there is a need for research to deal effectively with production problems at the local level. This calls for on-the-spot work that would adapt general research results to area-specific problems. It is believed these services are essential to the revival of the sector [191].

Institutional agricultural credit is provided by the Banco Agropecuario del Peru (BAP). Commercial banks did play an important role in the past, but when land could no longer be mortgaged they practically ceased making loans. In 1979, the BAP provided loans for 91 billion soles (approximately 405 million dollars). These credits were concentrated to over 60% in cotton and rice and mostly at cooperatives and other large associated agricultural units.

It should be mentioned also that the marketing system is heavily burdened by a large number of intermediaries and government regulations and interventions. In practice, all government policies had a strong bias towards the urban consumer and penalized the producer through inadequate prices. These constrictions contributed to the stagnation of agricultural production [183]. Trends in agricultural production are shown in Table 54.

Table 54. Indices of total and per capita agricultural production, 1970-74 and 1975-79[a] (1961-65 = 100)

	1970-74	1975	1976	1977	1978	1979
Total agriculture	104	101	101	101	97	99
Crops	104	98	100	100	95	97
Food	115	113	117	116	106	103
Total agriculture per capita	80	71	69	63	63	62
Food per capita	89	80	80	68	65	65

[a]SOURCE: [191].

In 1979, the Government imported 1.2 million tons of food with a value of 220 million dollars.

The preceding paragraphs have presented the state of the agricultural sector in Peru. From this, we must attempt to project and estimate its future development. Now the study will turn to the energy-consuming devices in agriculture.

Tractors would be the most important source of commercial energy consumption with a reported 10,000 tractors in operation in 1968 [15]. The Second Agricultural Census of 1972 reported 8,352 units in operation [191]: 76% of the tractors in the Costa farmland, 18% in the Sierra and only 6% in the Selva region. It has been observed that the number of tractors reported diminished from 1968 to 1972. Since the agrarian reform took place in 1969, one could attribute this fact to the lack of investment that follows a process of ownership change. The difference of almost 1,600 units could also be due, in part, to overestimation in 1968. Agricultural statistics are not well-known for their accuracy, but this author feels there is enough evidence to support the idea that no further mechanization occurred after the agrarian reform.

The picture of the agricultural sector presented is not a bright one. There are a number of things that could be done, but the purpose here is not to address these improvements but to make an educated guess of the future energy consumption of the sector based on its past performance and current prospects.

In terms of commercial resources, it uses oil to mobilize tractors and produce heat/steam in the mills, in addition to producing electricity. It is suggested a modest increase in oil and electricity utilization of 1% per year to the year 2000 be used in order to take into account improvements in total production. At least the levels of pre-reform could be attained in the next 20 years. Further improvement must come from specific government action. However, the delicate situation of public finances will probably delay this for a few years for any significant program.

Thus, commercial energy utilization in the agricultural sector could reach 11.5×10^{12} BTU of which 10.2×10^{12} BTU will come from oil and 1.3×10^{12} BTU in the form of electricity.

For noncommercial resources, the sector uses the bagasse to produce electricity and heat/steam in the processing sugar. The analysis of the agricultural sector just presented does not show possibilities of agricultural production increases beyond the modest rates of the past. Since bagasse is a by-product of sugarcane, it is the sugarcane production that should concern us here. It will be assumed that the same amount of bagasse will be available to the agricultural sector in the year 2000. This assumption is based on the fact that any increase in bagasse availability will probably go to the paper mill. So the amount of 8.2×10^{12} BTU will be used as the requirements of the agricultural sector for noncommercial resources.

Industry

The industrial sector is by far the most important consuming sector of commercial energy. The evolution of the sector by individual components will first be presented to set the stage for consideration of future development. For purposes of this study mining, manufacturing, fisheries, and construction will be included within the industrial sector.

Mining The mining sector has been a key sector of the Peruvian economy since the colonial days. Since the 1950s, the sector has gone through a period of rapid expansion supported by foreign investment. The value of exports expanded at an annual rate of 12% between 1951 and

1962. The share of Peru's exports earnings generated by the mining sector went up from 21% to 42% during this decade [190].

During the 1960s, no new major investments took place. Volume grew only 3.5% yearly between 1961 and 1969, but export values grew 12% yearly due to better world prices. By 1969, the share of mining exports in the total merchandise exports had increased to 55% [156].

With a military government a new mining policy entered into effect. In the 1970-76 period, mineral production grew very little and export volume practically stagnated. The value of exports expanded at an annual rate of 6.5% [191]. In Table 55, can be observed the evolution of the sector measured in its contribution to GDP.

Table 55. Mining and total GDP for selected years, 1950-1979[a]

	Total GDP	Mining	Percentage
	(millions of 1973 soles)		
1950	126,303	7,123	5.6
1955	166,937	10,046	6.0
1960	215,763	16,848	7.8
1965	293,544	19,861	6.8
1970	352,596	24,930	7.1
1975	441,073	25,243	5.7
1976	449,987	26,762	5.9
1977	449,738	32,909	7.3
1978	446,740	36,025	8.1
1979	461,831	39,425	8.5

[a]SOURCE: [98].

In terms of principal minerals, Peru exports cooper, lead, zinc, and iron. Table 56 shows the evolution of the first three exports.

Table 56. Production of principal minerals, 1973-77[a]

	1973	1974	1975	1976	1977
	(thousand metric tons)				
Cooper					
Blister	134.0	137.5	85.1	46.8	140.6
Refined	39.0	39.0	71.5	131.6	177.7
Concentrates	29.7	35.1	9.2	32.8	14.5
Total	202.7	211.6	165.8	211.2	332.8
Lead					
Refined	82.9	80.2	71.0	74.1	79.3
Concentrates	100.5	85.6	83.2	94.9	96.9
Total	183.4	165.8	154.2	169.0	176.2
Zinc					
Refined	69.0	70.8	65.1	64.7	66.8
Concentrates	321.6	307.2	299.8	338.6	369.8
Total	390.6	378.0	364.9	403.3	436.6
Total	776.7	755.4	684.9	783.5	945.6

[a]SOURCE: [172].

Other minerals mined in Peru are included in Table 57. The energy consumption of the mining sector has been estimated to be 46.2×10^{12} BTU in 1976, consisting of 1.6×10^{12} BTU of coal; 18.9×10^{12} BTU of oil, and 25.7×10^{12} BTU of electricity.

The coal used by the mining sector is not related to energy but is an input in the smelting operations. The need for coke in the existing operations has been estimated to be 3.0×10^{12} BTU in the year 2000

[172]. This figure will be used in this study because it is based on production estimates of individual plants.

Table 57. Other minerals production, 1970-76[a]

	1970	1971	1972	1973	1974	1975	1976
Silver[b]	39.8	39.9	40.4	37.4	34.8	37.7	38.1
Iron[c]	9.3	9.7	8.9	9.4	8.8	9.5	n.a.
Antimony[d]	1,167.0	687.0	749.0	770.0	681.0	803.0	603.0
Bismuth[d]	806.0	641.0	724.0	572.0	666.0	559.0	565.0
Gold[d]	3.3	2.6	2.7	3.2	3.2	2.7	2.5
Mercury[d]	117.0	110.0	119.0	156.0	123.0	112.0	57.0
Molybdenum[d]	606.0	800.0	766.0	647.0	718.0	493.0	n.a.
Selenium[d]	6.8	7.1	8.0	7.7	7.7	6.5	n.a.
Tellurium[d]	30.1	23.9	1.8	26.2	36.5	21.1	n.a.

[a]SOURCE: [190].

[b]In 10^6 Troy ounces.

[c]In 10^6 metric tons.

[d]In metric tons.

In general terms, the mining sector looks capable of growing at rates higher than the overall economy. Peru's resources are abundant, the key points are world prices, financing of projects and adequate management. Estimates of up to 6.5% per year have been made for the mining sector [172]. But that may seem unrealistic to the extent that the state has now the responsibility of the sector and its credit standing is not very good. The issue of direct foreign investment is far from resolved.

The painful experiences of the 1970s and the disastrous economic consequences are not forgotten; so the course of action seems to be to proceed with caution with respect to direct foreign investment, imposing conditions that will discourage some investors.

This study proposes to use a rate of growth of 3% per year for the mining sector to keep in in line with the general economic activity estimation. However, it should be kept in mind that this sector is one of the few, if not the only one, that shows promise for rapid expansion.

Following the estimation procedure from [131], it will be assumed that the mining sector will keep its relationship to GDP as in the last few years (8%). The total energy consumption in 1976 when compared to the sector's output gives a ratio of 1,726.3 BTU per sol of output. The mining sector will have an 8% share of total GDP in 2000, which comes to 69.4 billion soles of 1973 (about 1.8 billion dollars at the exchange rate of 1973). Total energy consumption will be 119.8×10^{12} BTU. Since coal needs had already been set at 3.0×10^{12} BTU, the remainder of 116.8×10^{12} BTU will come from oil and electricity; the proportion that has prevailed in the mining sector is 40:60 between these two inputs. Using the same proportion, a need of 46.7×10^{12} BTU from oil and 70.1×10^{12} BTU in the form of electricity is expected.

<u>Manufacturing</u> Peru, as many other development countries, has turned to industry for rapid economic growth since the 1950s; and like many others has built its industrial policy on high protective tariffs and nontariff barriers [110].

Real manufacturing output increased at a long-term average annual rate of over 8% in the 1959-75 period. Excluding fishmeal, the annual rate of growth has been accelerating from less than 7% in the 1946-55 period to over 9% during 1969-75. As it has consistently grown faster than the rest of the economy, the share of manufacturing valued added in total GDP rose from less than 15% in the 1950s to almost 22% in the 1970s, as shown in Table 58.

Table 58. Indicators of manufacturing output growth, 1946-75[a]

	1946-55	1959-68	1968-75	1959-75
Total manufacturing	n.a.	9.0	8.3	8.7
Total manufacturing (excluding fishmeal)	6.7	8.2	9.2	8.6
Total manufacturing (share of GDP at end of period)	14.8	20.2	21.6	21.6

[a]SOURCE: [112, 190].

The manufacturing sector was badly affected by the 1976 economic crisis and declined at an average rate of 1.6% per year during 1976-79 (Table 59). The relatively weak performances and present structure of the manufacturing sector are the results of policies of the 1960s and 1970s. There was credit at subsidized interest rates, cheap imports of capital and intermediate goods through an overvalued exchanged rate and low tariff, high protection for finished products, subsidized power rates and fuel prices. The structure of industry has changed over the years as shown in Table 100.

Table 59. Industrial sector performance, 1976-79[a]

	Average Annual Growth, 1976-79	Structure of Factory Sub-Sector, 1979	Contributions to Growth of Factory Subsector, 1970-79
	(percentage, constant 1973 dollars)		
GDP	0.7	---	---
Manufacturing	-1.6	---	---
Handicraft	0.7	---	---
Factory sector	-1.8	100.0	---
Food, beverages	-5.7	27.8	-9.2
Textiles, garments	-2.6	13.9	8.0
Wood products	-7.7	2.0	1.6
Paper products	-9.2	3.7	0.4
Chemicals	-1.3	18.7	34.8
Nonmetal minerals	-0.9	4.7	8.0
Basic metals	19.5	14.9	32.0
Metal products	-8,8	13.3	24.0
Other	-8.7	1.0	0.4

[a]SOURCE: [95, 98].

The manufacturing sector is still basically geared towards the consumption market. Although the capital goods production shows an increase in output participation, it includes many consumers' durables, such as automobiles and home appliances.

Peru's participation in the Andean Group and the announcement by the new civilian government of the new tariff policy, aimed at eliminating the distortions and inefficiencies of the past, will have an impact on the sector. At the beginning it may seem negative but it should prove to be beneficial in the long run.

Table 60. Structure of output in manufacturing, 1955, 1967 and 1974[a]

	1955	1967	1974
		(percent)	
Consumer Goods	66.3	51.8	48.7
Processed goods	29.3	22.3	14.7
Beverages	5.9	6.7	7.8
Tobacco	--	1.6	2.1
Textiles	14.8	11.2	12.4
Footwear and clothing	3.5	3.4	3.5
Furniture	0.6	1.3	1.2
Printing	1.8	2.6	2.7
Miscellaneous	10.4	2.7	4.3
Intermediate Goods	29.2	35.6	34.3
Wood products	1.7	1.3	1.3
Paper products	1.9	2.9	2.9
Leather goods	2.0	1.0	0.8
Rubber products	1.2	1.8	1.5
Chemicals	4.4	10.0	10.9
Petroleum	0.3	5.5	2.5
Nonmetallic	3.6	4.2	4.3
Basic metals	14.1	8.9	10.1
Capital Goods	4.5	12.8	16.9
Metal fabrication	2.3	3.1	4.5
Nonelectrical machinery	0.3	1.8	2.9
Electrical machinery	0.4	2.1	4.6
Transport materials	1.5	5.8	4.9
Total	100.0	100.0	100.0

[a]SOURCE: [98, 190].

From the preceding information it is felt that a 3% increase per year is well within what can be expected for the manufacturing industry. As we did with the mining sector, the manufacturing sector will be treated as a whole and its derived energy intensity per unit of output will be applied to the expected level of output for the year 2000. The value of manufacturing output in 1979 is estimated at 114.8 billions of 1973 soles [98]. At a 3% increase per year, in the year 2000 it will be 213.6 billions of 1973 soles.

Since the total energy consumed by the sector in 1976 was 101.9 x 10^{12} BTU, and the output for that year was 119.6 x 10^9 soles [98], dividing the first by the second would give an energy intensity of 852 BTU per sol of output. Thus, in order to produce an output valued at 213.6 billion soles, the sector would need 182.0 x 10^{12} BTU. The distribution of this energy amount among different fuels is set using the percentage distribution of 1976 which yields Table 61.

Table 61. Manufacturing energy consumption projections for 2000

	Percentage in 1976	2000 (10^{12} BTU)
Total	100.0	182.0
Coal	8.7	15.8
Oil	48.9	89.0
Natural gas	15.1	27.5
Electricity	27.3	49.7

<u>Fisheries</u> Peru has a large fishing potential which is the base of the fishmeal industry that developed rapidly in the late 1950s. However, the magnitude of the fishing potential remains uncertain and subject to violent fluctuations of ecological conditions. The cold Humboldt Current contains an abundance of fish food which makes the

offshore waters some of the world's richest fishing grounds, while the climate facilitates fishing operations all year around.

Anchovy catch, the most important fishing resource, peaked at 11 million tons in 1971 but fell drastically in the next year and has not yet fully recovered. The share of fish products in total exports has fluctuated widely. On an average, the share was 12% in 1960-62, 26% in 1965-68, 34% in 1970-71, and less than 14% in 1976 [190]. Table 62 shows the evolution of fisheries in the 1970s. Since 1970, the output has been diminishing at an annual rate of 2.25%. But there are signs of recovery, 1978 and 1979 showed an increase in value of output, however, the general opinion is that to avoid the repetition of the crisis of the early 1970s, the government will have to follow a policy of fishing restriction. A sound policy should bring stability to the sector providing less fluctuations but lower rates of growth.

Table 62. Evolution of fisheries, 1970-79[a]

	Value of Output	Percentage of GDP	Rate of Change
	(billion 1973 soles)	(percent)	(percent)
1970	7.7	2.2	+32.8
1971	6.7	1.8	-13.1
1972	3.5	0.9	-46.8
1973	2.6	0.7	-27.6
1974	3.6	0.9	+39.7
1975	3.2	0.7	-11.3
1976	3.8	0.8	+17.8
1977	3.3	0.7	-12.7
1978	4.1	0.9	+26.3
1979	4.6	1.0	+ 9.9

[a]SOURCE: [98].

Because of the outlook of the sector it is felt that the 3% general economy growth estimate will also fit this sector well.

The energy consumption of the fisheries sector for 1976 was estimated at 8.5×10^{12} BTU, all from oil. This includes the fishmeal industry as well as the human consumption of fish catches. The latter is a very insignificant part of the total fisheries.

The energy intensity for 1976 can readily be estimated with the figure just indicated, and it amounts to 2,236.8 BTU per sol of output. Compared to other activities it is more energy intensive per unit of output.

A 3% growth of output value will put fisheries contributions to GDP at 8.6 billions of 1973 soles: a share of about 9.9%. By using the same energy intensity of 1976 this study predicts the fisheries sector to require 19.2×10^{12} BTU of energy, all derived from oil.

<u>Construction</u> Construction is usually not included in manufacturing, so it will be treated separately in this study. Construction is an important supplier of employment in urban areas. Economically speaking, it is one of the sectors most influenced by the general economic activity. Its share of GDP has been consistently around 3% in the 1970s [98].

The energy consumption for 1976 is estimated at 1.7×10^{12} BTU, derived from oil. It is not very significant in terms of energy utilization. The value of construction in the year 2000 is projected to be 25.7 billions of 1973 soles. With an energy intensity of 100 BTU per sol of output, the total consumption in 2000 will be 2.6×10^{12} BTU.

The estimation of energy consumption in the industrial sector is now complete. Table 63 summarizes this study's findings.

Table 63. Projected energy consumption of industrial sector in 2000 (in 10^{12} BTU)

Mining	119.8
Manufacturing	182.0
Fisheries	19.2
Construction	2.6
Total	323.6

Electricity generation

Aside from water power, oil and natural gas are the commercial resources used in the generation of electricity. For 1976, it is estimated that 9% of the total demand for energy went to produce electricity [172]. In Table 64, a breakdown of the generating capacity in 1976 is presented.

Table 64. Generating capacity, 1976[a] (in megawatts)

	Hydro Total	Thermal			Thermal Total	Total
		Steam	Gas	Diesel		
Public Sector	1,156.0	14.5	143.9	180.6	339.0	1,495.0
Auto-Productores[b]	249.8	387.5	87.9	295.6	771.0	1,020.8
Total	1,405.8	482.0	231.8	476.2	1,110.0	2,515.8

[a]SOURCE: [115].

[b]Produced by industrial establishments for their own consumption.

The public sector operates 60% of the generating capacity, of which 77% is hydropower. The private sector operates 40% of the capacity installed, of which 75% is thermal. Table 65 has been constructed by using the standard conversion values.

Table 65. Production of electricity by sources[a]

	Hydro	Thermal				Total
		Steam	Gas	Diesel	Total	
		(gigawatts per hour)				
Public Sector	4,623.4	93.8	7.3	307.3	408.4	5,031.8
Auto-Productores	1,174.3	1,163.3	121.0	420.7	1,705.0	2,879.3
Total	5,797.7	1,257.1	128.3	728.0	2,113.4	7,911.1

[a]SOURCE: [115].

On the production side, the public sector provides 64% of the electricity needed, of which 92% comes from hydropower stations. On the private side, they produce their share of the total: 60% from thermal generation and the rest hydraulic. The fuel used and quantities are listed in Table 66-68.

Table 66-68. Fuel in electric energy production, 1976[a]

	Petroleum	Gas	Bagasse
	(10^6 barrels)	(10^9 cubic feet)	(10^6 tonnes)
Public Sector	0.85	0.6	0.0
Auto-Productores	3.00	3.3	0.8
Total	3.85	3.9	0.8

[a]SOURCE: [115].

In our estimations of hydropower in Chapter II, we indicated that the capacity to be installed by the year 2000 could provide 19,659.1 GWH of electricity. The caloric content of that amount is 67.1×10^{12} BTU; but with the efficiency of thermal stations at 30%, it represents an amount of 223.7×10^{12} BTU in fossil fuels.

CHAPTER IV. THE ENERGY RESOURCES OF PERU

The estimation of energy consumption entails a number of assumptions, which in many cases cannot be rationalized. The picture in the case of energy supply estimation is just about the same, especially with respect to hydrocarbon resources. The analysis of mineral resource availability starts with estimates of the earth's natural stock of such materials; but the knowledge of those stocks varies from one particular resource to another. For example, the origin of fluid hydrocarbons, the transformation of organic matter into rocks, and the maturation and migration of petroleum, is not fully understood yet.

For all practical purposes, the total amount of natural resources of any particular fuel can be considered fixed; but the fact that resources exist does not imply that there is knowledge on how extensive they are or where they are, much less that there is the technical and economic capability to recover them.

The total natural stock may be called the "resource base." The portion of this base which has been estimated with at least a small degree of certainty and which might be recovered some time in the future is termed "identified resources." The term "undiscovered or speculative resources" is used when it is assumed they exist on the basis of broad geologic knowledge and theory. The portion of the identified resource from which a usable mineral and energy commodity can be economically and legally extracted at the time of determination may be termed "reserves." This terminology follows the definitions adopted by the U.S. Geological Survey and the U.S. Bureau of Mines [130, 172].

Thus, data and estimates about minerals are classified along the spectrum from resource base through resources to reserves by two criteria: geological assurance of their existence and economic feasibility of their recovery. The distinction between resources and reserves is of basic importance in our analysis. Reserve data have a significance in the short run, perhaps also in the medium run. On the other hand, resource data give insights for the long run. Figure 9 illustrates the terminology just discussed.

