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Authors
Masera, O.
Freidmann, R.
Buen, O. de

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O. Masera, R. Friedmann, and O. de Buen

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Omar Masera, Rafael Friedmann, and Odón de Buen

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Energy Analysis Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California, U.S.A. 94720
and
Energy and Resources Group
University of California at Berkeley
Berkeley, California, U.S.A. 94720

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Abstract

This article examines the characteristics of residential energy use in Mexico, its environmental impacts, and the savings potential of the major end-uses. The main options and barriers to increase the efficiency of energy use are discussed. The energy analysis is based on a disaggregation of residential energy use by end-uses. The dynamics of the evolution of the residential energy sector during the past 20 years are also addressed when the information is available. Major areas for research and for innovative decision-making are identified and prioritized.

1. Introduction: Importance of the Mexican residential sector in energy planning

Mexico's residential sector energy demand is characterized by a large geographic, socio-economic and cultural heterogeneity. This diversity presents significant challenges and opportunities for energy planning.[1] Some of the salient features of the residential sector are:

1. Residential energy use accounts for more than 20 percent of the final energy demand of Mexico (Figure 1). It has a large growth potential due to the following three processes that occur in a parallel fashion: a) Significant demographic growth; b) Increasing urbanization; and c) Increasing appliance saturation.

Longterm scenarios indicate that residential energy demand could increase by 260 percent from today's levels by the year 2025 (Mendoza et al 1991).

2. The increasing residential energy demand requires large investments to increase the supply of energy. This is particularly evident with electricity, where the residential sector's lighting and air conditioning demand coincide and drive the peak system demand (Figure 2).[2] Also, since energy prices in the residential sector are the most subsidized, its continued growth puts increasing pressures on the budget deficits of

[1] Traditionally, the residential consumption has been aggregated with commercial and public energy use. Only since 1987 has the residential sector's energy use begun to appear independently in the National Energy Balances. Only since the mid 1980's has wood use been incorporated in the energy accounting. This shows the relatively minor attention that has been accorded the residential sector in energy planning circles in the past.

[2] Preliminary estimates show an increase of 9 GWe by the year 2000 to cover increased residential demand, with a cost close to 20 billion dollars (Friedmann 1990).

the utilities.[3]

3. The environmental impacts and health hazards from residential energy use are significant. Residential demand for modern fuels contributes to a large percentage of the total national pollutant emissions and environmental impacts associated with the production of primary and secondary energy forms and their continuing expansion. In the rural sector, high fuelwood demand contributes to forest degradation, and its combustion in open hearths leads to a high incidence of respiratory diseases.

4. Currently, there is a large and wide range of technical options which are economically feasible for reducing residential energy consumption and resulting environmental impacts. As demonstrated in other countries (Atkinson et al 1992; Gadgil et al 1992; Geller 1991; Koomey et al 1991; Reddy & Goldemberg 1990a), there is a wide range of options for saving energy at lower costs than those required to increase energy supply.[4]

Our main objective in this document is to present a general panorama of the residential sector that incorporates an analysis of its structure, the dynamics of its change, and the environmental impacts derived from its energy use. We identify priority areas for the development of research projects and illustrate opportunities for policy decisions in the energy efficiency and renewable resource areas. We hope the article will contribute substantially to future work on forecasting the evolution of residential energy use in Mexico.

In the next section of this paper, we describe briefly the structural changes of the residential sector since 1970. In the third section we analyze residential energy demand by fuels and end-uses. The fourth section examines environmental impacts of residential energy use. The fifth section explores the energy savings potential in the urban and rural households for the major end-uses. The sixth section describes barriers and policies to achieve energy savings in the residential sector. The last section presents the conclusions of our analysis.

2. The Mexican residential sector: structural changes during the past two decades

The patterns and dynamics of energy use in the residential sector result from the

[3] The residential electricity subsidy is estimated to have been 760 million dollars in 1990 (Friedmann 1991).

[4] For the U.S.A., it has been estimated that 40 percent of residential electric use (404 TWh/year) could be saved with measures costing less than 7.6 cents/kWh (Koomey et al 1991).

complex interrelation of technical and structural factors.[5] In this section the analysis focuses on the evolution of the structural characteristics of the residential sector. Technical factors are addressed in more detail when we discuss the potential for energy savings in section 5.

During the past 20 years the residential sector has undergone deep transformations, amongst which the following stand out:
1. An important population increase with asymmetry between the urban and rural sectors and regional variation;
2. A decrease in the size of the average household;
3. An increased polarization in the distribution of income, with significant differences between urban and rural areas; and
4. An increased integration of the country into a market economy.
Each of these four transformations is discussed in more detail below.

From 1970 to 1990, the population of Mexico increased from 48.2 to 81.1 million people, but, there has been a significant decrease in the rate of population growth. During the last decade population grew at an annual rate of 2 percent, much lower than the 3.4 percent during 1970 to 1980 (INEGI 1991; SIC 1970).

Almost all the population growth has occurred in the cities, mostly due to their own internal population growth, as well as the large rural to urban migration. Mexico's urban population grew from 59 percent of the total population in 1970 to 70 percent in 1990.[6] Among the urban areas, a concentration in the major cities is also evident. By 1990, half of Mexicans lived in cities of at least 100 thousand inhabitants, and more than 35 percent lived in the five largest urban centers.[7]

The rural population has remained constant in absolute numbers and is concentrated in the center and south of the country. These areas of the country are still characterized by the dispersion and isolation of small communities. It is estimated that there are around 86 thousand communities with less than one thousand inhabitants (Gutiérrez 1991). A large portion of these small communities still lack basic services such as electricity and sewers (Sepúlveda 1989).

During the last decade, the continuous urbanization process has led to a redistribution of the population from rural areas to the traditional metropolitan centers and new

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[5] By technical factors we mean the particular technology used to satisfy an end-use. By structural factors we mean demographic, socio-economic, cultural and physical surroundings characteristics.

[6] Urban areas are taken as those with more than 2,500 inhabitants.

[7] This tendency to hyper-urbanization is also evident on a State level, where 30 to 50 percent of each State's population is concentrated in the principal city (INEGI 1991).

poles of attraction in the Bajío and the Northern and Southern regions of Mexico (Figure 3).[8] These new poles of population growth have important impacts on total residential energy use. Figure 3 shows that the Pacific and North regions use more electricity than the national per capita average. This result, together with a simple analysis of the climate that predominates in a given area (using the same criteria used in determining the residential electricity tariffs--Figure 4), shows that increases of the population outside the Center and Bajío regions, imply a more than proportionate increase in electricity demand.[9] In the North, the closeness to the U.S.A. and the climate combine to increase energy consumption even further due to the enhanced ease of acquiring appliances and awareness of U.S.A. lifestyle.[10]

Average household size has decreased, both in the urban and rural areas. In 1980 average national household size was 5.7 persons per family. In 1990 household size was 5.3 and 6.1 persons per family in the urban and rural areas respectively, giving a national average of 5.5 persons per household (in the U.S.A. it is only 2.7 persons per family). This trend has led to a larger rate of increase in the number of households than that of population (Table 1).

On a socio-economic level, the economic crisis of the 1980's, together with the structural adjustment policies of the government, have led to a significant fall in the mean household income. For example, the current minimum wage in real terms is only 30 percent of its value in 1975 (Figure 10) (Gershenson 1991). About 30 percent of Mexicans live under the poverty line and 10 percent (20 percent in rural areas) are indigent (Table 1). It is evident that socio-economic class gaps are increasing. In 1983, calculations showed the lowest fifth of the population receiving four percent of total income, while the top fifth captured 53 percent.

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8 It is interesting to note that although the census figures show little or no growth in the heart of the largest urban centers during the past 10 years (Federal District -7 percent, Monterrey +2.4 percent, and Guadalajara + 0.2 percent), the peri-urban areas in these cities have experienced tremendous population growth (INEGI 1991).

9 Two sets of residential tariffs are applied in Mexico, one during the six "winter" months and the other during the "summer" months. All homes are charged the same 6-tier increasing-block rate (Tariff 1) during the winter. Five (four in 1987) slightly different residential tariffs are applied in summer, depending on outdoor temperatures with warmer regions tariffs (1A through 1D) being lower.

In figure 4 one can observe that the Bajio and Centro regions are almost entirely Tariff 1 customers. In all the other regions, there are significant proportions of customers living in hotter climates where air conditioning loads will probably become significant in the future.

10 This increased ease for purchasing appliances together with an enhanced awareness of U.S.A. lifestyles is evident when one compares the average household electricity consumption in Tijuana (2.1 MWh/year) with that for a household in Mexico City (1.2 MWh/year), although both cities have the same tariff 1 (and therefore non-extreme summer climates) (CFE 1989a).

The population's decrease in spending power, and the government's move toward real cost pricing of fuels since the early 1980's, have increased the proportion of household income spent for energy.[11] Increased energy bills have had different social impacts on urban and rural households and among the different income levels (Gutiérrez 1990). In general, the poorest sectors have been the hardest hit. As shown in Table 1, energy use in 1989 accounted for more than 13 percent of average rural income, but only 7.3 percent of average urban income. Taking into account the large income distribution inequalities known to exist, these aggregate numbers hide situations where price increases have had much larger impacts since low income households apportion their expenses amongst basic needs and do not have discretionary income to cover increased energy expenses.

The increasing national integration into a market economy has also led to important cultural and lifestyle changes. There has been a redefinition of basic needs, with an increased demand of mass production goods and an imitation of developed countries' lifestyles. The accelerated commercial opening of the country (which began in 1986 with a reduction of import duties and will culminate with the NAFTA) has only reinforced these new, more energy intensive trends.

3. Residential energy demand[12]

The structural changes indicated in the previous section have resulted in the following general trends of residential energy use:

1. An increase in residential energy consumption (averaging 3.1 percent annually between 1970 and 1989, Table 2), above the growth in population (2.6 percent per year). It is interesting to note that despite the deep economic depression of the 1980's, residential energy demand continued to increase at practically the same rate between 1970-1980 and 1980-1990 (Figure 5). This could be due to the growth in the informal economy, a coping strategy of households when incomes decline. The residential sector has remained between 20 and 24 percent of total energy demand of Mexico during the last two decades (Figure 1). In 1989, the 690 PJ of residential energy demand were obtained as follows: wood (49%); LPG (34%); electricity (10%); natural gas (4%); and kerosene (3%).

2. An increasing proportion of LPG and electricity in the total residential energy demand (Figure 5 and rates of growth of fuels as given in Table 2). This increase is

[11] National surveys suggest that the portion of household income destined to energy increased from 1.8 percent in 1983 (INEGI 1985) to nine percent by the end of the decade (Gutiérrez 1990).

[12] Included here are residential biomass and LPG energy use; two residential fuels for which no market-based energy use statistics exist. We estimate household consumption of these fuels using a end-use analysis as explained in the notes to Table 3.

partly due to an improved access to these energy sources (through rural and peri-urban electrification and an expansion of LPG serviced areas), as well as a more intense use of each fuel, either for more uses (particularly the case with electricity), or the acquisition of larger, more fuel consuming gas appliances (Figures 6 and 7).

3. A strong inter-fuel substitution, particularly of LPG for kerosene and wood (cooking), and electricity for kerosene (lighting). The demand for kerosene has dropped sharply during the past 20 years (Table 2).

4. In the rural sector, a relatively steady demand for traditional fuels, where wood still dominates the energy use.

To analyze in more detail the above trends, its is necessary to disaggregate the structure of residential demand by subsector (urban and rural), and by end-uses. Since energy is a means to an end, i.e., it is used to obtain goods and services (e.g., cooking, lighting, etc.), the end-use analysis will also permit an identification of the opportunities for energy efficiency in the residential sector.

There is not enough historically accurate data on residential energy end-uses to permit a time-series description. Tables 3 and 4 show an estimate of residential energy end-use for 1987. The values given in these Tables are based on a wide compendium of sources.[13] The lack of detailed end-use information makes our values illustrative; they should not be considered to be exact. Only further, end-use oriented research will refine their accuracy.

Energy demand by end-use (E_i) is calculated with the following formula:

$$E_i = S_{ik} \times UC_{ik}$$

where:

S_{ik} = Saturation (percent of homes that use the technology) for end-use i and fuel k,

UC_{ik} = Unit household energy consumption per year, by end use i and fuel k (measured in GJ or MWh if the resource is fuel or electricity).

Total energy demand of the residential sector is simply the sum of each end-use's demand.