In the following pages, we will analyze the information available on resources and reserves of energy commodities of Peru.

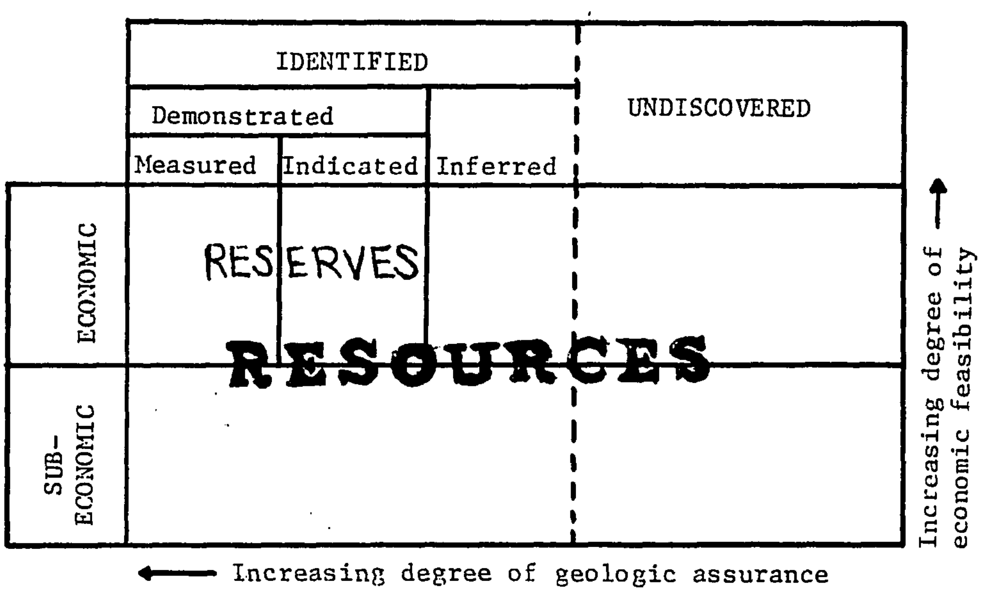


Figure 9. Energy reference terminology [149]

Commercial Resources--Oil

Oil production

The development of the oil industry in Peru began in the 1860s, but for the first 40 years growth was slow. During the late 1890s and early 1900s, the pace began to pick up, with a sharp increase in the amount of exploration and with the formation of new companies. The oil fields which became actual producers at that time were clustered in the coastal desert of the far northwest. A small field called Pirin on the shore of Lake Titicaca was discovered in 1875 on the basis of surface oil seeps. The field is now depleted [156A].

It is estimated that by 1900 a total of 1.5 million barrels had been extracted from the various fields. To the end of 1980, the cumulative production of oil in Peru is estimated to be 1,193.0 millions of barrels, which is shown in Table 69.

Table 69. Cumulative oil production[a]

	Production	Percentage	Rate of Growth
	(millions of barrels)		(percent)
1884-1900	1.5	0.1	38.7
1901-1910	6.4	0.5	18.1
1911-1920	23.1	1.9	6.7
1921-1930	90.8	7.6	17.2
1931-1940	144.4	12.1	0.7
1941-1950	136.7	11.4	1.5
1951-1960	176.9	14.9	1.6
1961-1970	233.3	19.6	3.0
1971-1980	379.9	31.9	10.5
Total	1,193.0	100.0	

[a]SOURCE: [156A, 1972].

In 1900, the yearly combined production of the existing fields was 289,000 barrels. The production of oil kept rising until the late 1930s.

In the 1940's, production dropped and moved slowly upward during the 1950s and 1960s, showing signs of decline in the early 1970s. Tables 70, 71 and 72 present this information.

Table 70. Peru's oil production, 1884-1930[a]

Year	Production (thousand barrels/year)	Year	Production (thousand barrels/year)
1884	6	1911	1,478
1885	8	1912	1,768
1886	8	1913	2,070
1887	16	1914	1,854
1888	16	1915	2,603
1889	18	1916	2,617
1890	31	1917	2,627
1891	114	1918	2,536
1892	167	1919	2,639
1893	114	1920	2,825
1894	95	1921	3,699
1895	95	1922	5,304
1896	95	1923	5,690
1897	99	1924	7,915
1898	151	1925	9,235
1899	204	1926	10,804
1900	289	1927	10,148
1901	295	1928	12,048
1902	243	1929	13,450
1903	281	1930	12,533
1904	293		
1905	376		
1906	536		
1907	758		
1908	953		
1909	1,424		
1910	1,270		

[a]SOURCE: [156A].

Table 71. Peru's oil production, 1931-1949[a]

	Annual Average
	(millions of barrels)
1931-1934	12.4
1935-1939	16.3
1940-1944	13.3
1945-1949	13.6

[a]SOURCE: [156A].

Table 72. Peru's oil production, 1950-1980

Year	Production	Year	Production	Year	Production
	(mil. barrels)		(mil. barrels)		(mil. barrels)
1970[a]	25.6	1960[a]	19.1	1950[b]	15.5
1971	22.0	1961	19.3	1951	16.2
1972	23.1	1962	21.0	1952	16.9
1973	25.1	1963	21.2	1953	16.1
1974	27.5	1964	23.5	1954	17.2
1975	25.8	1965	22.8	1955	17.3
1976	27.7	1966	22.6	1956	18.4
1977[c]	32.3	1967	25.2	1957	19.3
1978	55.1	1968	26.4	1958	18.7
1979	69.9	1969	25.7	1959	17.7
1980	71.4				

[a]SOURCE: [172].

[b]SOURCE: [190].

[c]SOURCE: Private communication, Petro-Peru (p. 191, herein).

The increase of production since 1977 is due to the oil fields discovered in the Amazon basin. The exploration of the jungle began in 1919. The first discovery was made in 1937 based on drilling. A second discovery was made in 1957. But it was not until 1970 that a new exploration effort led to the discovery of a dozen new oil fields, which in turn led to the construction of the North Peruvian pipeline, completed in 1977 and designated to transmit 200,000 barrels a day to the Pacific coast. Table 73 shows the origin of oil production in Peru by regions.

Table 73. Origin of oil production in Peru (by regions), 1977-1980[a]

Region	1977	1978	1979	1980
		(percentage)		
Costa	69.3	41.2	32.8	34.6
On-shore	37.0	22.5	18.0	20.3
Off-shore	32.3	18.7	14.8	14.3
Selva	33.1	58.8	67.2	65.4
Total	100.0	100.0	100.0	100.0

[a]SOURCE: Private communication, Petro-Peru (p. 191, herein).

Oil from the Amazon basin began flowing through the pipeline in 1977. Its importance to Peru's total production is increasing while the Costa fields are stable in production.

Oil and the balance of payments

Oil has always been for Peru a traditional export product, providing 30% of the total export earnings in 1930. Exports started on a large scale about 1908 [156A]. By 1924, oil was the leading Peruvian export. The share of oil in the exports rose in 1931 to 37.8% [156A] and since then began to decline. In terms of physical quantities it means exports of around 9.2 million barrels a year in the period 1925-29 to a maximum of 14.0 million in 1935-39. The import of oil for internal consumption started in 1963 with 1.5 million barrels, reaching the amount of 16.9 million barrels in 1976. The exports, imports and their respective values are presented in Tables 74, 75 and 76.

Table 74. Oil exports and imports[a]

	Exports		Imports	
	Quantity	Value	Quantity	Value
	(million barrels per year)	(million dollars)	(million barrels per year)	(million dollars)
1925-1929[b]	11.1	18.4	---	---
1930-1934	12.4	11.0	---	---
1935-1939	16.3	17.9	---	---
1940-1944	13.3	15.2	---	---
1945-1949	13.6	26.5	---	---
1950-1954	6.7	18.9	---	---
1955-1959	6.2	20.9	---	---
1960-1964	4.5	12.6	n.a.	13.9
1965-1968	3.4	9.0	n.a.	19.5

[a]SOURCE: [156A].

[b]Yearly average.

Table 75. Trade balance of crude oil, 1968-1980[a] (in millions of barrels and millions of current dollars)

Year	Imports		Exports		Balance	
	Volume	Dollars	Volume	Dollars	Volume	Dollars[b]
1968	4.9	9.9	2.5	4.7	-2.4	-5.2
1969	5.4	9.8	2.2	5.6	-3.2	-4.2
1970	4.8	10.8	0.8	2.0	-4.0	-8.8
1971	10.7	32.4	0.5	1.9	-10.2	-30.5
1972	12.0	36.0	0.5	2.0	-11.5	-34.0
1973	12.9	52.8	0.1	0.1	-12.8	-52.7
1974	11.9	156.4	---	---	-11.9	-156.4
1975	16.9	193.3	1.5	16.4	-15.4	-176.9
1976	16.4	208.6	2.0	22.5	-14.4	-186.1
1977	14.7	202.7	0.6	9.7	-14.1	-193.0
1978	0.4	63.0	10.7	142.5	+10.3	+136.2
1979	---	---	20.1	566.2	+20.1	+566.2
1980	---	---	60.0	834.5	+60.0	+834.5

[a]SOURCE: [156A, 172, 190] and private communication with Petro-Peru (p. 191, herein).

[b]Average rate of exchange has been used.

Although, because of differences in oil qualities, Peru has kept exporting petroleum and petroleum products, the oil deficit in foreign trade increased steadily since 1963 to more than US $200 million (at current prices) in 1976. The completion of the oil pipeline and the beginning of oil exports has changed the oil deficit into an oil surplus of 60 million barrels a year.

Oil resources

The U.S. Geological Survey in collaboration with the Government of Peru [172] has analyzed existing data on the potential for oil production in Peru. These data will be reviewed by the geographical regions of Peru.

Table 76. Evolution of the crude oil and petroleum products trade balance, 1977-1980[a] (in million barrels per year, million dollars)

	1977		1978		1979		1980[b]	
	Volume	Dollars	Volume	Dollars	Volume	Dollars	Volume	Dollars
Crude								
Export	0.6	9.7	10.7	142.5	20.1	566.2	60.0	834.5
Import	14.7	202.7	0.4	6.3	---	---	---	---
Balance	(14.1)	(193.0)	10.3	136.2	20.1	566.2	60.0	834.5
Petroleum Products								
Export	9.7	44.2	8.1	44.9	17.2	194.6	20.0	248.9
Import	12.2	79.6	4.7	33.0	0.7	12.4	0.7	16.2
Balance	(2.5)	(35.4)	5.4	11.9	16.5	182.2	19.3	232.7
Crude + Petroleum Products								
Export	10.3	53.9	18.8	187.4	37.3	760.8	80.0	1,083.4
Import	26.9	282.3	5.1	39.3	0.7	12.4	0.7	16.2
Balance	(16.6)	(228.4)	13.7	148.1	36.6	748.4	79.3	1,067.2

[a]SOURCE: [190].

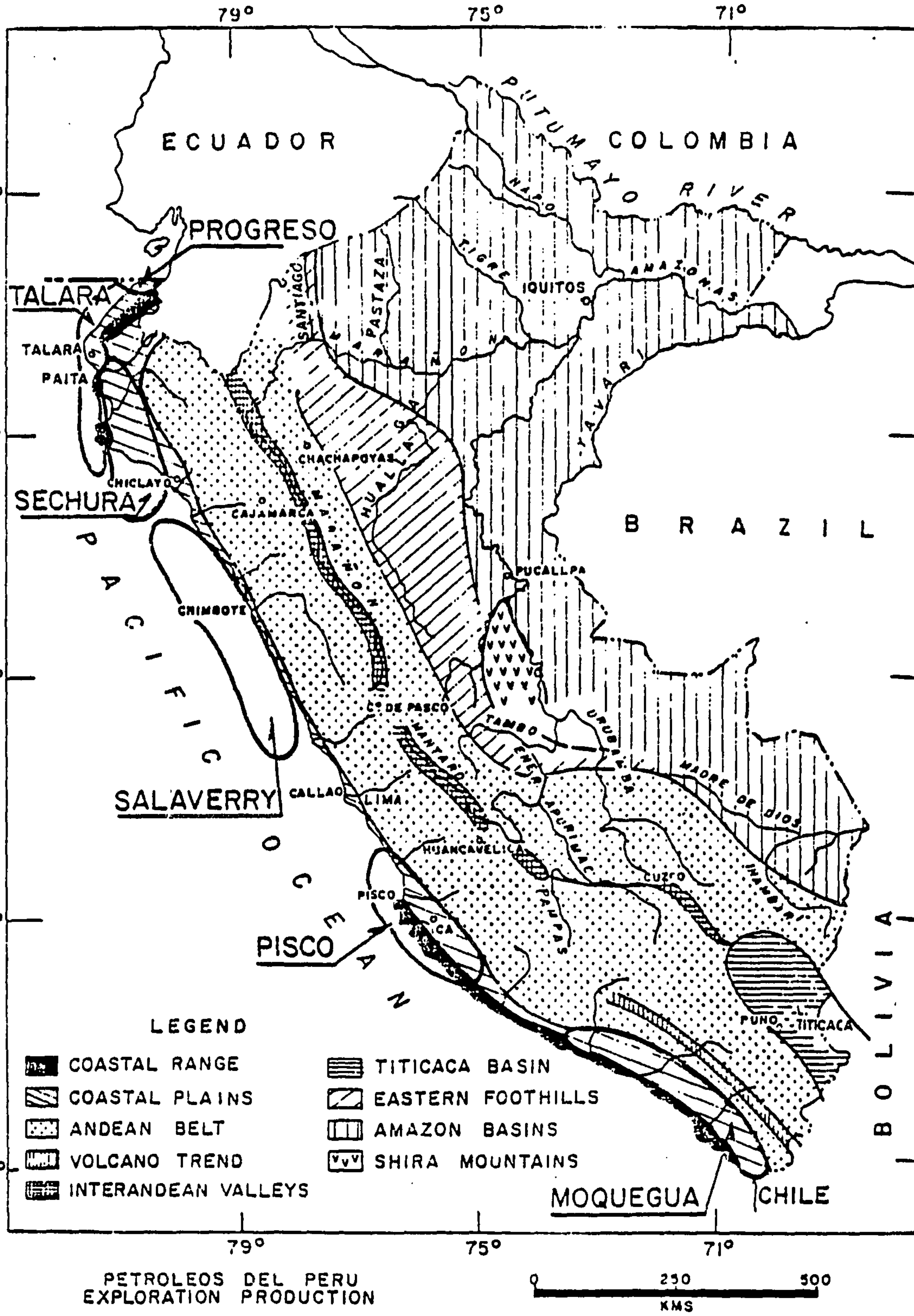
[b]Preliminary figures.

Costa The coastal belt includes a series of onshore and offshore basins. (See Figure 10 for reference.)

The "Progreso basin" covers 2,500 square kilometers (km^2) and is mainly offshore, oil has been discovered in this basin.

The "Talara basin" has an area of 16,500 km^2 mostly offshore. The bulk of Peru's production of oil and gas to date comes from this basin. Presently, the onshore fields produce about 34,000 barrels a day, and the offshore fields about 30,000.

Figure 10. Morpho-structual map of Peru [172]


79°
75°
71°
2°
6°
10°
14°
18°
ECUADOR
COLOMBIA
PUTUMAYO RIVER
NAPO
TIGRE
IQUITOS
AMAZONAS
SANTIAGO
PASTAZA
MARAÑON
YAVARI
BRAZIL
PROGRESO
TALARA
TALARA
PAITA
SECHURA
CHICLAYO
CAJAMARCA
CHACHAPOYAS
HUALLAGA
PUCALLPA
CHIMBOTE
PACIFIC OCEAN
SALAVERRY
CALLAO
LIMA
Co DE PASCO
MANTARO
TAMBO
ENE
URUBAMBA
MADRE DE DIOS
APURIMAC
HUANCAVELICA
CUZCO
PISCO
ICA
PISCO
PUNO
TITICACA
BOLIVIA
MOQUEGUA
CHILE
LEGEND
COASTAL RANGE
COASTAL PLAINS
ANDEAN BELT
VOLCANO TREND
INTERANDEAN VALLEYS
TITICACA BASIN
EASTERN FOOTHILLS
AMAZON BASINS
SHIRA MOUNTAINS
PETROLEOS DEL PERU
EXPLORATION PRODUCTION
0
250
500
KMS

The "Sechura basin" is mainly onshore with an area of 29,000 km^2. Attempts to extend oil and gas production southward from the Talara basin to the Sechura basin have been unsuccessful to date, but subeconomic gas deposits have been identified.

The "Salaverry basin" is entirely offshore and no oil or gas has been produced so far, but exploration of the basin seems to have been sparse. It covers an area of 54,000 km^2.

The "Pisco basin" is both offshore and on shore with an area of 25,000 km^2. Although no oil or gas has been produced in this area, seismic surveys suggest there could be deposits.

Finally, the "Moquegua basin" of 19,000 km^2 is considered to contain no hydrocarbon potential.

Sierra It is considered that the hydrocarbon potential of the Sierra is very low. At the beginning of this centruy oil was produced from the field of Pirin in Lake Titicaca, which is part of the Altiplane basin. Other small discoveries could be made but the complexity of the geology precludes serious exploration efforts.

Selva As shown in Figure 11, there are three basins within the Selva: Oriente (or Marañon), Ucayali and Madre de Dios. The "Oriente basin" has an area of 458,000 km^2 and production comes primarily from this area.

The "Ucayali basin" has an area of 200,000 km^2. Oil fields have been discovered in 1939 and 1957.

The "Madre de Dios basin" covers 95,000 km^2, although oil and gas potential is suspected, no production has taken place to date.

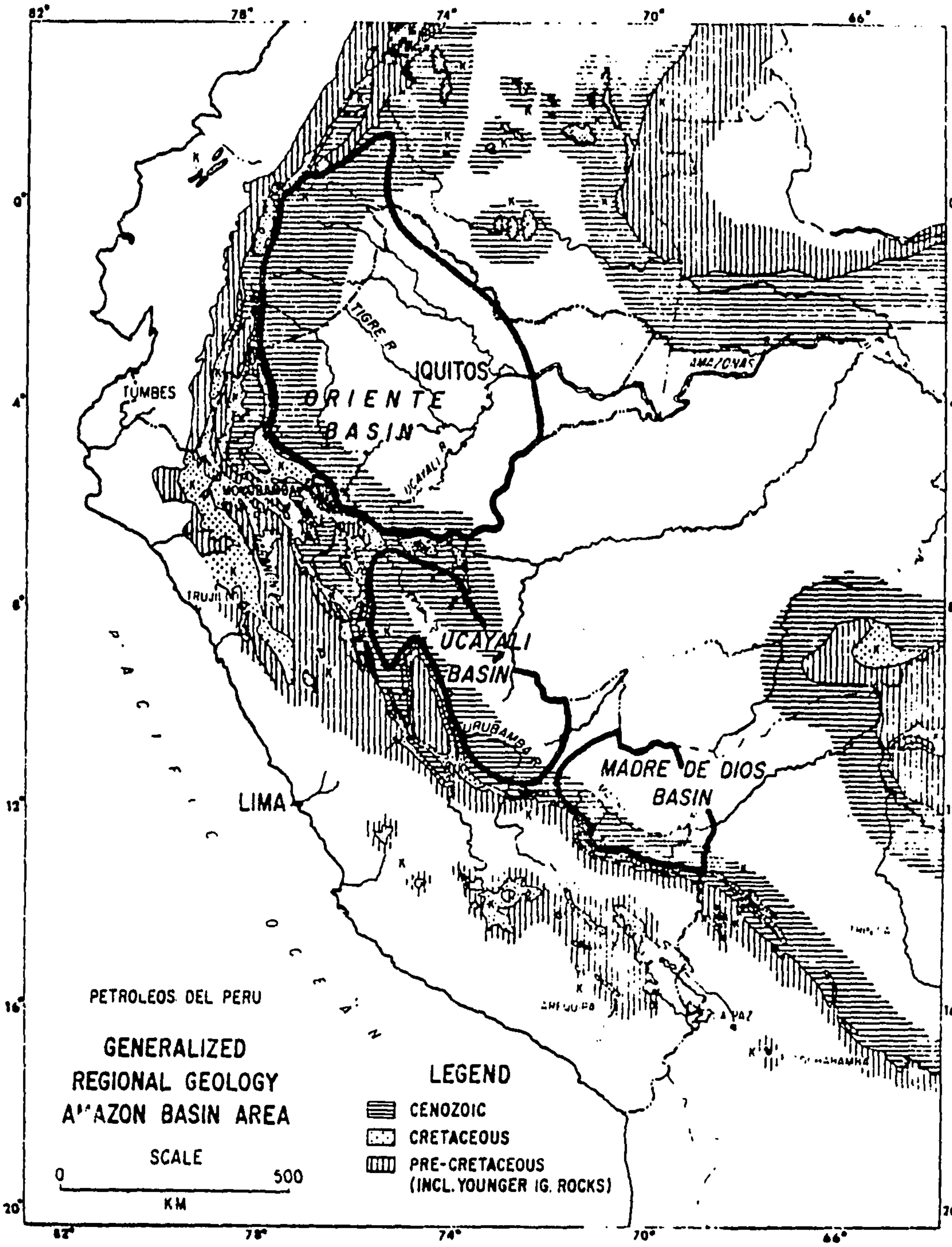


Figure 11. Generalized regional geology of Amazon basin area [172]

Oil reserves definitions

Bearing in mind the definitions of resources and reserves as applied to any mineral, further differentiations are introduced as they pertain to the oil terminology [149].