Our analysis suggests that cooking (61%), water heating (27%), lighting (5%), and refrigeration (2.6%) are the major end-uses of the residential sector energy demand

[13] See the notes at the end of Table 3 for a detailed description of information sources and assumptions used in the calculations.

(Table 3).[14] Wood and LPG are the main fuels for cooking and water heating. Lighting (35%) and refrigeration (26%) are the main uses of electricity.

There is a marked difference between the rural and urban sectors when comparing fuels and end-uses. In the urban sector there is an almost complete dependence on LPG and electricity.[15] Almost 100 percent of the homes are electrified--the exception being a few marginal areas or those of recent colonization in urban centers experiencing fast growth.

Urban households have significantly higher appliance saturation levels than rural households due to their relatively larger income, the variety of product markets to which they have access, and the increased reliability of the fuel distribution grid. In urban households, cooking is almost exclusively done with LPG. Almost 60 percent of families use water heaters (50 percent gas, 7 percent wood). As far as electricity is concerned, 88 percent of urban homes have at least one television (many have more than one); 70 percent have refrigerators, and 58 percent clothes washers (Sepúlveda 1989). Due to a moderate climate in most of the country, air conditioning is only used in the north, southeast, and in the coastal regions of Mexico. The highest saturation level and unit consumption values for air conditioning are found in the northwestern cities (Mexicali and Hermosillo).[16]

In the rural sector, cooking (particularly with wood) dominates the energy panorama. Use of two fuels is common. Wood is used by about 79 percent of the rural population and accounts for 75 percent of rural energy consumption (Tables 3 and 4). Fuelwood and other biomass fuels are mostly used in low efficiency, three-stone-fires. This leads to very high unit consumption values (60 GJ per household per year). Water heating is done with LPG (five percent of homes) and with wood (eight percent with stoves, and 79 percent with three-stone-fires for bathing). Approximately 43 percent of rural homes are lit with kerosene or ocote (a natural resin) in rustic fixtures. Electrical demand is mostly for lighting and to a lesser degree, refrigeration and entertainment (television and radio). The low purchasing power of the rural population

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[14] The determination of residential energy demand from end-uses can serve to corroborate official statistics presented in the National Energy Balances. In our case, we found differences for several fuels between the demand indicated in the National Energy Balance and that obtained with our end-use analysis (see notes at the end of Table 4 for a possible explanation of these differences). Although the data on which we based our end-use analysis still has many deficiencies, a comparison of the results from both methods serves as a mechanism to verify the base information.

[15] Traditional energy sources and kerosene can be significant in peri-urban areas of the large cities in the center and south of the country (for example, Uruapan, Pátzcuaro, San Cristobal de las Casas).

[16] For the municipality of Hermosillo, saturation of air conditioning equipment is estimated above 50 percent, resulting in an electricity demand equivalent to 36 percent of total residential electric demand for Baja California Norte State (De Buen 1990).

The use of kerosene in stoves and lights leads to significant pollutant exposures in rural homes which in the long term can lead to pulmonary cancers.

The use of LPG represents a substantial reduction in health risks due to its relatively clean burning and safer combustion products. Specific risks due to its use are death by intoxication (due to leaks) or explosions.

Wood, LPG, and kerosene can cause fires (the probability of which depend on the technology used). Electric appliances major risks are death by electrocution and fire danger.

b) Indirect impacts

Besides the direct impacts of every energy resource, their use has environmental and risk impacts which are regional, national and global.

Fuelwood use beyond the carrying capacity of the resource base leads to forest degradation, biodiversity loss, soil erosion, and watershed degradation. Current data do not permit an evaluation of how much of residential wood harvesting is done in a non-sustainable manner. Estimates of residential wood demand show it to be two-to-three times commercial wood production.[20] In many regions with high population density, low income levels, and lack of forest resources (Altos of Chiapas, Mixteca Oaxaqueña, Sierra of Guerrero, and large parts of the Central Highlands), the impact of wood use on the forest resource is substantial. The accelerating decline in forests due to commercial activities can be augmented by the continued use of wood by households as they begin to rely more on cutting down trees as the supply of dead wood, branches and bushes is reduced (SARH 1990).

In arid regions, electric generation with thermoelectric power plants contribute to ground water and aquifer depletion, and an increase in water salinity.[21] Hydroelectric plants flood extensive areas, resulting in some cases in species extinction, relocation of large populations, and flooding of archeological sites. Nuclear power plants pose a danger of accidents spewing forth radioactive materials. Their radioactive fuels and wastes also pose many problems for safe handling and disposal.

- Evaluate the health impact, which depends on the toxicity of the pollutant and the dose received. Due to the lack of detailed epidemiological studies on this theme, in this section we limit our analysis to calculating the emissions of the different pollutants only.

[20] One must be careful not to compare commercial and residential wood use using the same physical measure. Commercial wood use is based on cutting down live trees. Residential wood use is based on collecting dead wood, branches and bushes.

[21] In northern Mexico, where water is very scarce, electricity is generated with systems requiring large amounts of water for cooling (De Buen 1990).

Mexico's sole nuclear power plant complex is situated upwind (about 2/3 of the time) of the highly populated central highlands, and about the other 1/3 of the time upwind of the Gulf of Mexico.

The use of hydrocarbons leads to many environmental impacts throughout their fuel cycle (Willars 1992). Exploration and production have already led to significant environmental damage in Mexico's Gulf coast (e.g., Ixtoc offshore oil well spill) and the destruction of jungle in the Southeast. Hydrocarbons use for electricity also has led to important degradation of air quality on a local and regional level (e.g., Mexico City's unenviable claim to having one of the world's worst air quality).

The combustion of fossil fuels results in significant emissions of particulates, global warming gases ($CO2$, $CH4$, $N2O$), nitrogen oxides (NOx), and sulfur oxides (SOx). The continued addition of these gases to the atmosphere, besides having an impact on the immediate areas, can also lead to acid precipitation and global problems of climate change.

From the values in Table 4, we estimate that the residential sector accounts for five to ten percent of national emissions of particulates, gaseous hydrocarbons and NOx, 14 percent of SOx, and up to 27 percent of total national CO2 emissions. Wood dominates particulate emissions, electricity NOx and SOx, and LPG and electricity dominate global warming gas emissions.