Measured reserves: That part of identified resource which can be economically extracted by using existing technology, and where amount is estimated from geologic evidence supported by engineering measurements.

Indicated reserves: Reserves that include additional recoveries in known reservoirs (in excess of the measured reserves) which will be economically available by application of fluid injection.

Inferred reserves: Reserves in addition to demonstrated reserves eventually to be added to known fields through extensions and revisions.

Subeconomic resources: Identified and undiscovered resources that are not presently recoverable because of technological and economic factors, but which may be recoverable in the future.

Undiscovered recoverable resources: Those economic resources, yet undiscovered, which are estimated to exist in favorable geologic settings.

Estimated oil reserves

In late 1975, Petro-Peru indicated that the measured oil reserves in the Selva productive area amounted to 546 million barrels. They also felt confident that a total of 204 million barrels could be added to the first figure [172].

By the end of 1977, Peru's measured oil reserves were estimated to be 752 million barrels, distributed as shown in Table 77 .

Table 77. Distribution of Peru's measured oil reserves, 1977[a]

Region	Millions of Barrels
Costa	206
Onshore	132
Offshore	74
Selva	550
Total	756

[a]SOURCE: [172].

The figure of 756 million barrels in 1977 should be decreased by the production during 1977, 1978, 1979, and 1980 to bring the estimation to the end of 1980.

Cumulative oil production for the period 1977-80 is 228.7 million barrels, which brings the measured reserves to 527.3. Table 78 summarizes the information by region.

Table 78. Distribution of Peru's measured oil reserves in 1980

	Reserves in 1977	Cumulative Production 1977-80	New Level of Reserves 1980
		(million barrels)	
Costa	206	91.8	114.2
Onshore	132	50.4	81.6
Offshore	74	41.4	32.6
Selva	550	136.9	413.1
Total	756	228.7	527.3

In addition to measured oil reserves, indicated oil reserves of about 500 million barrels were identified. These indicated reserves are expected to be produced by secondary recovery methods from the onshore part of the Talara basin. The oil companies estimated that about 50% of the total amount extracted to date could be recovered by the secondary methods. Since the cumulative production of the Talara basin is around one billion barrels, the indicated reserves could be around 500 million barrels.

Inferred oil reserves, as estimated by the U.S. Geological Survey, amount to 30 million barrels of heavy crude. Therefore, in Table 79 are presented the final count of reserves.

Table 79. Estimated oil reserves of Peru, 1980

	Millions of Barrels
Measured Oil Reserves	
Costa	114.2
Onshore	81.6
Offshore	32.6
Selva	413.1
Indicated Reserves	
Talara basin	500.0
Inferred Reserves	30.0
Total	1,057.3

Undiscovered oil resources

A more difficult problem, that in which speculation plays a major role, will be addressed in this section. Travis et al. [157] have made the estimations found in Table 80 concerning undiscovered oil reserves in Peru.

Table 80. Estimation of Peru's undiscovered oil reserves in coastal regions

Basin	Billions of Barrels
Progreso	0.35
Talara	1.00
Sechura	0.10
Salaverry	0.50
Pisco	0.10
Moquegua	none
Total	2.05

The estimates in Table 80 do not include potential reserves from the Lima and Arequipa basins--both deep water basins.

Zuniga et al. [197] estimated the undiscovered resources in the Amazon basin as shown in Table 81.

Table 81. Estimation of Peru's undiscovered oil resources in the Amazon basins

	Billions of Barrels
Maranon	20
Ucayali	5-10
Madre de Dios	6-12
Total	31-42

These two studies will put Peru's potential between 33-44 billion barrels.

The U.S. Geological Survey in the study of Peru's oil potential [172] placed the undiscovered oil resources in a much more modest perspective, based on consideration of feasibility of exploitation in the near future. Table 82 presents these calculations.

Table 82. 1976 U.S. Geological Survey estimates of Peru's undiscovered oil resources[a,b]

Basin	Millions of Barrels
Progreso	150-350
Talara (onshore)	50-500
Talara (offshore)	150-200
Sechura	50-100
Salaverry	150-500
Pisco	20-100
Maranon	880
Ucayali	330
Madre de Dios	280
Total	2,060-3,240

[a]SOURCE: [172].

[b]Does not include potential resources that may exist in stratigraphic traps in the Amazon basins, nor in water depths beyond the continental shelf.

As can be seen in the table, the estimates place Peru's potential between two-three billion barrels which at present rates of production would last for about 26 years.

Oil production in the future

Estimation of oil production in future years requires assumptions about the level of reserves and about the rate of discoveries of new oil fields.

The level of measured reserves, which has been placed at 1.057 billion barrels, has already been discussed. In crude terms, this level of reserves could provide for 14 years of production at the rate of production of 1980. This is a crude estimate because each oil pool should be treated separately. In Table 83, estimates through 1985 prepared by the U.S. Geological Survey are presented.

Table 83. Estimates of oil production, 1981-1985[a]

	1981	1982	1983	1984	1985	Total
	(million barrels per year)					
Amazon Region	45.3	38.2	36.4	32.6	26.9	179.4
Talara Onshore (primary)	10.3	9.8	9.3	8.8	8.4	46.6
Talara Onshore (secondary)	12.0	12.0	12.0	11.4	10.0	57.4
La Brea y Parinas (secondary)	--	--	3.0	9.8	12.0	24.8
Talara Offshore	10.4	10.2	9.9	9.5	9.2	49.2
Total	78.0	70.2	70.6	72.1	66.5	357.4

[a]SOURCE: [172].

Production figures up to 1985 should not change much because new discoveries will not affect them. All exploration efforts were stopped around 1976. New contracts are in the process of being signed [85], but in any case, U.S. Geological Survey estimates that it would take around

10 years to complete the process of exploration to exploitation. So it should be expected that oil production from 1985 to 1990 will fall around 10% per year (estimates of the U.S. Geological Survey) which is illustrated in Table 84.

Table 84. Estimated total oil production of Peru, 1986-1995[a]

	Yearly Rate	Daily Rate
	(million barrels)	(thousand barrels)
1986	59.9	164
1987	53.9	148
1988	48.8	134
1989	43.6	119
1990	39.3	108
1991	35.3	97
1992	31.8	87
1993	28.6	78
1994	25.8	71
1995	23.2	64
Total	390.2	

[a]SOURCE: Estimations based on [172].

Beginning in 1995, it is expected that a good part of the undiscovered oil resources will be moved to the measured reserves category. The U.S. Geological Survey, using a ratio of 10:1 for yearly production rates versus measured reserves, estimates a production of 116 million barrels in the year 2000 (Table 85).

Table 85. Estimates of total oil production, 1996-2000

	Yearly Rate	Daily Rate
	(million barrels)	(thousand barrels)
1996	32.0	88
1997	44.2	121
1998	60.9	167
1999	84.1	231
2000	116.0	318

Commercial Resources--Natural Gas

Natural gas is much less important to the energy production and consumption of Peru. In 1976, it accounted for 6% of all commercial resources consumed and about 4% of the total estimated energy consumption.

Table 86. Production of natural gas, 1966-1976[a]

	Onshore	Offshore	Total
	(billions of cubic feet)		
1966	64.3	2.1	66.4
1968	65.7	10.1	75.8
1970	51.3	23.5	74.8
1972	41.4	23.0	64.4
1974	36.1	33.8	69.9
1976	34.5	32.1	71.6

[a]SOURCE: [172].

In Table 86, the production of natural gas from 1966 to 1976 is presented. These figures represent total estimated output. Most of the output is not used as energy inputs or in any other way. Most of it is flared.

Natural gas in Peru is produced chiefly from the Talara basin. Petro-Peru estimates the reserves to be one trillion cubic feet. At the present production rates, the estimated reserve would be used up in about 15 years.

In the Amazon region, the oil fields of the Marañon basin have a water drive, and gas production is small, being used as fuel, lift, and the remaining is flared [24].

In the Ucayali basin a gas field was discovered, but its reserves are considered subeconomic; their volume is estimated at 317.8 billion cubic feet [172].

In the Madre de Dios basin, there have not been enough exploration drilling to ascertain its oil and gas potential.

In Table 87, we compare the production and consumption of natural gas. Since only around 40% of the natural gas produced is consumed, there is still room for improvement. Nevertheless, the output of gas is estimated to decrease at a rate of 5% annually because the procedures of secondary recovery, to be utilized in the Talara oil fields, entail a loss in the volume of gas constrained in the reservoir. It has been estimated that the gas field of the Ucayali basin could start production in 1985, making up for the loss of the Talara fields.

Since the information on gas reserves in Peru is rather weak, the U.S. Geological Survey concluded that it is safe to presume a level of production in 2000 of around 55 billion cubic feet.

Table 87. Natural gas production and consumption, 1966-1976[a]

	Production	Consumption	Not Used	Percentage of Nonutilization
	(billion cubic feet)			
1966	66.4	16.9	49.5	75
1968	75.8	17.4	58.4	77
1970	74.8	17.4	57.4	77
1972	64.4	18.0	46.4	72
1974	69.9	19.1	50.8	73
1976	71.6	26.2	45.4	63

[a]SOURCE: [172, 190].

Commercial Resources--Coal

Coal is even less important in the energy production and consumption pattern of Peru. It accounts for about 2% of the total energy utilized and about 3% of commercial resources.

All of the coal consumed in Peru is used for nonenergy purposes, mainly coking for the steel mill. Peru imports coke from Japan and bituminous coal from the United States.

None of Peru's coal resources is currently being exploited. According to official statistics, coal was last mined in 1973. It is believed that because of oil prices in the past, it has been more attractive to use oil instead of coal.

From the point of view of resources, coal deposits are reported in 18 of Peru's 24 departments.

The U.S. Geological Survey has studied all the information existing on coal deposits, and concluded that four coal fields appear to hold potential as possible sources of fuel for producing energy and/or sources of coking coal [172]. They are identified in Figure 12. The findings of the U.S. Geological Survey are summarized in Table 88.

Table 88. Peru's coal reserves[a]

Field	Measured	Indicated	Inferred	Total
		(million metric tons)		
Alto Chicama	25.2	34.5	211.1	270.8
Santa Valley	0.6	3.4	2.7	6.7
Oyon	67.7	---	82.4	150.1
Jatunhausi	1.2	---	60.0	61.2
Total	94.7	37.9	356.2	488.8

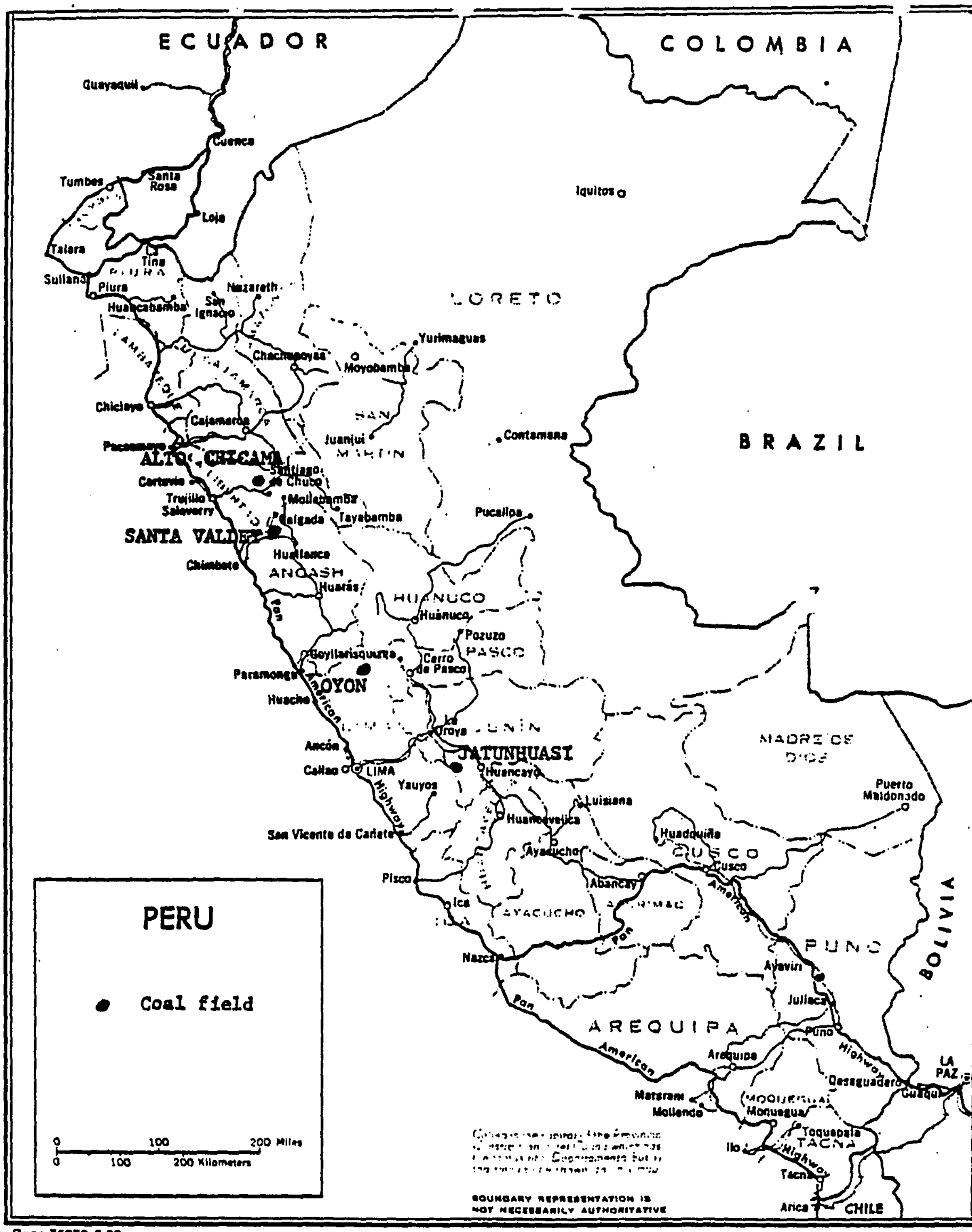
[a]SOURCE: [172].

Considering that Peru imports around 250,000 metric tons of coal every year, the country could very well cover the local demand.

The problem seems to be the high cost of mining coal in Peru. The exploitation itself seems to be costly, which associated with the transportation costs makes coal economically unattractive as a source of energy. As for nonenergy purposes, there are other problems associated with coal qualities. Not all coal can be used for coking processes [100].

Since there is no significant coal production at the moment, it is difficult to infer a rate of production.

Figure 12. Peruvian coal fields that have potential for development [172]



Base 76870 3-70

The U.S. Geological Survey [172] had placed the requirements of coal in Peru for the year 2000 at about 2.5 to 3.0 million tons. As it has been indicated previously, this coal could be provided by local sources, but competitive prices will in any case prevent coal exports. The increase use of coal for electricity generation cannot be forecasted at this point but it is a real possibility.

The Peruvian Electrical Corporation has plans for the installation of a plant with an initial capacity of 200 MW (megawatts) to be increased to 480 MW. It will be located near the coal fields of Alto Chicama. It is a rather small project that will not affect the general picture of coal utilization, but may be the starting point of future expansion [91].

Commercial Resources--Electricity

Peru is endowed with vast hydropower resources which are utilized in small quantities. In Table 89, the total installed capacity for electrical generation as of 1979 is presented.

As observed from the table close to 60% of the capacity installed is hydropower. The thermal generation is associated with the electrical needs of the big mining companies who produced their own electricity.

The production of electricity is presented in Table 90. In the production of electricity, hydropower provides close to 72% of requirements which tends to indicate that thermal units are less efficient or under-utilized.

The regional distribution presented in Table 91 indicates that the major consuming market is in the central region, where Lima, the capital, is by far the biggest consumer.

Table 89. Electricity generation installed capacity, 1968-1979[a]

	Hydropower		Thermal		Total
	MW	Percent	MW	Percent	MW
1968	915.1	57.0	691.4	43.0	1,606.5
1969	918.6	55.6	733.8	44.4	1,652.4
1970	922.6	55.0	754.5	45.0	1,677.1
1971	989.2	55.1	807.5	44.9	1,786.1
1972	1,056.8	54.7	873.2	45.3	1,930.0
1973	1,278.3	59.4	875.6	40.5	2,153.9
1974	1,388.0	61.0	876.8	39.0	2,265.7
1975	1,397.0	59.0	961.5	41.0	2,358.8
1976	1,405.8	55.9	1,110.0	44.1	2,115.8
1977	1,414.8	55.5	1,134.6	44.5	2,549.4
1978	1,414.8	55.0	1,161.4	45.0	2,576.2
1979	1,641.3	58.1	1,184.2	41.9	2,825.5

[a]SOURCE: [115].

Table 90. Production of electricity by sources, 1968-1979[a]

	Hydropower		Thermal		Total
	Quantity	Percent	Quantity	Percent	
	(gigawatts/hour)				
1968	3,487.0	69.0	1,551.3	31.0	5,038.3
1969	3,701.5	70.0	1,506.7	30.0	5,288.2
1970	3,820.6	69.1	1,708.2	30.9	5,528.8
1971	4,282.9	72.0	1,666.0	28.0	5,948.2
1972	4,536.3	72.1	1,753.0	27.9	6,289.2
1973	4,769.1	71.7	1,886.2	28.3	6,655.3
1974	5,220.4	71.7	2,054.8	28.3	7,275.2
1975	5,470.0	73.0	2,016.2	27.0	7,486.2
1976	5,797.7	73.3	2,113.4	26.7	7,911.1
1977	6,098.0	71.3	2,459.1	28.7	8,557.5
1978	6,354.0	71.8	2,501.0	28.2	8,855.0
1979	6,764.1	71.5	2,699.7	28.5	9,463.8

[a]SOURCE: [115].

Table 91. Percentage regional distribution of installed capacity[a]

	Percent
North Region	1.0
Central Region	89.0
South Region	10.0
	100.0

[a]SOURCE: [115].

Conceptually speaking, the hydropower potential of a country is measured by the total quantity of water descending a vertical distance. Not all of this potential may be realized ever, because of competitive uses of water and geographical problems, but it is a starting point; in a way it is equivalent to the concept of reserves in the case of mineral fuels.

Water supply

Water supply is the starting point for measuring hydropower potential. Mean annual rainfall in Peru ranges from near zero in the coastal desert area to as high as 3,400 mm (134 inches) in the high Selva region. The coastal region is dependent on streamflow in rivers draining the western slopes of the Andes.

The total annual surface water supply averages 1.5 x 10^{12} cubic meters [172]. The surface water supplies are divided between the Pacific, Atlantic and Titicaca watersheds as shown in Table 92.

Table 92. Surface water supply[a]

Watershed	Total	Actual Usable Volume
	(millions of cubic meters)	
Pacific	33,972	20,577
Atlantic	1,437,001	29,732
Titicaca	23,705	706
Total	1,494,678	51,011

[a]SOURCE: [172].

Over 12,000 natural lakes are scattered throughout the country, which could provide additional hydropower development.

Potential hydropower

With the assistance of the Federal Republic of Germany [101], a study was completed in 1979 that places the hydroelectrical theoretical potential at 194,129 MW divided as shown in Table 93.

Table 93. Theoretical hydropower potential

Watershed	Megawatts	Percentage
Pacific	29,955	15.4
Atlantic	163,617	84.3
Titicaca	557	0.3
Total	194,129	100.0

From these figures, the experts concluded that the economically feasible part is 58,346 MW, which is about 30% of the grand total. According to Table 89, the installed capacity is 1,641.3; i.e., only 3%.

There is plenty of room for development, but most of the potential is located east of the Andes, distant from the consuming areas.

Expansion of existing capacity

In this section, official information [91] in regard to programs for expansion of electricity generation by means of hydropower will be presented so a projected installed capacity in the year 2000 may be derived (Table 94).

Table 94. Expansion of hydroelectricity capacity[a]

Central-Station	Additional MW
Mantaro--second phase	456
Mantaro--third phase	217
Canon del Pato	50
Charcani V	135
Carhuaquero	75
Olmos I	150
Olmos II	150
Chamimochic	247
Poechos	7.6
Curumuy	9.0
Culqui	18
Macchu-Picchu	69.9
Sheque	600
Yuscay	2
Lluta 1	137
Lluta 2	137
El Chorro	126
Total	2,586.5

[a]SOURCE: [91].

If all of these additions are carried out, the total installed capacity of the year 2000 would be 4,227.8 MW or 7.8% of the feasible potential. Since the investment required to build these hydroelectric plants is valued at several billion dollars, there is no reason to believe that in the 20-year period to the year 2000 Peru would be able to speed up considerably its investment in this area.

By the year 2000, hydro electric plants in Peru would be able to deliver 19,659.1 GWh of electricity, an increase of over 150% of the 1979 installed capacity. This calculation is made using a capacity factor of 0.53.

Non-Hydropower electricity

In 1979 about 42% of the installed capacity of the generation of electricity was thermal. The fuel use is 90% from fossil fuels, as shown in Table 95. There are plans for the construction of a plant based on coal, but it is a very small project (Alto Chicama 200 MW to final 480 MW) and there are no projects to increase the use of coal.

Table 95. Generation of electricity by sources other than water power[a]

Source	1965	1970	1976
	(tons of oil equivalent)		
Oil	148,286	174,857	196,095
Oil by-products	169,238	227,619	257,143
Natural gas	8,000	8,667	72,762
Agricultural waste	52,667	70,762	80,190
Total	378,190	481,905	606,190

[a]SOURCE: [101].

In 1980, 340.3 MW were added to the installed capacity of thermal generation, reaching a level of 1,243.9 MW. Although it is expected that the hydropower will dominate the expansion of the installed capacity for electricity generation, thermal generation will continue to grow but at a moderate rate because of high cost of fuel.

Plans for increasing the capacity for thermal generation indicate that about 108.4 MW will be added in the next two years [91].

From Table 96, it is observed that additions have averaged 47.2 MW a year. Assuming modest additions of 30 MW per year on the average, total installed capacity could reach 1,892.3 MW by the year 2000 (Table 97).

Table 96. Additions to thermal generation[a]

Year	MW	Rate of Change
1969	42.4	6.1
1970	20.7	2.8
1971	53.0	7.0
1972	65.7	8.1
1973	2.4	0.3
1974	1.2	0.1
1975	84.7	9.7
1976	148.5	15.4
1977	24.6	2.2
1978	26.8	2.4
1979	22.8	2.0
1980	59.7	5.0
Total	108.4	8.7

[a]SOURCE: [91].

Table 97. Projected installed capacity in year 2000[a] capacity)

	MW	Percent	Conversion (hours at full capacity)	Possible Generation GWh	Percent
Hydropower	4,227.8	69	4,650	19,659.1	82
Thermal	1,892.3	31	2,300	4,352.1	18

[a]SOURCE: [172].

Noncommercial Resources

The use of biomass for energy purposes is still extensive in Peru, mainly in the rural areas. The use of such resources has been estimated to be around 161.7 x 10^{12} BTU in 1976. This represents about one third of all energy consumed in that year. Table 98 summarizes current bio-fuel utilization in Peru.

In the following four subsections, each energy source--agricultural wastes, animal wastes, forest sources, and phytomass--and its potential will be explored in more detail.

Agricultural crops waste

In order to examine the potential of certain agricultural wastes, Table 99 shows a condensation of the information on production, yield per hectare and estimation of wastes and their energy value.

In Peru, approximately 2.6 million hectares out of a total area of 128.5 million hectares are cultivated. The three geographical regions have differences in crops and crop yields. Tables 100, 101 and 102 present the information for each region for 1976.

Table 98. Biofuel usage in Peru, 1976[a]

Biomass Resource	Conversion Technology	Biofuel Type	Energy Produced	Uses
Wood	Direct combustion	Firewood	Process Heat	Cooking, Heating
Wood	Pyrolysis	Charcoal	Process Heat	Cooking, Heating
Sugarcane	Direct combustion	Bagasse	Process Heat, Steam Electricity	Industrial, Residential
Sugarcane	Fermentation	Molasses Bagasse	Alcohol	Industrial
Animal waste	Direct combustion	Dung	Process Heat	Cooking, Heating
Agricultural residues	Direct combustion	Cotton gin waste	Process Heat	Industrial

[a]SOURCE: [172].

The Costa region contains 27% of the total cultivated area in Peru. Virtually all agriculture on the coast is irrigated. The biofuel potential, as estimated from crops listed in Table 100, is approximately 50.26 x 10^{12} BTU. Bagasse, the residue of sugarcane is the most important agricultural waste in the coast. Practically all of it goes into the sugar mills as an energy input.

About half of the cultivated land is in the Sierra. The biofuel potential is placed at 14.93 x 10^{12} BTU from the crops listed in Table 101. Maize is the most important crop in terms of residue production.

Table 99. Production, residue, and energy estimates of crops grown in Peru

Commodity	1976 Production	1976[a] Yield	Annual Residue[b] Production Estimate	Estimated Residue[b] Energy Value
	(metric tons)	(metric tons per hectare)	(metric tons)	(10^{12} BTU)
Rice	570,415	4.28	855,623	10.800
Oats	741	0.83	1,482	0.018
Barley	149,517	0.92	224,276	2.800
Milo	465	0.85	465	0.010
Maize	725,659	1.88	725,659	9.200
Quinua	8,676	0.58	21,690	0.270
Sorghum	45,945	2.12	68,918	0.870
Wheat	127,497	0.95	191,246	2.400
Soybean	2,869	1.42	4,303	0.060
Plantains	711,065	11.45	106,660	1.340
Camote	162,547	11.51	24,382	0.300
Potatoes	1,167,000	6.59	250,050	3.080
Yuca	403,486	11.23	402,486	4.950
Cotton	164,511	1.67	164,511	2.090
Peanut	3,647	1.26	3,647	0.047
Sugarcane (for sugar) Sugarcane (for alcohol) Sugarcane (for molasses)	9,209,762	155.08	3,223,418	32.830
Coconut	1,311	7.95	1,967	0.028
Aguaje	5,460	21.00	5,460	0.066

[a]SOURCE: [92].
[b]SOURCE: [172].

Table 100. Production, residue and energy estimates of crops grown in the Costa region of Peru

Commodity	1976[a] Production	1976[a] Yield	Annual Residue[b] Production Estimate	Estimated Residue[b] Energy Value
	(metric tons)	(metric tons/ hectare)	(metric tons)	(10^{12} BTU)
Rice	426,431	4.88	639,647	8.120
Barley	2,570	2.37	3,855	0.047
Maize	417,444	3.45	417,444	5.290
Sorghum	45,145	3.16	67,718	0.860
Wheat	3,824	2.04	5,736	0.075
Soybean	2,301	1.42	3,452	0.047
Plantain	113,020	12.84	16,953	0.208
Camote	139,313	13.34	20,897	0.255
Potatoes	156,948	13.85	23,542	0.294
Yuca	50,392	10.67	50,392	0.626
Cotton	162,869	1.69	162,869	0.009
Peanut	967	2.54	967	
Sugarcane (for sugar) Sugarcane (for alcohol) Sugarcane (for molasses)	8,870,850	158.83	3,104,798	32.370

[a]SOURCE: [92].

[b]SOURCE: [172].

Table 101. Production, residue and energy estimates of crops grown in the Sierra region of Peru

Commodity	1976[a] Production	1976[a] Yield	Annual Residue Production Estimate	Estimated Residue[b] Energy Value
	(metric tons)	(metric tons/hectare)	(metric tons)	(10^{12} BTU)
Rice	1,593	4.55	2,390	0.028
Oats	741	0.82	1,482	0.018
Barley	146,947	0.91	220,421	2.796
Milo	465	0.85	465	0.009
Maize	236,915	1.07	236,915	3.014
Quinua	8,676	0.58	21,690	2.758
Wheat	123,673	0.94	185,510	2.360
Plantains	45,219	9.41	6,782	0.085
Camote	17,149	5.80	2,572	0.028
Potatoes	1,499,792	6.26	224,969	2.777
Yuca	37,749	7.43	37,749	0.464
Cotton	126	0.97	126	0.000
Sugarcane (for sugar)				
Sugarcane (for alcohol)	162,110	74.89	56,739	0.597
Sugarcane (for molasses)				

[a]SOURCE: [92].

[b]SOURCE: [172].

Table 102. Production, residue and energy estimates of crops grown in the Selva region of Peru

Commodity	1976[a] Production	1976[a] Yield	Annual Residue[b] Production Estimate	Estimated Residue[b] Energy Value
	(metric tons)	(metric tons/hectare)	(metric tons)	(10^{12} BTU)
Rice	142,391	3.13	213,587	2.711
Maize	71,300	1.66	71,300	0.909
Sorghum	800	2.00	1,200	0.018
Soybean	568	1.40	852	0.009
Plantain	552,806	11.4	82,921	
Camote	6,085	8.34	913	0.009
Potatoes	10,260	5.70	1,539	0.018
Yuca	314,345	12.07	314,345	0.085
Cotton	1,516	0.75	1,516	0.018
Peanut	2,680	1.07	2,680	0.038
Sugarcane (for alcohol) Sugarcane (for molasses)	156,380	51.78	54,734	0.568
Coconut	1,311	7.95	1,967	0.028
Aguaje	5,460	21.00	5,460	0.066

[a]SOURCE: [92].

[b]SOURCE: [172].

The Selva contains 23% of the cultivated land. The total biofuel energy, which could potentially be contained in crop residues of the Selva is 4.58 x 10^{12} BTU. Rice is the most important crop for residue utilization purposes.

In summary, the three regions of Peru produce a potential 71.16 x 10^{12} BTU of energy from crop residues.

Animal waste

The use of animal dung is very extensive in the Sierra region, above the tree level, i.e., in the parts where altitude prevents growing most types of vegetation. In Table 103, data on the 1976 livestock population is presented. The total count is 66 x 10^6 heads, which could produce 11.635 million tons of residue with an energy value of 161.03 x 10^{12} BTU. This is only a potential figure, i.e., if all residue was to be used as energy. In reality, of the total residue collected most of it goes into soil fertilization.

Forest sources

In Peru, most of the forests are natural, but plantations are becoming increasingly more abundant. Unfortunately, most of the forest growth occurs remote to the major population centers. The total land in forest is 84.5 million hectares [172]; of this total 75.5 million hectares are in the Selva, which accounts for 89% of the total.

The statistics prepared by the government, shown in Table 104, indicate that only 1% of the land suitable for planting is utilized in forestry.

Table 103. Residue production and energy potential from livestock in Peru

Animal/Region	1976 Population[b]	Annual Residue[a] Production Estimate	Estimated Residue[a] Energy Value
	(1,000 Head)	(1,000 metric tons)	(10^{12} BTU)
Alpacas			
Sierra	2,445	318	4.40
Poultry			
Costa	28,374	32	0.44
Sierra	6,671	7	0.09
Selva	2,637	3	0.05
Goats			
Costa	728	80	1.11
Sierra	1,278	140	1.93
Selva	16	2	0.03
Horses			
Costa	123	185	2.56
Sierra	1,138	1,707	23.62
Selva	66	99	1.37
Llamas			
Sierra	1,361	23	0.32
Sheep			
Costa	241	26	0.36
Sierra	15,025	1,653	22.87
Selva	27	3	0.05
Pigs			
Costa	587	65	0.90
Sierra	1,309	144	1.99
Selva	246	27	0.40
Cattle			
Costa	509	865	11.97
Sierra	3,327	5,656	78.27
Selva	353	600	8.30

[a]SOURCE: [172].

[b]SOURCE: [92].

Table 104. Designation of land use in Peru by region[a]

	Natural Forests	Plantations	Land Suitable for Planting	Total
		(hectares)		
Costa	950,000	6,683	493,317	1,450,000
Sierra	50,000	97,672	7,402,328	7,550,000
Selva	73,000,000	1,785	2,498,215	75,500,000
Total	74,000,000	106,140	10,393,860	84,500,000

[a]SOURCE: [123].

Current use of wood and its products in Peru is mostly for fuel (firewood and charcoal) to serve the domestic energy needs of rural communities. The proportion of wood used for fiber as feedstock is small. This is shown in Table 105.

Table 105. Production of fuel wood and forest products, 1975

Product Category	Production[a]	Estimated Energy Value[b]
	(10^3 m^3)	(10^{12} BTU)
Firewood	2,580	23.0
Charcoal	19	0.2
Forest industry products	578	4.9
Forest industry wastes	503	4.3
Pulpwood	23	0.2
Other	370	3.1
Total	4,073	35.7

[a]SOURCE: [123].
[b]SOURCE: [172].

It should be noted here that there are disagreements in figures relating to wood production and consumption. In Table 105, the production of firewood is estimated at a caloric content of 23 x 10^{12} BTU, while the consumption for 1976 has been estimated at 130.8 x 10^{12} BTU, which at the value of 18 x 10^6 BTU per ton, gives a total use of 7.3 million tons. This figure is three times the estimates of the government for production.

Since firewood is exclusively consumed by the rural population, the estimated consumption figure yields a per capita of 1.29 ton or in gross caloric values 23.230 x 10^6 BTU per capita per year.

Nevertheless, since the efficiency of firewood is only about 10% [172], the net consumption per capita is only about 2.3 x 10^6 BTU.

A worldwide study [11] estimates the per capita use in rural areas at 400 kilograms of coal equivalent. This figure is equivalent to 10.9 x 10^6 BTU per capita per year, which is about five times the estimates for Peru in net tons.

This only points out the many problems because of lack of data for an interpretation and analysis of the current situation and perspectives.

Phytomass potential

The forest resources in Peru are immense and will remain so even if exploitive forestry should continue. But this is a look at the national level which is adequate for the forestry industry. But the availability of firewood and charcoal depends on local supply since cost of transportation will render it too costly.

Local plantings could be made in the Costa primarily for fuel wood and rural use, but expanding forests in this area shows little promise. Climatic conditions are unsuitable except in a small area in the North [172].

In the Sierra, there is considerable opportunity to expand the forest resource. Current estimates predict that 10 million hectares could be forested in this region. Of course, forestry must not be looked at solely in the energy problem. The expansion of forests should address a number of questions and may even help the development of industry. According to research carried out in recent years, the eucalyptus (native to Australia) is a prime candidate for planting [172].

Each hectare of Sierra planted to trees will grow from 10-20 cubic meters per hectare per year during an 18-year growth period. At this rate 90 to 180 x 10^6 BTU of energy is fixed in merchantable wood (assuming 500 kg/m^3 and 18 x 10^6 BTU per ton of wood).

The Selva possesses about 8.7 million hectares. Currently only 2.7% of the forest is exploited with only an average 1 m^3/ha harvested. The harvests, however, only target certain prized species. Amazonian forests grow from 10 to 30 m^3/ha/year. If 40 million hectares were deemed accessible for harvest, then 2,700 to 10,800 x 10^{12} BTU would be produced annually as commercial wood without reducing growing stock. Half of this would be mill waste if processed for forest products and another similar quantity would be potentially available as noncommercial phytomass at the harvesting site [26].

Other Resources

In this section, a brief discussion of other types of energy resources that have not been used in Peru, but for which there are possibilities of development, will be included.

Geothermal energy

Also known as earth heat, geothermal energy results from the radioactive decay of rocks. As with any other type of resources, certain conditions must be met before it is economically feasible to exploit the resource. Geothermal energy is not important as an energy resource in the world today but its exploitation is older than some of our present forms. The first power station was built in Laudarello, Italy in 1904 [48].

In Peru, as in other countries, evidence of resources are shown by the emergence of warm and boiling springs in many parts of the country. The U.S. Geological Survey and the U.S. Bureau of Mines have developed a concept to classify geothermal resources. The geothermal energy resource base is all the heat above 15°C to a depth of 10 km, the greatest depth from which thermal energy is likely to be economically extracted in the foreseeable future [172].

Experts [172] have concluded that because thermal gradients and heat flow are poorly known throughout Peru, data are insufficient to estimate whether the geothermal resource is large or small. But geothermal regions can be inferred from information on hot springs. Figure 13 shows the geothermal regions so inferred.

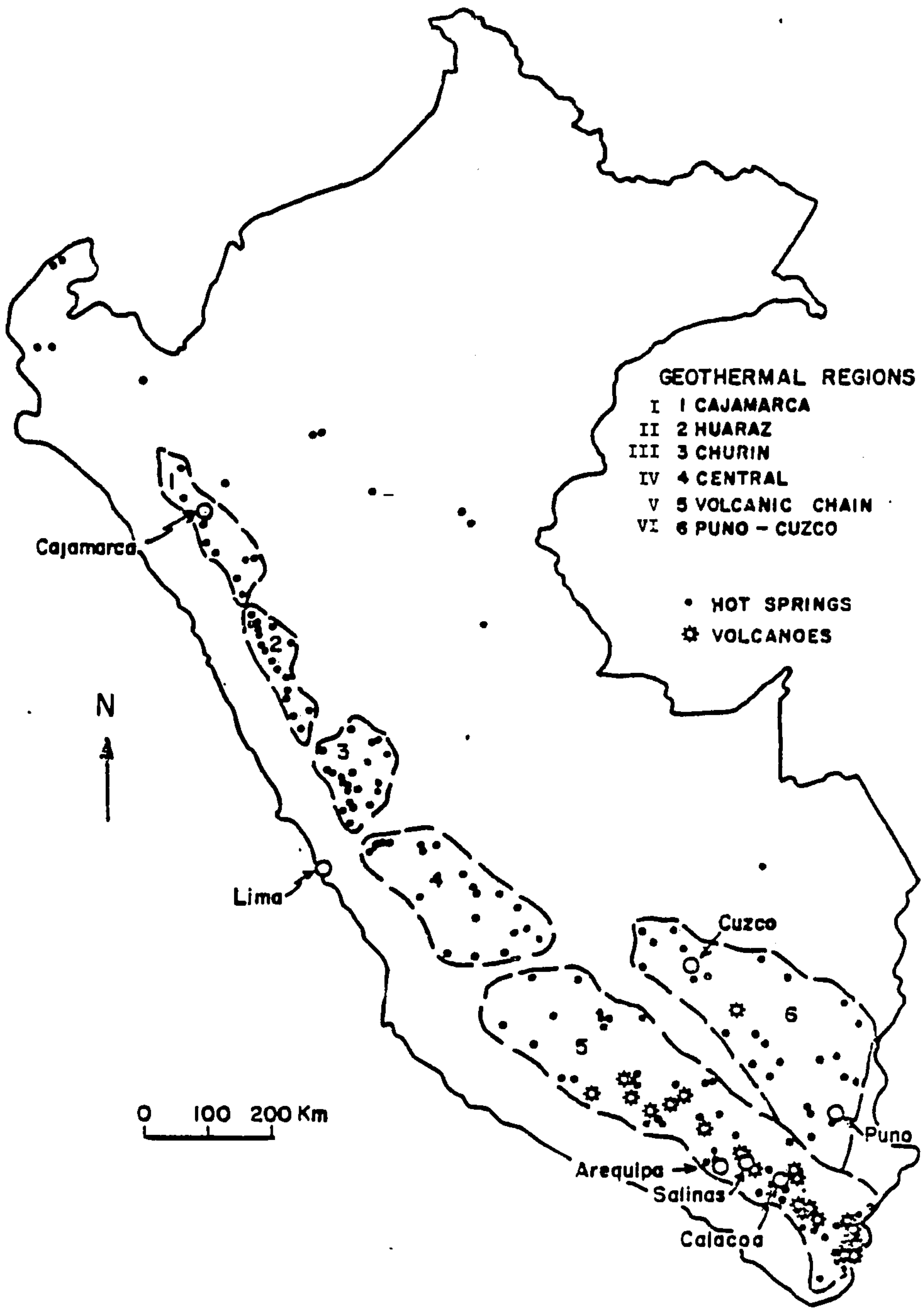


Figure 13. Distribution of volcanoes and hot springs in Peru [172]

In order to utilize geothermal energy economically for the production of electricity, minimum underground temperatures of about 170°C to 200°C are required at depths less than three kilometers. Furthermore, hot water or steam must be found in permeable zones in the hot rock because the thermal energy must be transferred to the surface by withdrawing that water or steam [172]. Table 106 presents estimations which have been made for geothermal resources at temperatures greater than 180°C and under 180°C.

Table 106. Geothermal reserves[a]

Temperature	Economic Reserves		Subeconomic Reserves	
	MW	BTU	MW	BTU
Over 180°C				
Inferred	100	0.34×10^9	1,000	3.4×10^9
Speculative	2,000	6.80×10^9	20,000	68.2×10^9
Under 180°C				
Inferred	300	1.0×10^9	Large	---
Speculative	6,000	20.8×10^9	Large	---

[a]SOURCE: [172].

As can be seen from Table 106, the short-term possiblities are only 100 MW of electricity. This corresponds to the field of Calacoa where independent studies have been conducted [180]. All other estimations are speculative in nature.

In the study cited earlier [172], the conclusion is that, at the most, Peru could have 200 MW of energy derived from geothermal plants by the year 2000, provided exploration and reservoir evaluation efforts are conducted during the 1980s. The possible installed capacity would generate 930 MWh of electricity at a caloric value of 3.2×10^{12} BTU.

Nuclear energy

There are no nuclear plants in operation at this time in Peru; but a nuclear plan that calls for a research reactor of 10 MW of capacity, to be in operation by the end of 1982, and a nuclear power plant with a capacity of 450 MW to 600 MW to initiate construction in 1995, are included.

Although the existence of radioactive minerals in the country is not a prerequisite for power plants to be built; undoubtedly its existence could induce the government to speed up its nuclear program.