5. Energy savings potential

Residential energy use is expected to continue to grow due to the increasing number of users and also an increasing intensification of energy use per capita. No significant changes are expected in the evolutionary structural trends of residential energy use. Population growth is still considerable and average family size continues to decrease. Thus, the number of households will continue to increase more rapidly than population. The increasing urbanization of the country, together with a continued expansion of the energy supply services to peri-urban and rural areas, will further increase the use of modern-fuels. The continued population shift to areas of warmer climates and easier access to consumption goods will probably further increase residential energy use. The opening of Mexico's market to international goods can also reinforce the growth in energy use. Saturation of most major appliances is still relatively low in Mexico, which implies a large potential for growth in residential energy use. This growth can be ameliorated if more efficient appliances are introduced. Household income is expected to grow as the economy comes out of the depression and trade with the US improves. This will further increase the potential for residential energy demand growth.

Under these circumstances, an efficient use of energy by the residential sector becomes very important since it can lead to significant social, economic, and environmental benefits. Socio-economically, it permits the population to obtain the same (or better) energy services with less expenditures and saves the country significant amounts in deferred energy supply investments.

From an environmental point of view, a higher energy efficiency translates into a reduction in pollutant emissions and other impacts from the extraction, production, and use of fuels, and a decrease in health impacts.

Schematically, energy efficiency in homes can be obtained through five, non-exclusive ways:

1. Improving the energy service conditions (for example, reducing the voltage fluctuations in the electric grid, ensuring the quality of fuels, avoiding gas leaks, or installing individual household meters);
2. Improving current appliances (for example, increasing insulation around water heaters) or housing conditions (for example, better insulation or increased use of passive solar architecture);
3. Substituting fuels, particularly traditional with modern and including renewable resources (for example, solar water heaters);
4. Using more efficient technologies for the same fuels used today (for example, improved wood cookstoves, compact fluorescent lamps); and
5. Change technology use patterns, which is linked with changes in lifestyle and education of users (for example, turning off lights, reducing the temperature of the water heater, or appropriately ventilating the refrigerator).

Using a technical and socio-economic evaluation of these five main ways of saving energy one can estimate the technical potential for reducing unit consumptions by technology and end-use. The analysis is based on comparisons between current technologies and the most efficient technologies commercially available internationally. The analysis is done separately for the urban and rural areas (Tables 6-A and 6-B).

In the urban sector, priority areas for intervention are LPG and electricity use. For LPG several options exist that would permit households to reduce their unit consumptions between 20 and 60 percent in cooking, and 30 to 70 percent in water heating (Table 6-A). Given the favorable insolation patterns in most of Mexico, the introduction of solar flat-plate water heating collectors could imply significant LPG savings.

State of the art appliances could permit reductions of 20 to 80 percent of unitary electric consumption values. Air conditioning (with a technical savings potential of 20 to 80 percent) and lighting (where 75 percent reduction per bulb or 20 to 30 percent per household are possible) are priority areas for intervention due to their contribution to peak electric load demand. In the high-income sectors, policy should avoid a transition from LPG to electric cooking and water heating, a phenomenon that for example, is taking place in Venezuela (Ketoff et al 1991; Ketoff & Masera 1990;

Figueroa et al. 1992).

In the rural sector, the highest priority is to decrease wood used for cooking. This can be obtained in the short term with the diffusion of improved wood cookstoves (30 to 50 percent reduction in unit consumption, see Table 6-B). Besides having important environmental and socio-economic advantages (reduced cash expenditures for purchased wood or time spent in its collection), the dissemination of improved cookstoves would also significantly reduce the indoor air pollution problem due to smoke inside the homes. As in the urban sector, an important fraction of the LPG or wood demand for water heating can be displaced in the medium term with the introduction of solar water heaters.

Rural electric uses also have an important growth potential as a result of the increasing rural electrification and low appliance saturation. Renewable resources such as solar, hydro, wind, and biomass can play an important part in this electrification and help reduce the demand for fossil fuels from centralized electric generation.

Lighting is currently the most important electric end use in rural areas. Television and refrigeration also have a large growth potential. For these end-uses, savings of 20 to 80 percent are attainable with current technologies. One important phenomenon that could happen and is very important to avoid (due to the low income levels of rural inhabitants and the increasing commercial openness of Mexico), is the saturation of rural homes with second-hand, inefficient technology. Policies to avoid this are implementing regulations that will ensure that national and imported appliances have minimum efficiency levels. Also needed are regulations to limit used appliance markets to try to rid society of very old and inefficient appliances. Policies should improve access to more efficient technologies to low income homes.[22]

It is important to note that since most of the rural and a good amount of the peri-urban areas have a non-saturated demand, the adoption of more efficient technologies will not necessarily result in a reduction of household electric use. Families may use the saved resources to cover more fully their needs (for example, using more lightbulbs in their home or buying a new appliance). The real savings potential can be seen as a reduction in the growth rate of electric demand.

6. Barriers and solutions for the efficient use of energy and/or renewable resources

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22 To avoid costly failures, the dissemination of efficient technologies in the rural sector (and in particular those based on renewable resources), must include not only the installation of the technology, but also an adequate technical support system that includes customer training, repair shops, and replacement parts markets. Also, the ambient characteristics where the efficient appliances will operate (voltage fluctuations, dust, etc.), must be taken into account in the design of these technologies to ensure their success in the field.

Although there is a substantial potential for the introduction of economically feasible efficient and/or renewable technologies, there are many obstacles to their rapid dissemination and adoption. These barriers occur at all levels of the actors involved: end users, appliance manufacturers, government agencies, and financial institutions (national and international). The success of programs that promote the adoption of efficient technologies will lie in identifying all the relevant actors and ensuring that all their interests and needs are met. In Table 7 we discuss briefly for each of the major actors, the barriers for adoption of energy efficiency and ways of overcoming them. Below we discuss some particularly troublesome issues for Mexico's situation.

a) Barriers

High income groups do not concern themselves with their energy expenses, which represent a small portion of their income. Their interest in emulating industrialized country lifestyles (characterized by a high saturation of a wide variety of appliances whose unit consumptions are larger than national brands) results in them using much more energy than the average population.

Low income groups lack the disposable income or access to credit to purchase more efficient appliances (which normally are also the luxury lines where efficiency is part of a package of luxury amenities). They are thus forced to buy low quality and/or used equipment whose low efficiency is usually a result of either deterioration with time and/or low quality technology. Similarly, in rural areas, they rely on inefficient three-stone fires instead of more capital intensive improved wood stoves.

Appliance manufacturers and distributors sell what is most profitable. This leads to a division in their product lines to serve two distinct markets: one for the majority of domestic consumers (where emphasis is on keeping production costs and price to consumers low), and the other for the high income or export market (where products are similar both in technology and cost to those available internationally). Under this scheme of things, energy efficiency only becomes an issue when it limits entry to the lucrative export market. In the national market, the incentives for them to produce and sell more efficient appliances are very weak.

The government and the public utilities are constrained from taking action to stress energy efficiency due to lack of or misallocation of financial resources, socio-political considerations, and their own institutional inertia. External debt payments limit the amount of funds available to promote local technological research and development. Although the government would like to reduce the large energy subsidy to the residential sector, it cannot increase energy prices abruptly since as seen in section 2, energy has become an important component of household costs for the majority of Mexicans. The government and public utilities also see their actions limited by their own institutional inertia, product of large bureaucratic apparatuses, entrenched centralized energy interest groups, and a past history where their mission was seen as one of increasing energy supply and where the perspective of energy as a means of obtaining a service is unknown.

The financial institutions have also historically, only focused on lending money to large projects and for centralized energy production. These institutions do not have innovative financing schemes to facilitate the adoption of efficient technologies. Their high overhead costs also inhibit financing many small accounts.

b) Solutions

Any group of measures and policies taken to promote efficient or renewable energy use will face the barriers just mentioned (also shown in Table 7). To succeed, they will have to harmonize all the interests of the groups involved.

Increasing energy prices to reflect long-run marginal costs is a first and essential task to put energy efficiency and renewables on an equal playing field with supply increases. This will also eliminate the costs of the subsidies being suffered by the public coffers and send the right price signal to users.

Tariffs must be designed so that they discourage wasteful uses of energy and also educate the user on the importance of saving energy. To avoid overwhelming low income families and overcome social resistance to tariff increases, it is fundamental to accompany the price policy with an effort to disseminate efficient technologies in such a way that there are no net increases in consumer bills. This can be accomplished by assuring that the more efficient technologies reduce consumption at least by as much as the tariffs are increased. To ensure access to the more efficient and higher first-cost technologies among the lower income groups, subsidies or innovative financing schemes can be set up to reduce the initial incremental cost of these technologies to users.

Appliance manufacturers can be pushed to make efficient appliances with the elaboration of minimum efficiency standards and energy consumption labels, which also assist consumers in appliance purchase (Turiel et al 1991).

For government and public utilities, a fundamental change in their energy planning paradigm is required. They must be made aware that energy is a means of providing services and obtaining goods. Current agencies in charge of promoting energy efficiency must see their authority and budget reinforced and strengthened to ensure that their actions result in change. It is also important to coordinate the actions of the various energy efficient agencies (Table 7). The national electric utilities could be key promoters and implementers of demand-side management programs.

Financial institutions have a crucial role to play to get energy efficiency implemented. Under a collaborative framework which involves all the concerned parties and which also includes government guarantees and/or trust funds, these institutions can provide the financing to help cover the high initial costs which characterize the more efficient equipment.

Mexico has already taken the first steps to promote efficient energy use. The government is committed to continue the process of real increases to electric tariffs. Institutions have been created whose sole purpose is the promotion of energy efficiency (for example, the National Commission for Energy Savings-CONAE); pilot projects have been begun between the electric utility and manufacturers for the dissemination of compact fluorescent lamps (Blanc 1990); and trust funds have been instituted with private industry involvement (FIDE) to finance research, development, and demonstration through pilot projects. International financial institutions (World Bank, Interamerican Development Bank) have also begun to back some of these initiatives. The country is in the process of elaborating consensus minimum efficiency standards and energy use labels for appliances (refrigerators, air conditioners, motors, televisions, and clothes washers). The government is also promoting the electrification with renewables of many of the 86 thousand rural villages currently not connected to the grid. Furthermore, a national program for the dissemination of improved cookstoves in rural areas is beginning (CONAE 1993; Navia 1992). The continued and increased size of these programs, and their enlarged scope to cover all aspects of the energy needs of urban and rural households, will in large measure determine the success of these programs in the medium and long term.

7. Conclusions and proposed future work

In the previous sections we have tried to present the first integrated vision of the Mexican residential sector, based on an end-use analysis. The general conclusions of our work can be summarized as follows:

- Currently more than 95 percent of the residential energy demand is for four end-uses: cooking (61%), water heating (27%), lighting (5%), and refrigeration (2.6%). It is estimated that in 1987, 72 percent of the population cooked with LPG and 25 percent with wood. Approximately 49% of the population had water heaters (primarily gas); 86% had electric lighting, and 58% had refrigerators.

- The structure of energy consumption is different for rural and urban areas. In the urban areas there is a larger and more diverse set of appliances, particularly for electricity end-uses (lighting, refrigeration, television, air conditioning), which account for 15% of total energy use. In the rural areas, wood cooking represents 75 percent of residential consumption. In 1987, over 40 percent of rural homes did not have electricity. Electric appliance saturation in the rural sector is very low due to lack of connections to the grid and low income levels.

- The urban and rural averages hide important regional and income differences in the total household energy consumption and its distribution among end-uses and fuels. These could not be analyzed due to the quality and scope of current data.

- Residential energy use is implicated in a wide range of environmental and health impacts. Wood burning in open hearths and kerosene in simple lighting fixtures in rural areas produce large amounts of particles and volatile hydrocarbons which result in respiratory ailments and increase long-term cancer risks. Among the major indirect impacts of residential energy use are the degradation of forests, flooding of large areas, decline in aquifers, potential exposure to radioactive particles, and other ecosystem damages from the exploration, extraction and use of hydrocarbons. Preliminary estimates of the residential sector's contribution to national emissions are 27% of CO_2 and 14% of SO_x.

- Residential energy demand has a large growth potential due to the evolutionary trends of its structural characteristics:

1. A large increase in the number of households, resulting from the demographic growth and the continued decrease in average family size in both urban and rural areas;
2. The increasing urbanization and energy services grid expansion to rural and peri-urban areas;
3. The redistribution of the population to geographic areas with warmer climates;
4. The government policy of opening the Mexican market; and
5. The low saturation levels for residential appliances.

- The greatest growth in the near future will continue to be in LPG and electricity.