The search for uranium in Peru dates back to the early 1950s, but in general terms it has not covered a significant part of the territory. No economic deposits have been found yet, but it is believed that uranium exists in parts of the country in difficult areas [18]. Uranium exploration continues but on a very modest scale [172].

With the high cost of building nuclear plants, the lack of locally produced radioactive minerals, the time for construction, and the abundance of hydropower potential, it is safe to assume that Peru will not have electricity generated by nuclear plants to the year 2000.

Ocean thermal energy conversion

There is the possibility of producing electricity by using the temperature differential between surface and deep ocean waters. The technology is at a research stage. It is considered [172] that a differential of at least 20°C is needed for the conversion.

In the case of Peru, because of the Humboldt current, the differential is less than 15°C. On this basis, energy conversion from surface-subsurface temperature differential does not seem to be prospective for the foreseeable future in Peru.

Solar and wind

The most abundant resource on earth is solar energy. Although we usually think of solar energy as sunlight, the term includes many other resources. By heating the earth and its atmosphere the sun generates wind, waves, rainfall for rivers, and ocean temperature differences. The sun helps grow trees for firewood and plants that can be converted into alcohol.

In this case, we are interested in direct radiation and usable sunlight diffused by clouds, dust, and water power. Its utilization may be for direct conversion into energy as electricity, or in devices that substitute for others driven by conventional resources such as water heaters, etc.

In order to be economically feasible to exploit the resource in such manners, a certain amount of radiation must fall per day per year. The levels of radiation vary considerably within continents and within countries. Peru is no exception to the variability of solar availability. Very high insulation levels are predominant in some coastal and Sierra regions. Areas such as Piura and Arequipa receive about 2,500 KWh per m^2/year (800,000 BTU/ft^2/year). The Lima area gets 1,600 KWh per m^2 per year (500,000 BTU/ft^2/year). The Sierra region has an average of

1,900 KWh/m^2/year (600,000 BTU/ft^2/year) [172]. Therefore, the parts of the country with the greatest potential are rural.

The utilization of solar energy today involves a complex technology associated with high costs. It is very unlikely that an important program to install solar energy devices will be instituted in the rural areas of Peru, where energy needs are met by noncommercial means that doe not cause economic stress.

The utilization of eolian energy is one of the most traditional ways of using the free resources of earth. Today in Peru small wind-powered pumps can be found in windy coastal areas. Technological efforts have been directed towards obtaining electricity in significant quantities. The small wind power units are in the range of 1KW to 25 KW. Larger systems with rated outputs of 100 KW to 4 MW are under development [172]. In order to assess the potential for either large or small systems, detailed measurements must be taken. No such data exist for Peru at this time.

At any rate, it is considered that certain locations have good winds to support small and large systems [172]. But a comment should be made concerning the government's willingness to invest in technologies that will substitute for nonconventional sources, which are apparently in good supply.

CHAPTER V. PROSPECTS FOR ENERGY IN PERU

We started with the objective of searching for a methodology of energy consumption estimation that, having been applied and proven to be sound, could also be readily applicable to the developing countries of Latin America and the Carribbean, where the author has done previous work. The common denominator of these countries is the scarcity of data, and wherever available it is usually irregular in its periodicity, in its format, and sometimes definitional changes have been introduced in a set of new data without adjusting older statistics.

The energy modeling field is still in its infancy, facing tremendous model specification problems, price elasticities are in the core of the models making them less attractive for long-run forecasting; and they require sophisticated data in the form of time-series. Noneconometric approaches to energy consumption estimates are older. We have been able to identify quite a few efforts since the 1950s. They range from the simple projection of total energy consumption based on historical trends to the more detailed consideration of sector and subsector of energy demand.

We chose a methodology that has received wide attention in the literature of energy economics. It is a work admired for the amount of data that was able to be retrieved from diverse sources, producing the first time-series of energy production and consumption by sectors, and also by energy sources. But its fame comes from its predictive ability.

Using 1955 data, the study was completed in 1960 and made predictions to 1975. In spite of the oil embargo of 1973, it mapped the course of energy supply and demand with enough accuracy to be termed reliable.

The methodology had to be adapted to the characteristics of the country where it was to be applied. Our case study is Peru and we have to work with a lot less information than the original version dealt with in its U.S. application. However, we still feel that it is the best alternative open to us.

Energy Consumption

In Chapter III, the demand of energy by consuming sectors and sources was estimated. The results are presented in Table 107. Total energy consumption is expected to grow from 509.7 x 10^{12} BTU in 1976 to 897.0 x 10^{12} BTU in 2000. This represents an average annual rate of growth of 2.4%. The rates of growth of individual sources are presented in Figure 14.

We have prepared Figure 15 excluding noncommercial resources. We can observe that our predictions leave the pattern of consumption unchanged. Oil will still be the major source of energy. This is a logical conclusion since we have not been able to identify existing policies that will introduce changes in consumption patterns. If things are left unchanged, Peru's dependency on oil will be relatively the same but requiring increasing amounts of oil in absolute terms.

When all the resources and sectors are put together, as is done in Table 107, we note the relative importance of the Households/Commercial and Industry sectors. They are expected to use 74% of all energy.

Table 107. Projected energy consumption by sector and by fuels, 2000

	Oil	Coal	Gas	Biomass	Hydropower	Electricity	Total	Percent
Households/Commercial	72.3	--	--	194.9	---	72.2	339.4	37.8
Automobile	38.8	--	--	---	---	--	38.8	4.3
Transportation	183.7	--	--	---	---	--	183.7	20.5
Agriculture	10.2	--	--	---	---	1.3	11.5	1.3
Industry	157.5	18.8	27.5	---	---	119.8	323.6	36.1
Electricity	39.7	--	4.0	8.2	141.4	(193.3)	---	--
Total	502.2	18.8	31.5	203.1	141.4	--	897.0	--
Percent	56.0	2.0	3.5	22.6	15.9	--	---	100.0

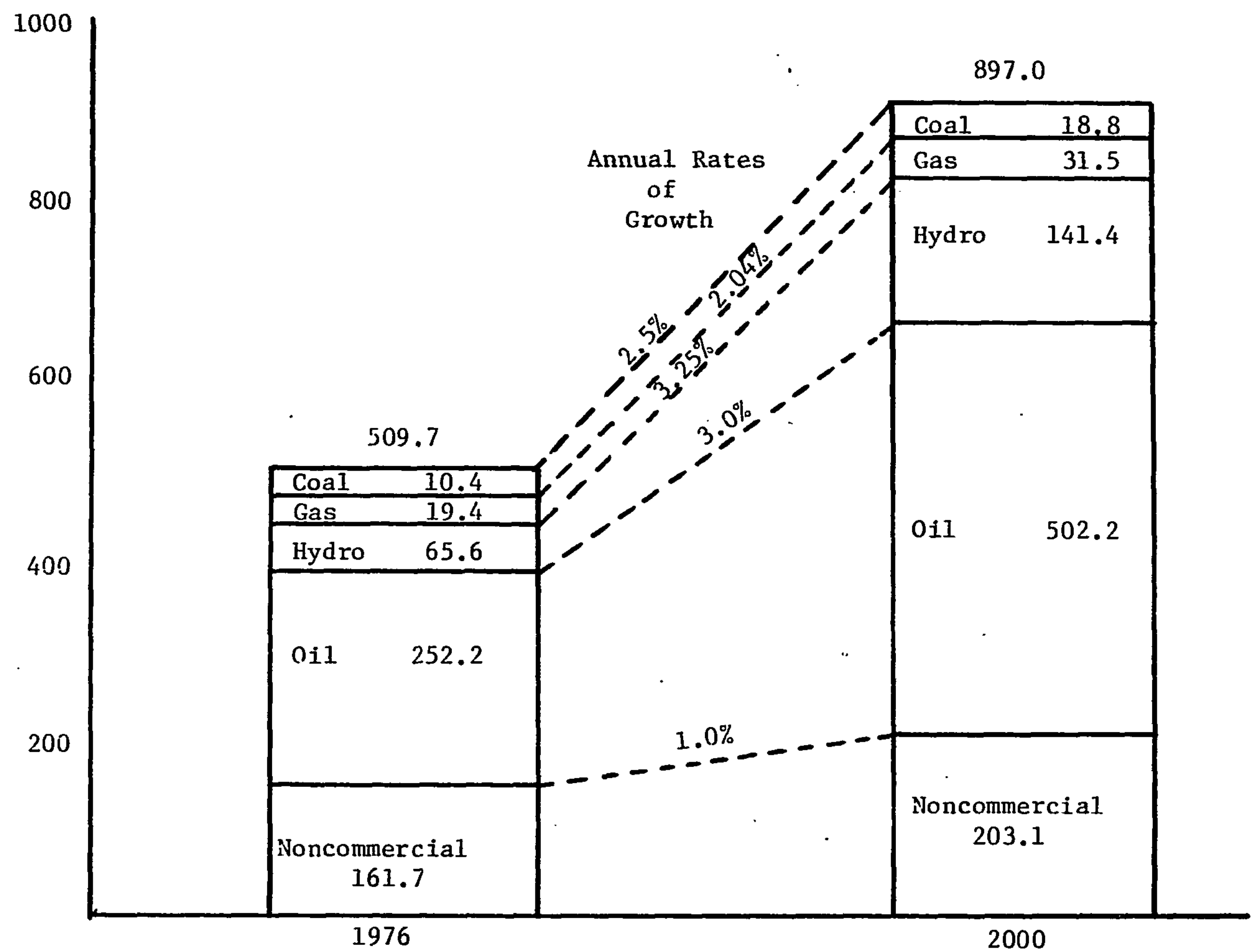
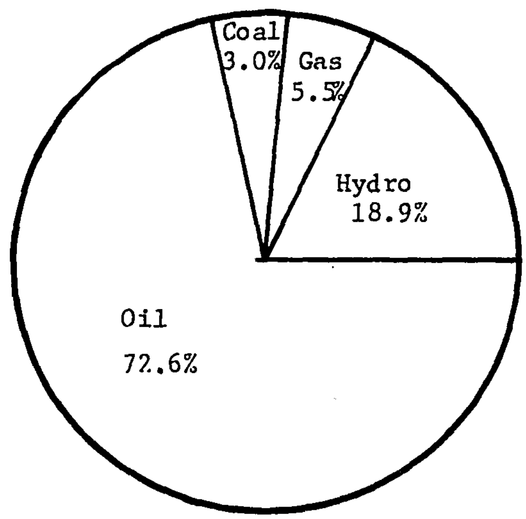
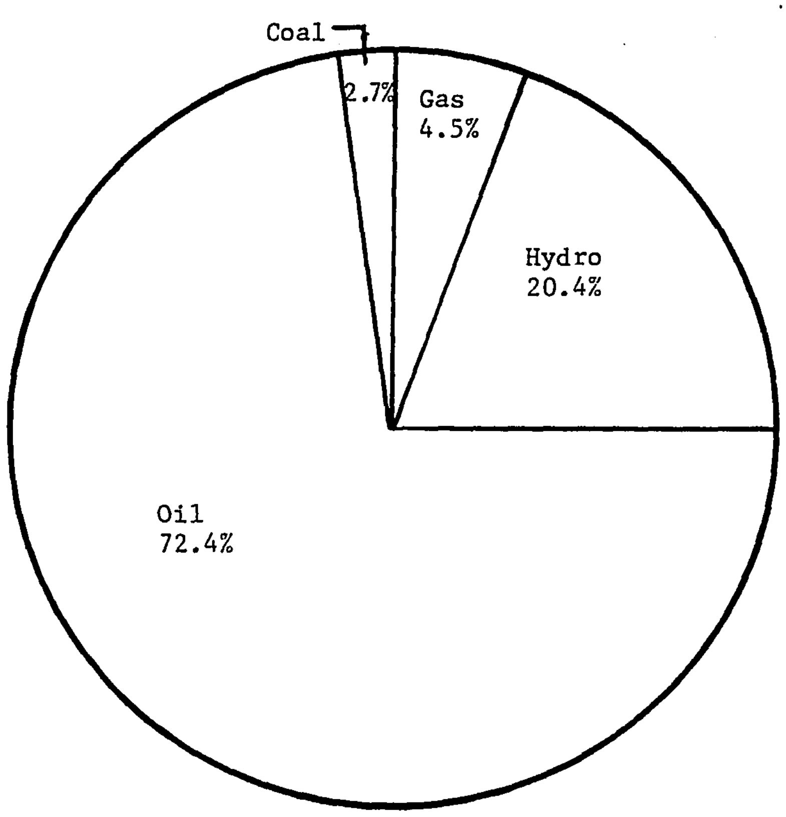


Figure 14. Total resource consumption by fuel, 1976 and 2000

Figure 15. Demand for energy, 1976 and 2000, commercial resources only


Coal
3.0%
Gas
5.5%
Hydro
18.9%
Oil
72.6%

1976


Coal
2.7%
Gas
4.5%
Hydro
20.4%
Oil
72.4%

2000

However, biomass resources tend to distort the view becasue of their inefficiency. In Figure 16, a comparison is made between 1976 and 2000 by consuming sectors based on commercial resources only. There it can be seen that the major consuming sectors are Transportation and Industry.

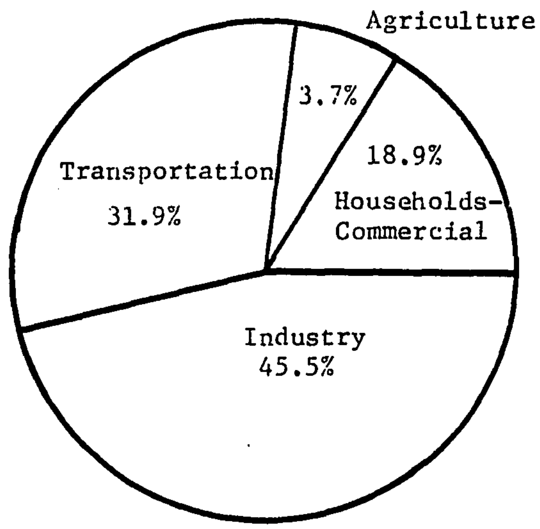
The composition of consumption in the transportation sector, including private transportation, is shown in Figure 8. The sector is dominated by truck and buses with 61.7% of the energy consumption.

In the industrial sector, more than half of the consumption goes to mining. There is not doubt that mining will continue to be a dynamic sector of the Peruvian economy in years to come.

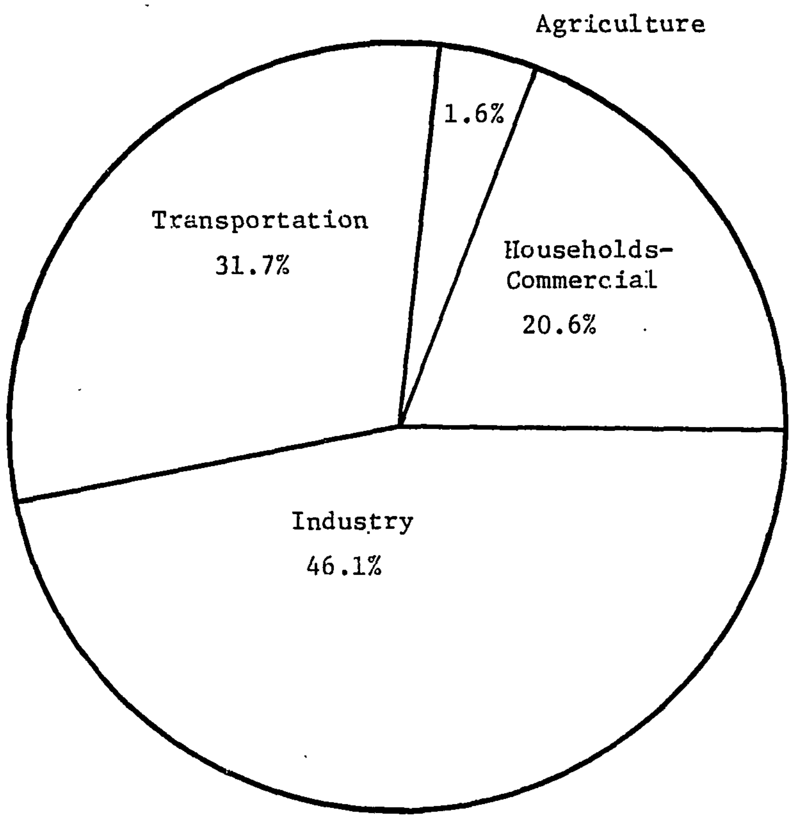
The electricity sector will use 8% of total oil consumed and about 13% natural gas. The consumption of natural gas for the production of electricity is an isolated case. It occurs in the Northern region where oil is produced. The plant was built to make use of the natural gas that was otherwise going to be flared. But, oil consumption, although still not extremely important, could very well be substituted when hydropower is expanded and when some of the systems become interconnected.

Energy Availability

In Chapter IV, the production of energy in the year 2000 in physical quantities was estimated. In order to compare these estimates with the demand estimates they must be transformed into a common unit: the British Thermal Unit (BTU). This conversion is presented in Table 108. This study's figures are dependent on a number of assumptions which will be explained in this section.


Agriculture
3.7%
18.9%
Households-
Commercial
Transportation
31.9%
Industry
45.5%

1976


Agriculture
1.6%
Transportation
31.7%
Households-
Commercial
20.6%
Industry
46.1%

2000

The level of oil production predicted is based on an exploration program which is in the first stages of elaboration, and the initiation of secondary recovery in the oil fields of the Northern Coast. There is confirmation that the secondary recovery has been started.

The coal figures are derived from requirements that are not related to the energy sector. In other words, it is assumed that Peru will not turn to coal for energy in the next 20 years. Furthermore, it has been assumed that since there is enough coal in Peru to meet industrial demand, it will be mined to satisfy the local needs. This in turn means that coal and coke importation will cease. The coal import bill is not significant for the balance of payments, so it is felt that this assumption will not distort the general view of the economic and energy situation of Peru.

Table 108. Projected energy availability in 2000 by sources

	Production Level	Energy in 10^{12} BTU
Oil	116 x 10^6 barrels/year	672.8
Coal	994,709 metric tons	18.8
Natural Gas	55 x 10^9 cubic feet	56.7
Hydropower	19,659.1 GWh	223.7[a]
Biomass	-----[b]	2,730 - 10,230
Produced as Electricity	24,011.2 GWH	277.8

[a]Measured in fuel equivalent to make it comparable with the demand estimations.

[b]Since it is composed of different sources no production level is given.

Electricity production, either by hydropower stations or thermal generation, is based on expansion programs updated by the government very recently [91, 118].

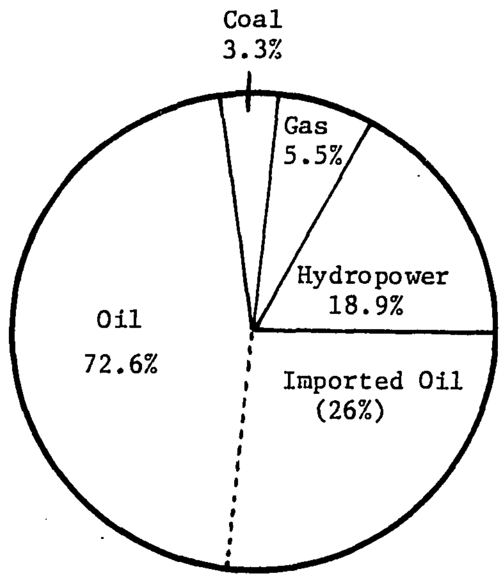
The biomass resources were calculated at a national level and reflect a potential rather than a predicted availability. In most of this study's analysis, commercial and noncommercial resources are separated. This is done because of the extreme differences in resource availability and utilization. Figure 17 compares commercial energy production in 1976 and the predictions for 2000.

Supply and Demand Integration

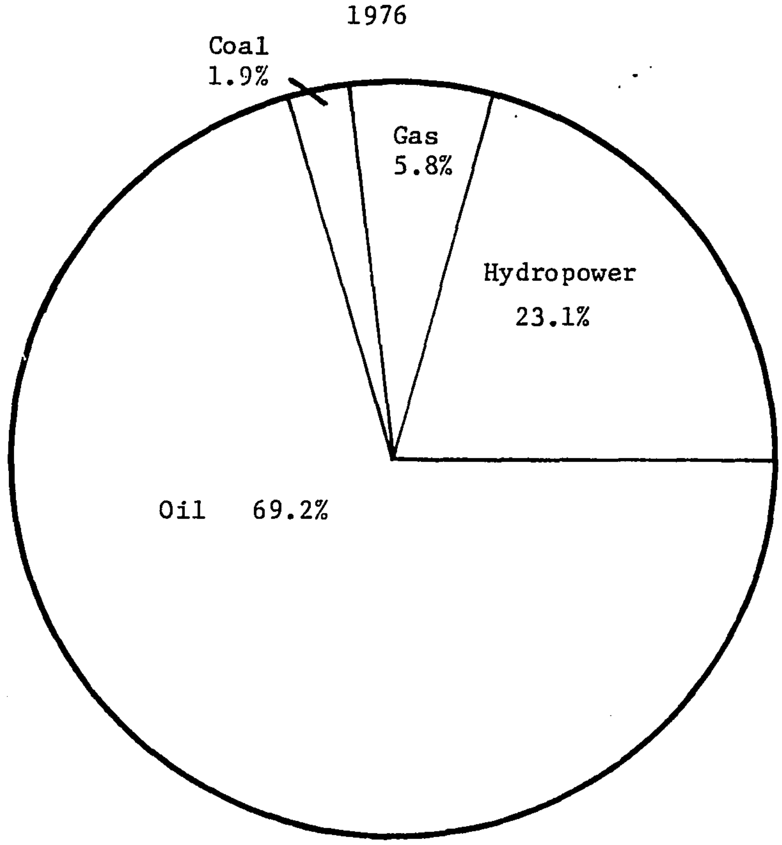
From Tables 107 and 108, the first conclusion to be drawn is that in very general terms Peru is endowed with abundant resources that should be able to provide for the energy needs of the population and the economic activities that support them. This means that energy, when viewed in this general context, shall not pose a threat for economic growth in the case of Peru. Furthermore, it is also implied that a higher rate of economic accomplishment could also be obtained without being constrained by the availability of energy.