- The efficient use of energy and renewables constitutes a viable and important option for reducing the rate of growth in residential energy demand and facilitating a development process that is socially, economically, and environmentally sustainable. Principal areas for achieving increased energy efficiency in the short term include:

a) In the rural sector: Reduction of biomass consumption through the introduction of improved wood cookstoves. In the medium and longer term, substitution of wood with liquid or gaseous fuels and the introduction of renewable and decentralized energy technologies. Ensure that the rural sector does not become a refuge for discarded second-hand technology.

b) In the urban sector: Due to lighting and air conditioning's impact on peak electric demand, dissemination of compact fluorescent lamps and efficient air conditioning equipment (this last one in particular in the north of Mexico). Promote the purchase of other important electric uses with the most efficient appliances (refrigeration, television). Reduce the LPG consumption in cooking and water heaters with simple measures such as electronic-pilot lighters and insulating blankets. As with the rural sector; the measures taken must be wide in scope to ensure that service conditions and the equipment used improve.

- To ensure the success of energy efficiency it will be necessary to overcome a series of barriers that exist among end-users, appliance manufacturers and distributors, government agencies, and financial institutions. Important actions to overcome the many barriers (some of which are already being implemented) are institutional reforms, restructuring the price and tariff systems of fuels and electricity, establishing minimum efficiency standards and labels for appliances, and setting up innovative financing schemes. It is important to ensure at least neutral impacts on low income sectors, for example by having price hikes together with efficiency measures.

One of the most urgent tasks we have identified is the need to generate a national residential energy data base disaggregated by end-use demand. It is crucial to have more precise and detailed information on appliance saturation and unit consumptions for any residential energy efficiency program. Indispensable activities are the processing of current household sector surveys (Gutiérrez 1990; SEMIP 1988b; Willars 1989) from an end-use perspective as well as the elaboration of new, detailed, regional and national residential surveys.

A second crucial task is a better determination of the environmental and health impacts of residential energy use. Research on these impacts must cover the entire fuel cycle, including the determination of emission factors of each fuel, concentrations and doses suffered by the population for each of the main pollutants, and epidemiological studies on the associated health impacts.

Another important task is promoting research, development, and dissemination of efficient and renewable technologies in Mexico. This should include the development of new technologies and also the adaptation of foreign products and processes to Mexico's reality.

Pilot projects must be initiated to learn the technical and institutional difficulties and challenges that will be faced in the dissemination of the more efficient and/or renewable technologies.

Within the energy sector two main fundamental tasks are required:

1. The energy planning paradigm must be changed. Energy must be viewed as a means to satisfy needs and services (cooking, lighting) and not an end in itself. The basic question planning should ask is not how to supply more energy, but what is the most economically, socially, and environmentally viable way of supplying the energy services to the population: by increasing supply, reducing demand, or a combination of these; and

2. Set up a planning framework that provides a level playing field for centralized and decentralized energy resources and efficiency. This includes a revision of the current policy of support for research, development and dissemination of technologies and energy resources and a restructuring of the economic methods used in their assessment (including for example the costs of saving energy and the environmental externality costs).

The suggested actions are not simple nor are the results easy or quick to get. We are talking of a radical change in the way in which energy is conceived in the economic development process of Mexico. Continuing with business as usual is nevertheless impossible for the country, its inhabitants, and the environment.

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TABLE 1

RESIDENTIAL SECTOR: GENERAL INDICATORS

Indicator	National	Urban	Rural[a]
Demographic (1990)[b]			
Population (million)	81.1	57.6	23.5
Dwellings (million)	14.7	10.9	3.9
Persons/dwelling	5.5	5.3	6.1
Growth rates 1980-1990			
Population	2.0 %	2.7 %	0.4 %
Dwellings	2.3 %	2.6 %	1.7 %
Persons/dwelling	-0.4 %	0.0 %	-1.1 %
Average Income			
Number of minimum wages[c]	1.6	1.8	0.97
Poor (% of population)[d]	30 %	23 %	43 %
Indigent (% of population)	10 %	6 %	19 %
Income distribution[e]			
Lowest income quintile	3.0 %	4.0 %	3.5 %
Highest income quintile	52.0 %	48.0 %	54.0 %
Average expenditure on energy[c]			
1989 (% of income)	9.0 %	7.3 %	13.1 %

Notes: a. We considered rural all villages with less than 2,500 inhabitants.
b. Population figures taken from INEGI, 1985 and 1991.
c. Figures for average income and average expenditures in energy taken from Gutiérrez-Elizarrarás (1990); the minimum wage in mid-1989 was 8,640 $MEX/day(Elizalde, 1990).
d. From CEPAL, 1990. Poor are those who do not satisfy their basic needs (including non-food related). Indigent are those who do not fulfill their alimentary needs.
e. Data for income distribution taken from INEGI, 1985. Figures indicate the proportion of total income represented by the quintiles of lowest and highest incomes, respectively. For example, the population quintile of lowest income only received 3% of total national income.

TABLE 2-A

RESIDENTIAL FINAL ENERGY USE BY SOURCE

Energy Use	1989 (PJ/yr)	AAGR[a]	
		1970-1989	1980-1989
National Energy Demand	3276	5.2 %	1.7 %
Residential Demand	690	3.1 %	2.8 %
Fuelwood	335	1.1 %	1.2 %
L.P.G.	238	7.8 %	6.7 %
Natural Gas	29	4.2 %	4.5 %
Electricity	67	9.3 %	7.2 %
Kerosene	17	-3.6 %	-10.2 %
Intensities (GJ/capita/yr)	**1987**	**1970-1987**	**1980-1987**
Fuelwood	16.9	1.7 %	1.4 %
Gas (L.P.G + Natural)	4.3	1.4 %	1.9 %
Kerosene	2.7	1.3 %	-3.6 %
Electricity (kWh/cap/year)	244	4.0 %	3.6 %

Notes: Data taken from SEMIP, 1990. Average growth rates for residential fuels were calculated by estimating residential energy use within the period 1970-87 (from 1987 to 1989 these appear desaggregated in the National Energy Balances). Energy use intensities by fuel are calculated as residential demand over the number of users of each fuel.

a. AAGR = annual average growth rate.