However, the analysis does not stop at this point. Some details must be observed before some of the policy implications can be derived. First of all, we feel that bringing all the resources together, as in Table 108, distorts the situation. This is so because biomass resources in the Selva region are so vast that theoretically they could supply all of the Peruvian demand of energy; in reality, however, this is not so. Biomass from the Selva cannot be utilized except for providing basic necessities. Therefore, all of the commercial

Figure 17. Commercial energy production, 1976 and 2000


Coal
3.3%
Gas
5.5%
Hydropower
18.9%
Oil
72.6%
Imported Oil
(26%)

1976


Coal
1.9%
Gas
5.8%
Hydropower
23.1%
Oil 69.2%

2000

demand cannot be satisfied. The rural households that depend on biomass resources are located in the Sierra region, far away from the abundant supplies of the Selva, thus this demand cannot be satisfied either.

In putting all of the resources together, this study has attempted to call attention to the fact that the Selva has a potential, but in this instance it will be removed in order to present a more realistic analysis.

To begin, the study will separate commercial and noncommercial resources. By using the data developed, Table 109 has been prepared. In terms of commercial resources, it also seems that Peru will not face major problems to the year 2000. A surplus of approximately 278.1 x 10^{12} BTU is predicted. That surplus comes mainly from oil, therefore, it also means that Peru will retain its position of oil exporter with a volume of 29 million barrels for that year, compared to the present export level of 24 million barrels.

Table 109. Projected supply and demand of commercial energy by source, 2000 (in 10^{12} BTU)

	Coal	Oil	Gas	Hydro Electricity	Total
Supply	18.8	672.8	56.7	223.7	972.0
(percentage)	(1.9)	(69.2)	(5.8)	(23.1)	(100.0)
Demand	18.8	502.2	31.5	141.4	693.9
(percentage)	(2.7)	(65.9)	(3.9)	(27.5)	(100.0)
Difference					+278.1

In terms of the balance-of-payments considerations, oil will occupy an important place among Peru's exports, a position that could be enhanced by increases in world prices. Volume-wise, it will diminish because other sectors have better prospects for increased production.

As can be observed, Peru's future energy demand is dominated by the energy needs of the industrial and transport sectors. Petroleum and petroleum by-products will continue to be the dominant element in Peru's energy system through the year 2000.

We also observe that there is the possibility for natural gas production to be continued in excess of demand. Since the gas is produced in association with oil production, it is either used or flared. This is an indication that some measures could be taken to fully utilize the resource within economic feasibility.

We also note that the installed capacity for the generation of electricity may be in excess of demand. This raises serious questions since the supply calculations were made by using a capacity factor of 0.53, i.e. 4,643 hours in one year at full capacity. This is not in the upper limits of the utilization of electric plants. It could be increased. What we are saying, in fact, is that the program for investments in either hydroelectric plants or thermal units may not be economically justified in its entirety. Peru has made serious mistakes in the past building facilities that turned out to be unprofitable.

The question of biomass resources and the demand for these must be approached with caution. This study's estimatations suggest a demand on the order of 203.1×10^{12} BTU. The supply of biomass at the national level is well beyond that figure, but it will not make sense unless regional distribution and demands are prepared. Data were not available to elaborate on this idea, so it was felt that it cannot be stated that future demand for biomass for energy purposes could be satisfied at local levels. This is a very important problem because rural areas may turn to conventional sources such as kerosene, creating an oil dependency that might be avoided by supplying alternative forms that may better suit rural conditions.

CHAPTER VI. IMPLICATIONS FOR AN ENERGY POLICY FOR PERU

In this chapter, we will first refer to the generalities of an energy policy and then we will proceed to elaborate the fundamentals of a National Energy Policy for Peru on the basis of our study.

The Concept of Policy and the Policy Process

A policy is defined as a purposive course of action followed by an actor or set of actors in dealing with a problem or matter of concern [2B]. It is important to note that a policy is different from a decision in the sense that the policy represents what is actually done or going to be done, while a decision is a choice among competing alternatives.

It follows from the definition cited that public policies refer to policies developed by governmental agencies and officials. Figure 18 presents in synthesis the policy process, as it refers to either the general context or one sector in particular.

This study identifies five stages. In the first one, a problem is recognized. This may come from the public in general or the government itself or interest groups. By accepting that a problem exists, a formulation process is put into work. This part of the process means gathering and analyzing pertinent data and selecting possible courses of action.

The adoption of a policy is the domain of the political element of the system. The implementation stage deals with the question of how to carry a policy into effect.

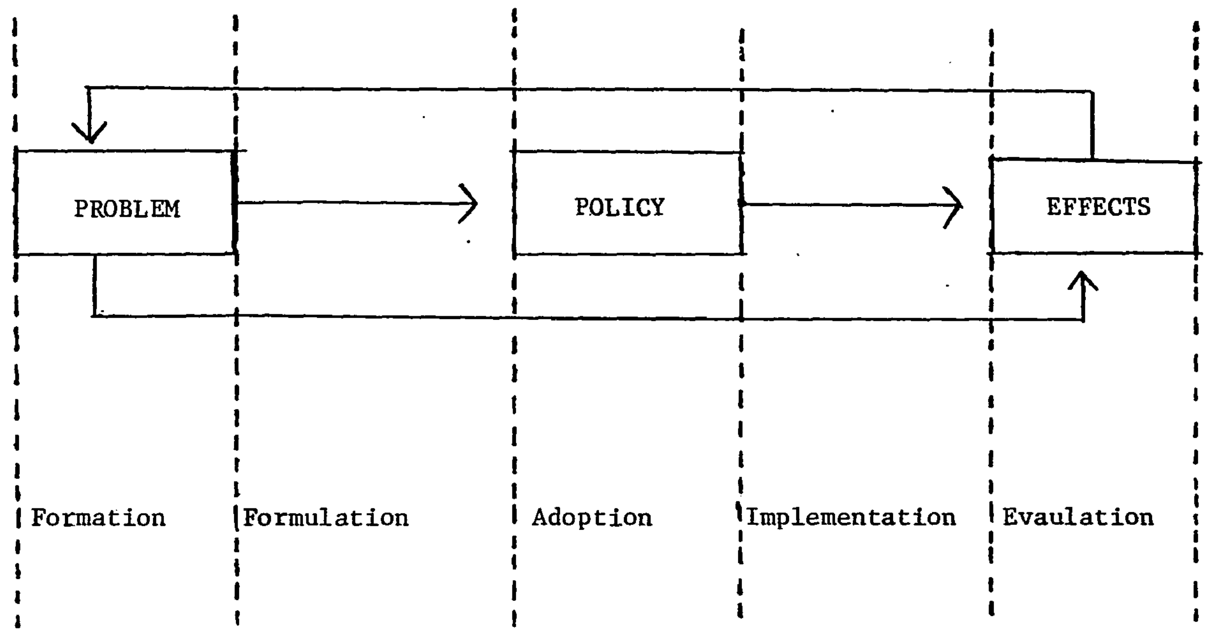


Figure 18. Synthesis of policy process

In the final stage, the effects of a policy are measured and questions such as who evaluates policies and what are the consequences of the evaluation must be resolved. In this context policy formation, adoption, and implementation are perceived as clearly political in nature while the others are technical activities.

Objectives, Strategies and Policies

Any sectoral policy embraces objectives, strategies and policies. Although they should not be confused, it is often that one finds that they are used interchangeably [20B].

An objective is a point or situation where one wishes to arrive or to reach. A strategy is a large-scale plan; it is an element of support for reaching the objectives. Policy has already been defined as a chosen course of action.

The Nature of Energy Policy

Energy policy is essentially concerned with the coordinated development of the energy sector. From our economic point of view, there are several questions that are of interest, such as: How should the energy market be divided between the different available fuels? What should be the relationship between the prices of the different fuels? How to incorporate environmental aspects into energy policy decisions? What are the instruments for implementation of energy policy?

As with any other sectoral policy, energy policy must be formulated and implemented in a given framework. It must be stressed that energy policy cannot be formulated in isolation from other economic and social objectives.

Ideally speaking the choice of an energy policy involves the selection of a course of action which is designed to achieve a particular set of objectives within the overall plan for the development of the energy sector and for the economy as a whole. There are many ways in which an energy policy could be operated. In one extreme, the government exercises complete control and allocates the resources. In the other extreme, the market mechanism is left alone to achieve equilibrium.

A Reference Case: The U.S. Energy Policy

It is considered that the first attempt of the U.S. government to formulate a comprehensive energy policy is contained in the National Energy Plan--NEP--submitted to Congress in 1977 [20B, 185].

The main objective of NEP was to reduce imports of crude oil and oil products and to limit the effects of interruptions of energy availability. There were a number of objectives to be achieved by 1985. These included a reduction in the annual growth of U.S. energy demand to less than two percent; a reduction of oil imports in 1985 from a potential of 16 million barrels a day to 6 million barrels a day; a 10 percent reduction in the consumption of petroleum; the establishment of a strategic petroleum reserve of one billion barrels; the insulation of 90 percent of all homes and other buildings; an increase in the annual production of coal by at least 400 million tons; and the establishment of the Department of Energy with responsibilities for energy policy.

The emphasis of NEP was on energy conservation, the only mention of increased production is in relation to coal.

The consumption of oil and natural gas was to be discouraged by imposing taxes. For example, it proposed an excise tax on what were called "new gas-guzzlers." If gasoline consumption targets were not met, it proposed a tax of five cents per gallon for each percent that consumption in the previous year exceeded the target.

It is interesting to note that NEP recognized that the regulation of oil and natural gas prices has tended to maintain them too low encouraging consumption; but at the same time it argued that total decontrol could have severe adverse effects on the U.S. economy, producing large windfall profits for producers.

NEP relied on the workings of the price-mechanism to achieve its objectives. In October of 1978 the U.S. Congress approved an Energy Bill. Although Congress agreed with the objectives of NEP, it did not endorse many of the proposed measures to achieve them.

Economics and Energy Policy

It should be stated, not only implied, that economics has a contribution to make on the making of energy policy; but it is not the only one. Energy policy is concerned with the attainment of a number of objectives--economic, social, technological, scientific, etc.--therefore, an interdisciplinary approach is needed.

Nevertheless, we would like to point out some of the explicit ways in which economics can contribute to energy policy. One of these is energy forecasting. There is no doubt that energy policies must be based on forecasts of supply and demand. We have attempted in this study to fill this gap in the case of Peru, by providing an estimate of energy consumption. What is important here is not if the figures turned out to be right or wrong, but the derivation of policies which are intended at the end to modify the course of action that the forecast indicates.

In energy pricing, we find another direct application of economics. We know what is going to happen if prices are set below the equilibrium price. The same is true in the case of taxes and subsidies.

Just as an illustration of the way economic principles should form the base for rational decisions, we would like to refer to the case of conservation. Conservation has drawn considerable attention in developed countries and it is forcing its way into the developing nations. However, this may not be such a good idea, we will try to examine the issue and illuminate the discussion. Conservation at the macro level must be interpreted as the reduction of the energy/GDP ratio. The record of developed and developing nations shows that this ratio varies so much that it is difficult if not impossible to draw any valid conclusions [66, 76].

We may use some microeconomic theory to rationalize the idea of energy minimization. In Figure 19, an isoquant is defined for the production of a good by using two inputs: labor and energy. For example, our isoquant represents an output of 100 units. The isocost line represents the total cost of using a number of units of one input and the number of units of using the other. We can represent this as $C = P_L L + P_E E$ where C is cost, L is labor, E is energy, and P_L and P_E are the prices of labor and energy, respectively.

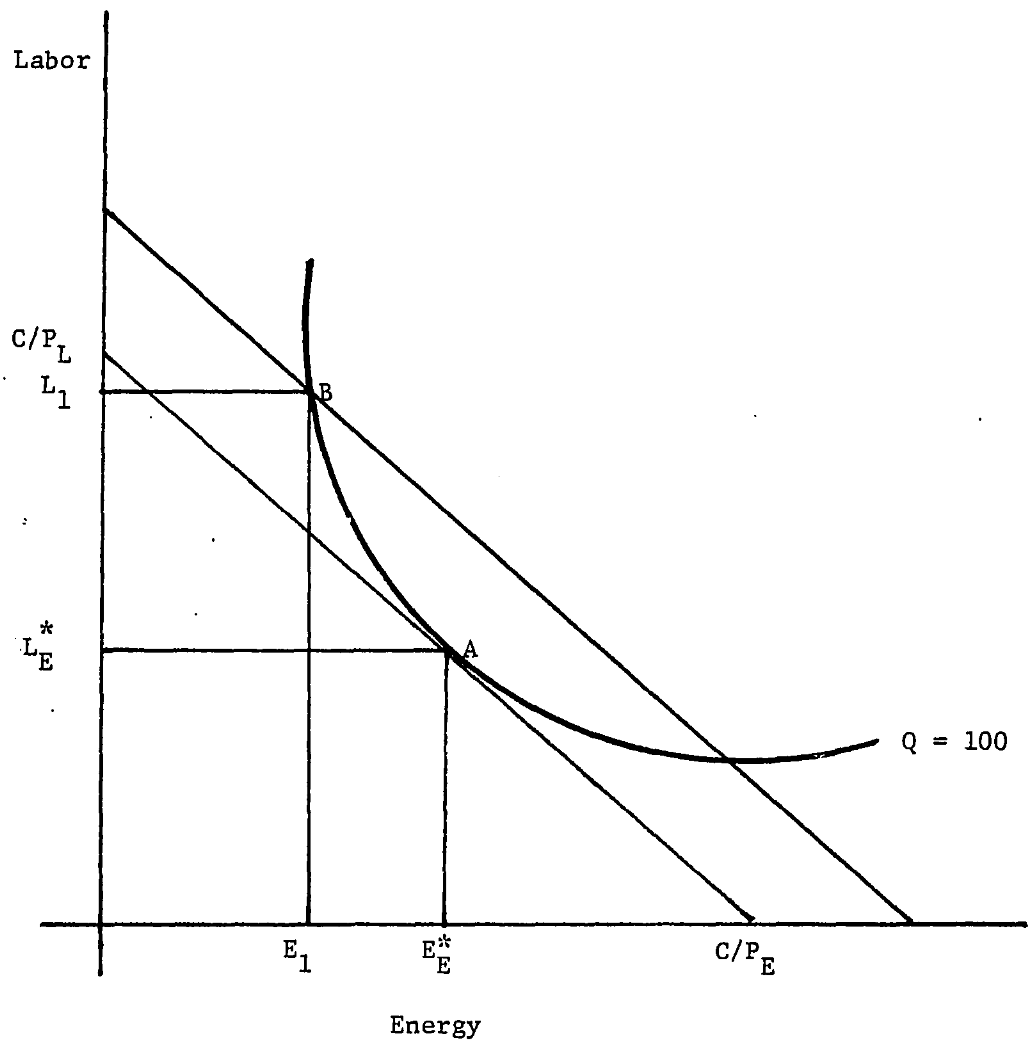


Figure 19. Production equilibrium with energy as an input

From the economic point of view, we are looking for the minimization of C to produce Q = 100. Our solution is at the tangency of the isocost line with the isoquant point A with L_E and E_E as the quantities of both inputs. This is standard theory of production. We feel that the argument that calls for decreasing energy inputs may be forcing solution such as B in Figure 19. Point B is the least energy intensive, at the given inputs prices. The result for the economy as a whole may be the higher cost that the new isocost line represents, obtaining the same input as before.

Our analysis may be simple but has economic theory foundations that we feel cannot be overlooked.

An Energy Policy for Peru

With the elements developed so far, we are going to attempt to present the basis of an energy policy as applicable to the case of Peru.

Policy issues

The formative stage is the one in which the problems or issues are identified and recognized as such. This is, in general, a difficult phase. No one perceives a situation in the same way; besides, problems change over time. We feel that the following could be identified as issues of the energy problem :

a) Energy demand management,

b) Resource allocations for energy development,

c) Energy pricing,

d) Structure of ownership of energy industry,

e) Foreign participation in resource development,

f) Energy research, development and demonstration,

g) Balance of payments considerations, and

h) Energy production and resource utilization.

We now briefly examine each of these to point out where we perceive the problem to be.

Energy demand management

The primary purpose of energy demand management is to reduce the consumption of energy per unit of GDP and/or control the growth of energy demand by sources and consuming sectors.

In the particular case of Peru, problems such as the needs of the rural sector should be addressed directly. The rural sector uses fundamentally renewable resources; but depletion in some areas has prompted the introduction of kerosene--a petroleum by-product. This substitution of a renewable resource by a nonrenewable one can only be conceived as a short-term solution of a problem that was not anticipated. There is no reason why proper planting of trees could not provide for the needs of rural populations, at least until long-term objectives and strategies are designed. But this is only one example. Energy demand must be examined in each consuming sector, identifying the possibilities for action.

Resource allocation for energy development

The development of the energy sector requires financial resources of such magnitude that they enter into direct conflict with needs of other sectors. The elements of this conflict are not easy to resolve. It is not in the end a technical question but a priorization of political objectives.

Energy pricing

It is essential to any energy policy to have an energy pricing policy. In Peru, energy prices for most energy resources are regulated. Unfortunately, they have been used with short-term political objectives in mind. The prices of energy goods have a very important impact across the economic spectrum. It is not only a matter of selecting alternative fuels, but they may decide the type of technologies the country will use. Once an industry has made a decision based on fuel availability and prices it may not be able, or afford, to change it [12].

Despite the social pressure, energy must be priced to cover the cost of producing it, a sufficient return on capital to keep energy producing entities financially viable, especially so they will be able to carry on exploration for new resources; and also to induce efficiency and discourage waste [75, 82, 182].

Ownership structure of energy industry

The Peruvian government has become the main owner of the entities involved in energy production and distribution. Petroleos del Peru has an internal monopoly on oil production, refinery and distribution. Foreign participation has been permitted in exploration and exploitation where the state entity is unable to risk the large amounts of money needed for exploration.

In the electricity sector, the government created Electricidad del Peru in 1972, to execute the policies in that area. The state owns all the electricity generating plants dedicated to public service. It has reserved for the government the right to generation, transmission, distribution, and commercialization of electricity [115]. The privately-owned generating plants are exclusively associated with the needs of particular industries or mining facilities.

Coal is not at the present time mined in Peru. There is no particular policy for coal except the general principles that govern the ownership and rights of mineral resources. Private participation in the mining sector is extensive, but the government controls about 65% of the total production [115].

The ownership structure just described puts the government in the driver's seat. One would tend to think that it should be easier to implement an energy policy when there is control of the means of production. There are many arguments in favor of state direct control and many arguments against. It is not the intent of this study to analyze either argument here, only to point out that this is a very important policy issue that should be in the agenda for a national energy plan. It should be noted, however, that if the government is to keep control of the means of production it should at least assure that these entities apply standard management practices and follow efficiency rules in order to become net contributors to the economy and not a burden on public finances.

The question of open participation of national investors in the energy industries should also be discussed. There are extensive benefits to consumers from competition.

Foreign participation in resource development

This issue is, in some ways, connected with the ownership policy for the energy industry. Foreign participation should be discussed in all of the aspects of energy development; for example, participation in the exploration stage with rights to some of the resources found. This does not commit the government to grant rights to commercialize the product or to compete in local markets.

Due to the investments needed to develop some resources, Peru cannot avoid adopting specific policies regarding the way in which foreign interests could participate in the energy industry.

Energy research, development and demonstration--RD&D

When energy RD&D in a context of a country like Peru is discussed, it it not meant to be work on the frontiers of knowledge. Investments in the basic and applied sciences tend to produce results in the long run, and mostly when there is a technological infrastructure capable of absorbing and transforming knowledge into practical use.

In Peru, all RD&D activities are performed by governmental agencies and universities. Why private industry in developing countries does not invest in RD&D has been the subject of much debate. Let it suffice to say that the costs and risks of individual research is surpassed by the cost of acquiring technology abroad; the markets are too small to be able to bear the cost of innovations.

But in spite of what has been said, RD&D has a place in developing countries. There are a lot of intermediate technology projects that could be developed with local resources. It could also have a role of technological gatekeeper, accumulating and analyzing technical development in other countries, developed and not, and searching for opportunities appropriate to Peruvian conditions. The issue here is not only the creation of the institutional infrastructure, but the financial support to achieve whatever the goals may be.

Balance of payments considerations

As indicated previously, oil has always been an important item in Peru's balance of payments. Peru has an export-led economy, therefore, anything that affects or may affect the balance of payments becomes quite important. A negative aspect of the dependence on oil would be if the need to import energy in large quantities arises. This could be disastrous for the economy. We feel that it is reasonable to rule out this possibility in the next 20 years. But oil exploration must start as soon as possible to avoid oil importation after 1985, when demand is expected to surpass present levels of production. The time gap between exploration and exploitation could put Peru back onto the net importers list [60, 192].

The prospects for continuation of oil exportation, practically continuously until the year 2000 looks sound. However, there is an item that causes preoccupation. Never has Peru used raw materials exports as a major instrument of economic policy as since 1978 with oil. In 1978, Peru was at a brink of default of its huge foreign debt, refinancing practically all of it, at high interest rates [195]. Oil exports came to the rescue by producing the much needed foreign currency, reaching one billion dollars in 1980.

The use of a nonrenewable resource, whose quantities are not only finite but apparently relatively small, to reimburse a foreign debt that was acquired without proper economic considerations [190], seems to be a high price to pay for the country as a whole today, as well as for future generations.

It has been indicated previously that no energy decision should be taken without considerations of its side effects. Such would be the case if land is dedicated to grow crops to produce energy and no attention is given to alternative uses, or even to the consequences to the soil itself. Hydroelectric projects should also take into account their effects on water availability and the agriculture of the areas downstream.

The same type of reasoning should be applied when an energy input is used for the sake of an economic policy. The energy implication of such action cannot be ignored. In this case, Peru might be risking an oil deficit in the future, and if so, this should be clearly understood.

Energy production and resource utilization

In all of the publications of the Peruvian Government, we have never come across any concern for resource depletion. The possibility of resources running out must somehow be part of the consideration when formulating policies about energy futures.

Some authors approach the problem with pessimism, arguing that demand is growing exponentially while supply is finite. On the optimistic side, it is argued that substitutions between resources and technical change will run ahead of depletion. Without analyzing the merits of the arguments, let us simply state that resource depletion as a policy issue is very complex.

It must be stressed that the calculations of energy supply in this study were based on assumptions of specific government actions. In the case of oil, it is expected that demand will surpass production around 1985 [172]. This is because production of known oil fields tend to diminish over time from decreased pressure of the reservoirs. Therefore, since production from the same oil pools will continue for many years its rate of extraction sharply decreases creating the gap between consumption and production. Since the government has already moved to insure oil production to meet domestic needs, it is felt that the levels of production predicted for 2000 are within reasonable limits [84, 85].

The same is true for the electricity sector. Peru uses only 3% of its hydropower potential. To expand this to about 7.2% in 20 years is not an unreasonable expectation, but it must be done otherwise the unsatisfied electricity demand will promote further demands for fossil fuels, thus aggravating the oil dependency situation.

It seems reasonable that Peru's energy strategy should lean toward the development of unused sources, especially the renewable ones. The most important nonrenewable resource not exploited at the present time is coal. However, before going into large-scale coal utilization for energy purposes, consideration should be given to the environmental aspects of such action. The mining of coal and the burning of coal are plagued with cases of extensive damage to the land and air. Peru should not repeat the mistakes of others, especially if there is plenty of other resources. Among the sources that have been identified with certain potential are: geothermal energy, solar, wind power, and biomass.

The needs in the policy analysis process

Policy formulation involves the development of pertinent and acceptable proposed sources of action for dealing with the issues. We feel that policy formulation should be viewed as a process and, therefore, be given an appropriate institutional structure.

During the 1970s, the government of Peru established a National Planning System headed by the National Planning Institute. Almost all ministries have a sectoral planning office, which forms part of the system, and provides the sectoral inputs from which the Planning Institute prepares the development plans of short and long term.

In accordance with this, a planning office exists within the Ministry of Energy and Mines. This system, although it appears theoretically acceptable, has not produced the desirable results. Overall growth rates and sectoral rates were not only not achieved but lagged behind considerably. The Planning Institute was unable or unwilling to anticipate the catastrophic impact that foreign borrowing was destined to produce. But these comments are not to be taken as a rejection of the existing infrastructure. The bottom line is that the formulation of policy alternatives should be based on sound technical work, and it is with that aim in mind that we suggest that an energy agency should be established with responsibilities of energy planning, policy analysis, promotion of research, development and demonstration, and evaluation.

We perceive the role of the energy agency in providing policy decision-makers with analysis of policy issues at three levels:

1. The effects of energy policies on other national goals. Questions such as impacts for balance of payments, the role of energy prices in the economy, etc., must be addressed at this level.
2. The relationship of the energy subsectors within the energy sector. This deals with, for example, rates of oil and gas development versus hydropower.
3. Optimal policy within the domain of each subsector. This deals with the optimal expansion of the power generating system, as an example.

A policy decision involves action by a person or institution with the authority to approve, modify or reject a policy alternative. Adoption of a policy ends a long and complex process of policy formulation. Policy makers do not necessarily face policy alternatives from which they have to pick one. It is more the case that the persons or agencies involved in the policy formulation will present what is termed a preferred policy alternative. From the preferred policy alternative to the final decision, a process takes place in which proposals will be rejected, differences will be narrowed, bargaining will take place, until a decision is reached.

Within the present political structure in Peru policy decisions are made between the Legislative and Executive branches. Not all policy decisions end up in Congress. The Executive Branch has responsibilities for policy decisions, too. Nevertheless, a National Energy Policy will most probably have to be submitted to Congress, if not because of a legal requirement, because of the need for policy decisions to gain the consent of the political bodies so they will be accepted favorably by everybody.

In preparing this study, the author has become aware of the information needs in the area of energy in Peru. There are needs of data about consumption and production in Peru. In order to be of assistance to policy analysis, the data must be specific by consuming sectors and by fuels. Price time series do not exist, this poses a disadvantage to those interested in energy models.

There is another facet of the information area that must also be mentioned. This concerns the transfer of knowledge and its application to useful purposes. The technical knowledge generated in other countries should be available to interested persons or institutions. This is a necessity since technical developments are not built from scratch, the flow of information facilitates research in any discipline.

Implementation and instrumentation of energy policies

Once a policy is adopted it must be transformed into specific actions. Normally the process of implementation involves an interaction between the political level and the technical level. Policies adopted are hardly so clearcut that they could be carried out without further analysis. Policies are implemented through instruments. In this section, we will discuss what we perceive to be the instruments open to the Peruvian government in the implementation of a National Energy Policy.

Taxes and subsidies One of the most obvious and frequently used fiscal instruments is taxes and subsidies. Taxes and subsidies are similar government energy policies because both are interventions in the normal operation of the price system.

The important aspect of a tax or a subsidy is that it changes a price and, therefore, affects income. This form of government intervention is adopted for a number of reasons and produces effects in a variety of policy issues. We will examine briefly some of the forms that have been used.

Severance tax This tax is related to the production side in the form of excise taxes on the output of extractive industries. These severance taxes could be specific if applied at a certain rate per unit of physical output, or <u>ad valorem</u> when it is based on the price of each unit. The effect of this tax is in the rate of depletion of the resource. In general, these taxes are expected to produce a reduction of the depletion rate. Due to the special importance of extractive industries in the Peruvian economy, this tax is a common instrument of policy implementation.

<u>Property taxes</u> A tax imposed each year on the value of mineral deposits is an example of property tax. The effect of this tax is to advance the rate of depletion. In Peru this tax has been used to bring known deposits into production, but mainly in the mining sector where individuals and companies had the right to reserve deposits for future production. Since the oil is the only extracted energy good in Peru, and it constitutes a state monopoly, the tax may be irrelevant.

<u>Income taxes</u> The tax imposed on income of companies dedicated to the extraction of energy inputs, as well as in any other extractive industry, is subject to controversy. Again, these taxes exercise an influence on rates of depletion. Because of the state control of the energy industry, income taxes cannot be used to produce any change in energy production.

<u>Capital gains taxes</u> A tax on a realized increase in the value of a capital asset is a capital gains tax. This form of taxation is also familiar in the extractive industries, but they no longer apply to the case of Peru.

<u>Tax allowances</u> If the rates of income tax have caused debates, tax allowances are an even greater issue. The income tax is a tax on

net revenue, i.e., the revenue that remains after all the costs are subtracted, but there are practical problems in defining the components of cost.

All of these taxes have really lost significance in the context of the Peruvian energy industry. The principal operators have become units of the Ministry of Energy and Mines, they no longer operate under the principles of the market mechanism. The central government makes the most important decisions such as prices and investments. The large deficits produced in the operation of the energy-producing industries have been specifically pointed out by the World Bank and the International Monetary Fund as short and long term issues to be resolved as part of the better use of resources. The first issue to be faced is about the ownership of the industry--should the State be the sole owner and operator? If this is so, under what economic and financial principals should this be done?

Fuel taxes   A tax per unit of energy used is a direct way to intervene in a market to achieve a number of goals. Some of the questions raised about taxes on fuel consumption are the effects on income distribution. We feel that income distribution aspects of energy policies should not prevent the policies from being adopted, but ways of coping with the problems created could be found, without upsetting economic principles.

Taxes on fuel consumption are expected to be regressive, i.e., they will have a greater impact on the poor than on the rich. The answers lie more in the social values and political positions than in economic theory.

Taxes on consumption could be made less regressive if the criteria are changed. For example, if we were to tax electricity consumption on the basis of the quantity of electricity. Minimum levels of consumption could be tax-free and as consumption increases the tax value will do so also.

Tax on energy-using appliances This form of taxation is sometimes viewed as regressive. It taxes not the fuel itself but the appliance or equipment that uses it. The tax could be specified in such form as to penalize the purchase of higher fuel utilization; for example, an automobile with a rated efficiency of 15 miles per gallon will have a larger tax than the one with 30 miles per gallon.

The only problem with this tax is that it does not attack the root of the problem; i.e., energy consumption directly.

Nonfiscal instruments Governments are, generally speaking, quite imaginative in coming up with new ways to intervene in the market mechanism. No intent is made to exhaust the topic, but we will consider some of the alternatives.

Price regulations Price regulation may be adopted when it is expected that producers will receive large rents from the exploitation of the resource. Social pressures in developing countries have forced policy decisions that may end up creating larger problems. We make look at the implications by using standard economic theory as depicted in Figure 20. If the price is set below the equilibrium price P_E at level P_R, then consumers will gain the area $P_R abP_E$, but an excess demand equal to $f_2 f_1$ will be created. In other words, a shortage is going to appear.

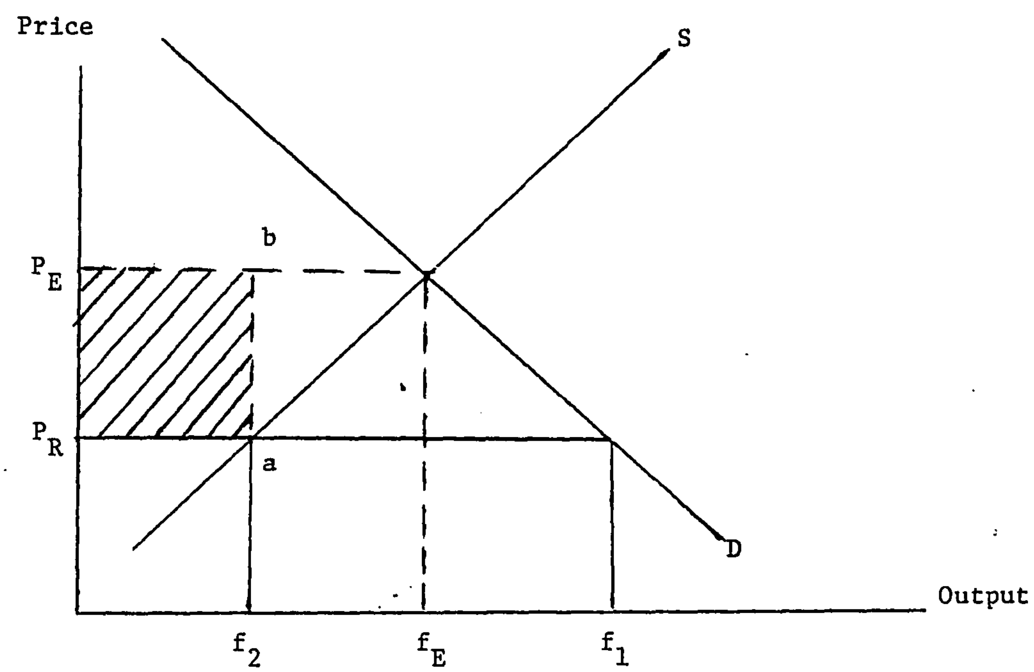


Figure 20. Effect of price regulation

The effects of regulated prices being less than equilibrium prices may not be seen in the very short run; but the experience of Peru for oil products shows that sooner or later a shortage will appear to signal the existence of an abnormality.

Monopoly purchasing Peru has used a nonfiscal instrument of forcing mineral producers to sell only to a government agency. In this case, an equilibrium price can still be given to the producer while the government may decide to charge lower prices to consumers. This has not yet been used in the energy area in part because it was decided that the State should own the means of production, but if local and foreign investors are allowed to operate this instrument could provide the price regulation that is sometimes socially unavoidable.

Monopoly producing In order to capture all of the rents from the development and exploitation of resources, the State may undertake directly the investment and operate the projects. This has been the policy decision of Peru in the 1970s. One of the problems that such action carries is that there is no clear distinction between private and social objectives. Peru's experience with total ownership of the energy industry has not been good. By being the owners, the government takes the political risk of being blamed for price increases. They are reluctant to make decisions that should normally be of a business nature.

Rationing There is no economic argument that could justify rationing as means of achieving the objectives of an energy policy. Rationing, aside from emergency situations, is most probably associated with control of demand. In principle, a tax on consumption could achieve the same results, with less cost, since the administration of a rationing system will need a bureaucratic apparatus.

Persuasion Through the media the government may try to achieve certain degrees of conservation of energy for nonessential uses. It may work, but it cannot be as effective and direct as the price mechanism. It must not be forgotten that we are facing utility-maximizing consumers. Using our economic principle of consumer equilibrium we see in Figure 21 that the maximum satisfaction is attained when the tangency of an indifference curve and the income line occurs, such as at point A. We are suggesting to the consumer to move to a point such as B, where he will voluntarily consume less energy, but he will move to a lower indifference curve. There may be times of national necessity when he will accept this loss of utility but we do not feel that it has a long-run validity.

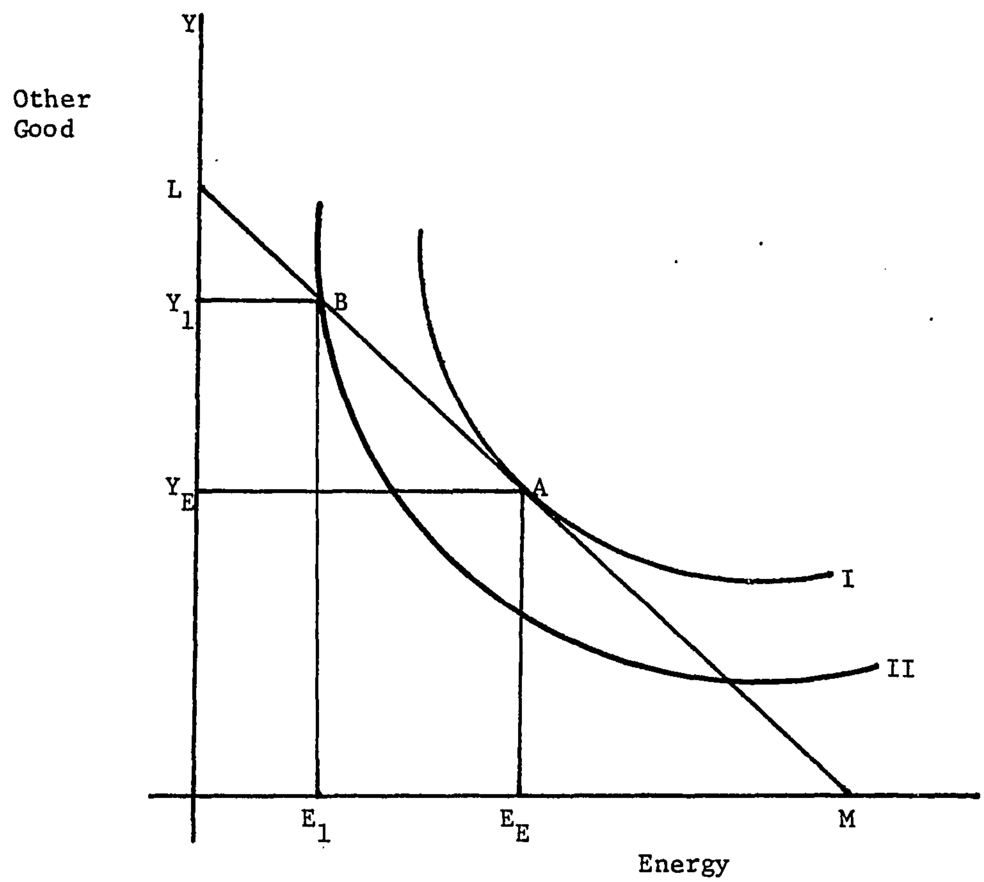


Figure 21. Energy and the consumer's equilibrium

Fuel efficiency standards In developed countries where technology is being produced, policies regarding fuel efficiencies of certain equipment have been adopted. For countries like Peru, setting fuel efficiency standards does not make much sense. The only alternative that we can think of is the monitoring of efficiencies of equipment currently imported, discriminating in favor of those with higher fuel efficiences. However, the complex control mechanism may not justify the results.

Other instruments Research, Development and Demonstration--RD&D--is one of the instruments of a special nature that could complement an energy policy. For a country like Peru, the expectation of RD&D is somewhat limited, but we feel that an investment in RD&D will pay off if the projects to be carried out are carefully selected, taking into account the resources that the country has, size and cost of projects and state of the art.

Five phases should be accomplished for each energy source under investigation:

1. Problem identification and analysis;
2. Technical research;
3. Development of primary technological approaches;
4. Demonstrations; and
5. Research and trial of project design and implementation techniques.

Based on the knowledge acquired in developing Chapter IV on energy resources, we have selected a number of projects feasible for use in Peru.

Small-scale hydropower Waterwheels designed and built by artisans are used in several countries. Modern turbine systems with capacity of less than 50 kilowatts have been installed in a number of developing countries including Peru. Most micro-hydro systems require a head of at least 3 meters to operate [194]. Several sites have been identified in the Sierra and Selva regions with heads of 100 to 300 meters [101]. This is the most promising option for decentralized energy production in the rural areas for Peru. Small mining establishments are also potential users.

There are about 800 small mines in Peru [172]. About 60 concentration plants for ore serve the small mines. Approximately 20 of these plants obtain electricity from hydropower, the rest from diesel generation.

Another aspect of micro-hydropower that makes it of interest is the possibility of local design and manufacturing. The estimated total of economically feasible potential is one million kilowatts distributed in 1,000 sites of 1,000 kilowatts each [101].

Solar energy Solar energy can be harnessed by using technologically complex devices or very simple artifacts. The difference is that the complex and costly technology is needed to increase the efficiency. On the other hand, we have that low-temperature heat may be achieved in more economical ways, as for example, for water heating, building heating, crop drying, fish drying, and water distilling.

Solar water heaters are widely used in Japan, Israel and Australia [194]. The technology should present no major problems and a local industry could be established. But in general terms, water heating is a luxury in Peru; thus, instead of addressing a present demand it could be creating one. Nevertheless, a solar energy research program could be beneficial by working on applications that are currently feasible so that the capabilities exist should the need arise. In some areas experiments could include hotels, hospitals and schools. Solar driers can provide controlled heat to reduce drying time and reduce losses due to rotting, insects and rodents.

Photo-voltaic cells cost about $15 per watt with additional costs required for structures, electrical equipment and storage. Although expensive at this time the cells are expected to decline sharply in price in this decade [194]. At present applications are limited to cases such as telecommunications equipment and navigational lights that require small amounts of electricity in locations where alternative sources are extraordinarily expensive.

Wind power   Windmills were widely used in developed countries before being displaced by rural electrification based on centralized generating systems. Windmills can be used to pump water for drinking, drainage or irrigation, grinding grain, or generating electricity. Wind-driven electric generators are now available with up to 15 kilowatts of power. Windmills have been designed and built with a range of materials and manufacturing requirements including designs appropriate for construction by artisans as well as equipment that would have to be produced in a modern industrial setting.

Biomass Since there are several items under the biomass heading, there exists several alternatives for utilization of Peru's vast biomass resources.

a) Pyrolysis Pyrolysis is the chemical decomposition of waste in the absence of oxygen, where materials are heated at atmospheric pressure and several products are obtained: low BTU gas, char and heavy tar-like oil [149].

One of the most common pyrolysis activity is the use of wood to produce charcoal. It is more efficient than wood and much more economically transported and handled than an equivalent amount of wood. The process can be very rudimentary but there are wastes associated with it. Although it has been improved in several ways it is generally the kiln that must be modified to increase efficiency. There are several alternatives and should be included as part of the research program to determine what best to use. The vast resources of wood in the Selva could provide a steady production of charcoal.

b) Anaerobic digestion Anaerobic refers to processes that occur in the absence of oxygen. The anaerobic decomposition of organic materials produces a mixture of gases containing 55-65% methane. It is usually referred to as biogas. The technology is relatively simple and has been developed at the village level in a number of developing countries, especially in Asia.

One of the advantages of the biogas digestion is that the residue of the organic matter from which the gas has been extracted is rich in nitrogen to use as fertilizer. The implementation of a program of this nature would call for the solution of social and institutional problems involved in waste collection and management.

<u>c) Gasification of wood wastes</u> A low BTU gas could be produced by using wood wastes. This option is interesting for the lumber mills which are at the present time using fuel oil to generate electricity and steam.

CHAPTER VII. SUMMARY AND CONCLUSIONS

Objectives and Results

The main objectives of this study were:

1. Describe and discuss different approaches to the problem of energy demand estimation.
2. Identify the major determinants of the demand for energy.
3. Quantify energy consumption levels for Peru in the year 2000.
4. Analyze the existing data on production and potential of Peru's energy resources, either presently utilized or not.
5. Establish the energy position of Peru in the year 2000, by integrating the demand and supply estimations.
6. Review the appropriate instruments of energy policy.
7. Infer the policy implications of the case of Peru, suggesting feasible options.

An analytical framework to assess energy demand was developed. This framework was used to forecast energy consumption by end-users. In going through the process, population and gross domestic product were identified to be the major variables in the determination of energy utilization. By estimating both of them, in the year 2000, a number of intermediate factors were derived. The energy intensities of the base year were applied to the levels of activity predicted for 2000, finally obtaining estimates of energy consumption.

On the supply side, since Peru operates a state monopoly of the energy industry, no attempt was made to anticipate reactions to market conditions; therefore, attention was concentrated not on economic supply but on physical supply.

The several studies on resources and reserves of oil point in the direction of a relative abundance of oil, compared to present levels of internal consumption. Of all other resources, hydropower is the one that shows greater possibilities. Peru uses only 3% of the economically feasible hydropower, and it plans to expand its installed capacity to a level in which the percentage of utilization will be 7.8%.

When estimates for demand and supply are compared, under the limiting conditions that had been indicated previously, the general conclusion that energy resources in Peru are abundant and should provide both for national needs, for energy exportation well beyond the year 2000 was reached.

Needed Extension of the Basic Framework

In building a demand schedule, prices enter directly into the analysis. There is valuable information to be gained when elasticities are calculated. For example, cross-elasticities for final demand of energy goods would tell us the degree by which consumers are willing, or able, to substitute energy goods.

Energy goods also serve as inputs of the production process, and substitution also occurs at this level, although it requires knowledge of the production function before it can be empirically measured.

The extent of the substitution of energy resources is dependent upon the relative prices of the other energy resources, the technological feasibility, institutional constraints, personal income for the case of final demand, and cost/benefit consideration at the firm level. This type of analysis could contribute in a very positive way to shape energy policies, and will guide the energy pricing process. We cannot but insist on the importance of prices in energy development.

Regional Analysis

One of the logical extensions of the analysis would be to derive regional energy consumption patterns. The regional partition should not make, in principle, much of a difference, but we suggest starting with the natural regions. The geography of Peru explains, in part, the regional differences of energy consumption. The need is not only for energy sources, but also for energy uses. The energy use is an important element when considering the introduction of a new energy form. It has to be known, *a priori*, if the new energy source will be able to substitute, i.e., if it could be consumed with the devices currently in use in the particular area under consideration.

The supply side has also a regional characteristic. Commercial resources can be easily transported, therefore, their location is largely irrelevant, in the sense of availability in the different regions. But this is not true in the case of biomass resources. Their location is crucial in satisfying local demand. There is a clear need for availability studies at the regional level.

The detailed regional analysis will also provide a better basis for energy policy decisions aimed at avoiding local shortages, and the introduction of energy forms that may not be convenient for the overall energy development plans at the national level.

Sectoral Analysis

The derivation of industrial demand was done by using the energy intensities observed in the base year. We constrained the growth of industry by the growth of GDP. Although this is an acceptable procedure, our methodology could allow a different approach. We feel that much more information will be gained by estimating output levels of the different industries. There is no need to count all of them. We already indicated that six industrial groups accounted for nearly two-thirds of total industrial energy consumption in 1976. We could estimate production for the six groups in physical units. Their energy requirements per unit of physical output could be applied to obtain energy needs. The process of obtaining information at this level should prove to be a good investment. Energy policies aimed at inducing better efficiencies in the industrial sector or the change in the fuel mix must be based on knowledge of the industry's use of energy by fuel and by activities. Capital investments needed to modify the pattern of fuel consumption could also be deducted from these sectoral studies.

Other Analytical Tools

We also feel that, along with pure economic analytical tools, other types of analysis must be incorporated in the policy analysis process.

In this respect, energy analysis has been described as a systematic way of tracing the flow of energy through an industrial system in order to apportion a fraction of the primary energy input to the system to each of the goods and services which are outputs of the system [182]. Energy analysis is performed by using either of three methods: 1) process analysis, 2) statistical analysis and 3) input-output analysis.

The process approach is technological in nature. Knowing the production process and the inputs used, an energy value can be given to each unit of output.

In the statistical approach, the published information is used to identify all of the energy inputs to an industry. These data are then used to calculate the energy cost per unit of output.

The input-output analysis involves taking an input-output table and using it to calculate the quantity of inputs required to produce any given commodity, from this the energy cost per unit of output is derived.

The kind of energy analysis just described becomes especially important in the evaluation of new projects. As an extension of the analysis a comparison between alternative sources of energy, assuming they would be readily available, could also be made. If energy analysis is included in project evaluation, there is the possibility to produce long-term changes, without the painful adjustments via prices or restrictions.

Resource Allocation in Energy Economics

Among the concerns that should be incorporated in further analysis of energy supply and demand is resource allocation, especially the so-called intertemporal decisions; i.e., those that have long-term implications for benefits and costs.

In static criteria, the efficient resource allocation occurs when the Pareto optimality is obtained. Optimization must occur among consumers, between producers and between producers and consumers. This type of approach is not satisfactory when dealing with nonrenewable resources. There we must introduce the time element. When viewed in this context, new elements are incorporated into the analysis such as the rate of interest. It affects resource allocation through the introduction of the price of future consumption into current decisions.

Our demand estimations may prove to be of assistance if the state monopoly were to apply profit maximizing criteria. Firms tend to maximize the present value of future profits. In the simple case of a good, the firm would select that output where the marginal revenue of production equals its marginal cost.

However, when this type of reasoning is translated into a nonrenewable resource, the scarcity or limitation in its quantity cannot be ignored as a relevant variable. In this case, the calculation of opportunity cost will prove necessary to reach a solution, because we are dealing with intertemporal choices. So the production consideration where present value is maximized, the loss in present value from reducing current consumption will just equal the discounted gain of increasing consumption in the future period.

The Supply Function

We have pointed out that energy resources are limited in supply. It seems that those resources that are most economical to extract are the ones that have the most severe ultimate limitations in availability. In the long run, the question of supply rests on the amount of the resource and the price at which the resource can be extracted and transformed, so that it will be ready to be used as an energy good. Resource estimates are highly speculative. Costs of extraction and processing are also unreliable since they are based on past information, which, in turn, depend on different technologies.

More than a supply function, a more practical concept of an availability function [82], could be developed. This function is defined as the functional relationship between the cumulative extraction of a given resource at a point of time and determining variables. The determining variables include: a) the natural availability of the resource, b) the state of the technology for finding and extracting the resource and c) the marginal cost of the resource. Such a function will make more sense than the traditional supply curve, in the particular case of Peru, and should be very useful in determining differences that may occur in future supply and demand.

Depletion of Energy Resources

When examining the supply of energy resources, a question about the exhaustion of nonrenewable resources cannot be avoided. Estimation of future demand allows for decisions to be made on how to meet the possible level of demand. Assuming that the resources should be exploited at the rates that the increase in consumption dictates will not only be too simple, but ignores important issues associated with the use of exhaustible resources.

In competitive markets we can expect producers to behave in the profit-maximizing fashion under the principle of rationality. When the resources can only be exploited by one producer, such as the state monopoly in Peru, we do not have a framework of reference to anticipate decisions that are not under the economic rationality principle. But even in this case, some economic principles could be applied to induce efficiency in the energy industry. This takes us into the normative field, i.e., we do not ask the question how fast the resources are going to be depleted, but how fast they ought to be depleted. In this sense, the Pareto efficiency concept plays a crucial role in economic theory. The reasoning of Pareto efficiency is based on the idea that the social welfare would be improved if at least one person could be made better off without making another worse off.

The Pareto efficiency principle applied to nonrenewable resources is considered to be unsatisfactory. Other models have been developed to deal with this case.

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APPENDIX A. A NOTE ON PERU

Historical Perspective of Peru

The history of the Republic of Peru can be divided into four parts: a) Pre-Inca, b) Inca, c) Colonial, and d) Independence [74].

The Pre-Inca civilization was not one but many different groups that flourished in the Andes and in the coastal valleys.

The Inca period is the time of conquest and integration of all different groups by the one seated in the city of Cuzco, capital of the Empire, and one of the oldest cities in the world. The Incas' remarkable achievements are numerous, but from our economic point of view we have to single out the production, storage and distribution of foodstuffs. It may not have been perfect, but to manage a nation with the geographical obstacles of that region, and a population in the millions in the 15th Century, is certainly worthy of admiration.

The conquest of the Empire by the Spaniards in the early part of the 16th Century coincided with the civil war in the Empire as two sons of the last Emperor disputed the throne of Cuzco. Rather than uniting in the face of an enemy, the losing group sided with the Spaniards and facilitated their enterprise, while destroying all of the economic, social, scientific, technological, and artistic accomplishments of the era.

The Colonial period lasted about 300 years. There were several attempts of rebellion, some of them with the intention of bringing about better conditions for the indigenous population. But it is in the end the Criollos, those of Spanish descent, who sought and achieved the end of the Spanish rule, mostly to expand their wealth and consolidate their power. The independence struggle of the 19th Century had nothing to do with social justice to the Indians or their rights, nor did it bring any changes for them.

The Independence and the establishment of the Republic of Peru is officially set on July 28, 1821, and was declared by the Argentinian General don Jose de San Martin. San Martin intended to make of Peru a sort of monarchy, as he thought such a system would be best. But as it occurred in many other countries the declaration of independence was not the product of military victory but rather a declaration of war. Although San Martin won a few battles, the final chapter of the colonial era was to be written by the Libertador don Simon Bolivar, in 1825. Bolivar, born in Caracas, Venezuela, brought independence to his native land, then Colombia, Peru, and in the process created the Republics of Ecuador and Bolivia carved out of the original Inca Empire and the Spanish Viceroyalty of Peru.

With Bolivar the idea of a Monarchy was phased out and democracy in the sense of an elected government began to consolidate. Nevertheless, the governments in the history of the Republic have been the product of force rather than votes. In the post-Second-World-War period, Peru has had a military president 60% of the time [25, 32].

Peru's Geographical Setting

Peru occupies the west coast of South America between Ecuador on the north and Chile on the south. To the northeast, it is bounded by Colombia and to the east and southeast by Brazil and Bolivia. The country's land area is about 1,285,000 square kilometers (496,22 square miles). It is roughly the size of the European Common Market minus the United Kingdom, or less than two times the state of Texas. Peru is the fourth largest country in Latin America.

The country is divided by the Andes mountains into three regions with extreme contrasts in topographic and climatic features. Between the 3,000 kilometers (1,860 miles) of coastline along the Pacific Ocean and the Andes is a narrow belt covering 11% of the country (the Costa). It is made up mainly of dry, flat plains and sand dunes, below 300 meters (980 feet), and equally dry Andean foothills. It does not rain but humidity is high.

The Andean Highlands (the Sierra) above 2,000 meters (6,560 feet), covering 26% of the country, are composed of steep mountain slopes and high valleys located between the mountain ranges. The climate varies widely during the year and at different altitudes.

East of the Sierra are vast tropical lowlands which account for 63% of the country (the Selva). The Selva is subdivided into Ceja de Montana and the Low Selva, below 600 to 700 meters (1,970 to 2,300 feet). The Ceja is made up of hills and valleys and has a continuous rainfall of 1,000 to 3,000 mm (40 to 118 inches) with an average daily temperature of 18°C to 21°C (64°F to 70°F). The Low Selva is very hot and humid, a plain of dense vegetation consisting primarily of rain forest. The temperatures range between 30°C to 33°C (87°F to 92°F) and rainfall is around 2,000 mm (78 inches) well-distributed over the year. Figure A-1 is a map of Peru showing the three natural regions.

The rugged topography limits trade and interdependence between the three regions of Peru and modern economic activity has concentrated in the Costa, particularly Lima. Transportation and communications between regions and within the Sierra and the Selva are extremely costly and difficult. Still today there is no all-weather road connecting the Costa and the Sierra with the Selva.

Peru's.Economic and Social Background

In 1531, Francisco Pizarro and his followers started the conquest of the Inca Empire that was to change, permanently, the nature of the country's economy from agricultural autarchy to export-led development. In 1546, silver deposits were discovered in Potosi starting the boom of the mining production. The first mining boom lasted until 1620-40 after which production declined. Political upheavals, rapid depopulation, natural disasters, all made recovery impossible, so when in 1821 the independence of the Viceroyalty of Peru brought the creation of the Republic of Peru, the economy was in a state of disarray.

The growth of guano exports was the single most important economic event in 19th Century Peru. It lasted for about 40 years, between 1830 to 1870, although guano was still produced after than date and even today, the volume so much decreased that it no longer provided stimulus to the economy [61, 69].

Figure A-1. Map of Peru by regions

During the Guano Era a new economic elite emerged, but the rigid pyramidal structure of Peruvian society that had existed at the end of the Colonial period changed little. The new rich made their wealth primarily in activities related to the guano and nitrate industries, and in general commerce. They supported the traditional landowners families that remained from the Colonial period in holding political power, although government leaders changed often and constitutions were frequently rewritten. The Indian population remained isolated with few links to the rest of the economy, and with incomes well below those of the Costa.

Important social and political changes started occurring in the first part of this century. With the progress of industry, rapid urbanization and general economic growth on the Costa, a new middle class emerged formed by: the new industrial entrepreneurs on top (mainly foreign immigrants), the professionals and commercial employees in the middle, and the permanent workers in urban industry and in the large sugar enterprises, at the bottom. This middle class became increasingly articulate and influential in the political arena [146, 156A].

The Post-World War II period has been the most successful in Peruvian history in terms of economic growth. All controls on the economy were dropped in 1948, and 20 years of remarkable integration into the international system followed. The GDP grew in real terms 4.7% a year from 1950 to 1959, 8.8% a year from 1960 to 1962, and thereafter at 3.9% a year until 1968. In per capita terms, these growth rates became 2.4% per year for 1950-59, 5.9% per year 1960-62, and 1.3% for 1963-68 [93, 156A].

In 1968, the military seized power and embarked upon a series of expropriations and controls which rapidly converted Peru into a state-dominated economy [32]. By the end of the 1970s, Peru's economy was in a very bad state, some authors have described as . . .

> the worst economic, social, and political crisis that the country has seen in the 20th Century: record unemployment figures, workers and peasants in the streets violently protesting the dismissal or imprisonment of their leaders, desperate entrepreneurs attacking the government for its lack of economic leadership, increasing inflation at the same time that a generalized recession paralyzes the economy, huge deficits in the public budget and the balance of payments, and severe loss of political authority of the Revolutionary Military Government [133].

It is important to note that at least one study on income distribution in the democratic government of 1963 to 1968 and under the pro-socialist military government of 1968 to 1980 found that the pattern of redistribution has been similar, if not slightly better in 1963-68 [183].

One of the most remarkable indicators of Peru's problems is the foreign public debt. It grew from US $737 million in 1968 to US $5.559 in 1979, growing at a rate of 21% per year. The total foreign debt (public and private) of Peru stands at about US $9 billion [99].

The Gross Domestic Product of Peru for 1980 was around US $14 billion, with a per capita of US $850.

APPENDIX B. ENERGY DEFINITIONS, UNITS OF MEASUREMENT AND CONVERSION FACTORS

It is customary to measure the energy content of fuels in British Thermal Units (BTU), the energy content of foods and chemical substances in Kilocalories (Kcal or Cal) and the amounts of electrical energy in Kilowatt-hours (KWh).

However, one set of units can as well be used for all applications, and relationships are made much clearer by doing so. The BTU will be used as a common measure. The BTU is a very small unit of measurement, thus, the energy contents are expressed in trillions of BTUs. Table B-1 presents the BTU equivalents of common fuels, Table B-2 the conversion factors of common measures and Table B-3 some miscellaneous conversions.

Table B-1. BTU equivalents of common fuels[a]

Fuel	Common Measure	BTUs
Crude Oil	Barrel (Bbl)	5,800,000
Natural Gas	Cubic foot (CF)	1,032
Coal	Short ton	24,000,000 to 28,000,000
Electricity	Kilowatt/hour (KWh)	3,412
Firewood	Metric ton	15,400,000 to 20,900,000
Bagasse	Metric ton	10,400,000
Charcoal	Metric ton	28,173,000
Cow dung (dry)	Metric ton	15,872,000

[a]SOURCE: [27, 40, 149, 172].

Table B-2. Conversion factors[a]

	BTU	Joule	kcal	kWh
BTU	1	1,055	0.252	2.93×10^{-4}
Joule	947.8×10^{-6}	1	2.39×10^{-4}	2.778×10^{-7}
kcal	3.968	4,184	1	1.163×10^{-3}
kWh	3,413	2.655×10^{6}	860.2	1

[a]SOURCE: [88, 149, 172, 188].

Table B-3. Miscellaneous conversions[a]

1 barrel	42 gallons (USA)
1 gallon	3.785 liters
1 cubic foot	28.32 liters
1 cubic meter	35.31 cubic feet
1 barrel	159 liters
1 MCF (10^3 cubic feet)	28.32 cubic meters
kilo (thousand)	10^3 (k)
mega (million)	10^6 (M)
giga (billion)	10^9 (G)
tera (trillion)	10^{12} (T)
peta (quadrillion)	10^{15} (P)
exa (quintillion)	10^{18} (E)

[a]SOURCE: [88, 149].

The following listing presents definitions of common units.

BTU: British Thermal Unit: A unit of energy. It is used in connection with energy as heat, but also as work or energy in any other form. Originally defined as 60° BTU quantity of energy as heat required to increase the temperature of one pound of water from 59.5° to 60.5° Farenheit, at a pressure of 1 atm. (one atmosphere). It is now defined in terms of electrical units: 251.996 IT Calories or 778.26 foot-pounds. By definition IT Calorie = 1/860 Watt-hour, hence one BTU is equivalent to 1/3 Watt-hours.

Joule: A unit of work of energy in the "systeme internationale" system of units, being equal to the work done by a force of magnitude 1 Newton when the point at which the force is applied is displaced 1 meter in the direction of the force. Joule is a short name for "Newton-meter of energy or work" and hence is equivalent to 10^7 ergs and also to 1 watt-sec.

Newton: A unit of force in the "systeme internationale" system of units. One Newton is the force which will impart 1 m/sec^2 acceleration to the International Prototype Kilogram Mass.

Watt: A unit of power in the "systeme internationale" system of units. One Watt equals one Joule per second, or 10^7 Ergs/sec, and 746 Watts equal one Horsepower. In electricity one Watt is the power developed in a circuit when the current is 1 Volt. It is also equal to: 1 Watt = 0.239 cal/sec and also 0.000948 BTU/sec.

Erg: A unit of energy or work in the "systeme internationale" system of units. It is equal to the work done by a force of magnitude 1 Dyne when the point at which the force is applied is displaced 1 Centimeter in the direction of the force.

Dyne: A unit of force in the "systeme internationale" system of units. The Dyne is based upon a mass unit (gram) which is 1/1,000 kg and a length unit (centimeter) 1/1,000 meter; hence, 1 Dyne is the force which imparts 1 cm/sec^2 acceleration to a 1 gram mass. One Dyne is 10^{-5} Newton.

Calorie: A unit of measure of energy. It has been defined as the quantity of energy as heat required to raise 1 gram of water 1 centigrade under a constant pressure of 1 atm. It is equal to 1/860 of a Watt/hour.