TABLE 2-B

RESIDENTIAL FINAL ENERGY USE BY END USE, 1987

End Use	Urban	Rural	Total National
Total (PJ/year)	325.9	234.4	560.2
Cooking	47.3 %	80.3 %	61.1 %
Water heating	38.0 %	12.5 %	27.3 %
Space heating	0.4 %	n.d.	0.3 %
Lighting	5.8 %	4.0 %	5.0 %
Refrigeration	4.0 %	0.7 %	2.6 %
Television	1.8 %	0.2 %	1.1 %
Air conditioning	1.4 %	0.0 %	0.6 %
Clothes washer	0.4 %	0.0 %	0.2 %
Ironing	0.7 %	0.3 %	0.5 %
Other	0.2 %	2.1 %	1.0 %

Note: See notes to Table 3 for explanation of these estimates.

TABLE 3

RESIDENTIAL ENERGY USE BY END USE IN 1987

	Urban		Rural		Country	
Population (million)	54.1		22.5		76.6	
Household size (persons/hh)	5.3		6.1		5.5	
	Energy use	Satur.	Energy use	Satur.	Energy use	Satur.
TOTAL (PJ/yr)	325.9		234.3		560.2	
(Percent)	58%		42%		100%	
COOKING (PJ/yr)	154.1		188.1		342.2	
L.P.G. (PJ/yr)	123.2		10.0		133.2	
UC (GJ/hh/yr)	13.7	87%	15.9	17%	14.3	67%
Natural Gas (PJ/yr)	9.2		0.0		9.2	
UC (GJ/hh/yr)	13.7	7%	0.0	0%	10.1	5%
Fuelwood (PJ/yr)	16.4		175.2		191.5	
UC (GJ/hh/yr)	51.7	3%	60.1	79%	54.2	25%
Kerosene (PJ/yr)	5.3		2.9		8.2	
UC (GJ/hh/yr)	17.1	3%	19.9	4%	17.9	3%
WATER HEATING (PJ/yr)	123.8		29.3		153.1	
L.P.G. (PJ/yr)	87.8		4.2		92.0	
UC (GJ/hh/yr)	16.9	50%	22.7	5%	18.5	37%
Natural Gas (PJ/yr)	6.6		0.0		6.6	
UC (GJ/hh/yr)	16.9	4%	0.0	0%	16.9	3%
Fuelwood:w. heater (PJ/yr)	28.1		13.6		41.7	
UC (GJ/hh/yr)	39.0	7%	44.3	8%	40.6	7%
Fuelwood:three-stone fire (PJ/yr)	1.2		11.5		12.7	
UC (GJ/hh/yr)	3.9	3%	3.9	79%	4.0	25%
Kerosene (PJ/yr)	n.d.		n.d.		n.d.	
UC (GJ/hh/yr)	n.d.	3%	n.d.	0%	n.d.	2%
SPACE HEATING (PJ/yr)	1.4		0.0		1.4	
Fuelwood (PJ/yr)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
UC (GJ/hh/yr)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Electricity (PJ/yr)	1.4		0.0		1.4	
UC (MWh/hh/yr)	0.3	14%	0.0	0%	n.d.	10%
LIGHTING (PJ/yr)	18.9		9.3		28.2	
Electricity (PJ/yr)	18.0		2.1		20.1	
UC (MWh/hh/yr)	0.5	98%	0.3	57%	0.4	86%
Kerosene (PJ/yr)	0.9		7.1		8.0	
UC (GJ/hh/yr)	5.6	2%	5.6	34%	5.7	11%
Fuelwood (PJ/yr)	0.1		0.1		0.2	
UC (GJ/hh/yr)	0.7	0%	0.7	1%	0.7	1%
REFRIGERATION (PJ/yr)	12.9		1.6		14.6	
UC (MWh/hh/yr)	0.5	70%	0.5	24%	0.5	58%
TELEVISION (PJ/yr)	5.9		0.4		6.0	
UC (MWh/hh/yr)	0.2	88%	0.1	38%	0.2	76%
AIR CONDITIONING (PJ/yr)	4.7		0.1		3.5	
UC (MWh/hh/yr)	1.6	8%	0.8	1%	1.4	6%
CLOTHES WASHING (PJ/yr)	1.3		0.0		1.3	
UC (MWh/hh/yr)	0.1	58%	0.1	3%	0.1	42%
IRONING (PJ/yr)	2.2		0.7		2.9	
UC (MWh/hh/yr)	0.1	80%	0.1	38%	0.1	68%
OTHER ELECTRIC (PJ/yr)	0.7		4.9		5.5	
UC (MWh/hh/yr)	0.0	100%	0.4	100%	0.1	100%
TOTAL ELECT (PJ/yr)	47.0		9.8		56.9	
UC (MWh/hh/yr)	1.3		0.7		1.1	

Notes to Table 3:

a. satur. = saturation (percentage of households that use the fuel indicated); UC = unit consumption (annual energy use by household or device); n.d. = no data available.
b. Fuel saturations were obtained from the survey of Willars (1990) (only urban sector), the survey by SEMIP (1988b), and from Masera (1990) (rural sector). General reports with data on residential energy use were also used (Mendoza and Macías, 1991a) as well as additional information: TV and refrigerators (Sepúlveda, 1989); and clothes washers (ANFAD, 1990). In this report the urban sector is constituted by settlements with more than de 2500 inhabitants. Willars (1990), considers as urban settlements those larger than 15,000 inhabitants. For this reason we adjusted his data to fit our criteria. Average household size is from Partida (1988) and INEGI (1985)
c. We used the following assumptions: (i) Energy equivalents: fuelwood (18 MJ/kg); L.P.G. (51 MJ/kg), natural gas (40 MJ/m^3); and kerosene (39 MJ/lt) (SEMIP, 1990); (ii) Cooking: 0.14 kg/cap/day (L.P.G.); 1.5 kg/cap/day (fuelwood) (Masera et al., 1987); we assumed that the UC for natural gas is the same than that for L.P.G. and that the UC for kerosene is the same as that for L.P.G. adjusted by the difference in efficiencies between stoves for each fuel (50% L.P.G.; 40% kerosene, Leach and Gowen, 1989). (iii) Water heating: UC taken from Mendoza and Macías (1991a), three-stone fires (Masera, 1990) -we assume that rural inhabitants lacking water heaters use three-stone fires for water heating; (iv) Space heating: we couldn't determine UC for fuelwood, but it could be important in regions with cold winters; electricity (Mendoza and Macías, 1991a); L.P.G. is also used for space heating, but it wasn't possible to estimates the UC; (v) Lighting: an accurate estimate of the number of electrified households is difficult because of the different conventions used: CFE (1989b), for example, indicates 14.1 million users for 1987, but overestimates the total country population (82 million instead of 76.6 million for 1987). Therefore, their electrification figures are also overestimated. In this report we assumed an electrification of 86% national and 98% urban, assigning the rural electrification that fits the national figure. Non-electrified population is partioned between fuelwood and kerosene users; UC for electric lighting are from Friedmann (1991) and Mendoza and Macías (1991a) (urban) and Dutt (1989) and SEMIP (1988b) (rural); UC for kerosene 10 lt/dwel/month/month (Mendoza and Macías, 1991a) (high estimate); fuelwood 0.1 kg/day (Masera, 1990) -fuelwood used for lighting corresponds to ocote, a resinous portion of pine trees; (vi) Refrigeration: UC determined assuming average consumption of 2 kWh/lt and an average refrigerator of 250 lt., --these values correspond to an average for the values reported by Campero (1991) for refrigerator tests; (vii) TV: urban UC corresponds to an intermediate value between those reported by Mendoza and Macías (1991a) (400 kWh/year/dwel) and international comparisons (100-200 kWh/year), Geller (1991); rural UC form Dutt (1989); (viii) Clothes Washing: UC from international (60 kWh/year)(Schipper et al.,1988); (viii) Air conditioning: UC estimated from data on residential use for regions with hot summer (CFE, 1989a) and assumptions on average size, efficiency, and hours of use per device; (ix) Ironing: adapted from Mendoza and Macías (1991a); (x) Other electrical appliances: estimated as the difference between total electricity use per dwelling minus the sum of electricity consumption by end use.

The totals by source in Table 3 do not always coincide with those indicated by the National Energy Balance. This is the case for L.P.G. (225 PJ vs 203 PJ in the Balance); natural gas (16 PJ vs 28 PJ); fuelwood (246 PJ vs 324 PJ) and kerosene (16 PJ vs 23 PJ). Possible explanations for the divergences between the estimates in this report and those from the Balance -in addition to the potential errors in the estimates of saturations and UC- include: (i) L.P.G.: probably the UC are slightly over-estimated and there is an underestimation of the number of users of natural gas; (ii) Natural gas: it is possible that saturation is underestimated. However, even if the National Balance indicates that all natural gas goes to the residential sector, it is very likely that a fraction of natural gas demand goes for the commercial and public sectors; (iii) Kerosene, part of the underestimation of the demand is because this fuel is commonly used for non-energy end-uses (cleaning clothes and tools, etc.); (iv) Fuelwood, the most important divergence between this study and the Balance is because in the latter all fuelwood demand is assigned to household demand, even if there is a relatively important use of fuelwood in small rural industries (brick-making, ceramic workshops, bakeries, etc.).

TABLE 4
ENVIRONMENTAL IMPACTS AND HEALTH RISKS OF RESIDENTIAL ENERGY USE

Fuel/ Technology	Direct Impacts[a]	Indirect Impacts[a]	Total Residential Emissions	
	Health/Environment	Health/Environment	thous. ton.[b]	% Res. total
Fuelwood three-stone fire water heater	Volatile hydrocarbon -VHC- (0.1 kg/GJ), particulates (0.6 kg/GJ), NO_x (0.1 kg/GJ) and CO emissions cause respiratory illnesses, cancer and intoxication;[c] home fires	forest degradation, biodiversity loss, erosion, changes in the micro-climate and hydrology, greenhouse gas emissions CO_2 (assumed 23 kgC/GJ), CH_4 and CO.	187 P 37 HC 19 NO_x 8 SO_x 0-7727 CO_2[e]	85.2 62.2 14.7 10.4 0 - 48.8
L.P.G./Natural Gas stove water heater	CO, and NO_x (0.2 kg/GJ) emissions; leaks can cause death for intoxication, explosions and home fires	pollution, deforestation for extraction of crude oil and gas; refineries: CO_2 (L.P.G.: 16.1 kgC/GJ, natural gas: 13.6 kgC/GJ)emissions; emission of CH_4 by leaks in gas pipelines	0.5 P 0.5 HC 54 NO_x 4271 CO_2	0.2 0.8 41.9 27.0 - 52.7
Electricity bulbs refrigerator, etc.	death by electric shock electromagnetic radiation home fires	refineries/ power plants; average emissions: CO_2 148 tonC/GWh; CH_4 5 kg/GWh; N_2O 103 kg/GWh; particulates 146 kg/GWh; acid rain; SOx 2.8 ton/GWh; NOx 1.6 ton/GWh;[d] risks of nuclear accidents and death by cancer; flooding of areas for hydro dams and relocation of people	3 P 10 HC 38 NO_x 67 SO_x 3512 CO_2	1.4 16.8 29.5 87.0 22.2 - 43.4
Kerosene wick stove water heater	VHC, particulates and CO cause respiratory illnesses and cancer; home fires	pollution, deforestation by exploration and extraction of crude oil; refineries, emission of particulates 1.7 kg/GJ; HC 0.7 kg/GJ; NO_x 1.1 kg/GJ; SO_x 0.1 kg/GJ; CO_2 18.9 kgC/GJ.	29 P 12 HC 18 NO_x 2 SO_x 316 CO_2	13.2 20.2 14.0 2.6 2.0 - 4.0

Notes to Table 4:

a. Direct impacts refer to the consequences, at the level of the end-use, of the utilization of determined energy source/technology. Indirect impacts indicate those produced in the site of generation and/or production of the fuel. Not all health consequences indicates apply to every technology listed with each fuel. Unit emissions for pollutants shown were taken form DeCicco, 1990; Gleick, 1989; OTA, 1991; and Ottinger, 1990. Unit emissions for modern fuels are indicated as indirect impacts, but they include the production of pollutants both at the end-use and at the generation site. We do not include methane and N_2O emissions from biomass and hydrocarbon combustion because of the large uncertainties in these pollutant unit emissions.
b. P = particulates, HC = volatile hydrocarbons, NO_x = nitrogen oxides, SO_x = sulfur oxides, CO_2 = carbon dioxide. Total pollutant emissions are the product of unit emissions and the energy use of each fuel.
c. It has been shown that the high concentration of pollutants that result from biomass combustion in three-stone fires might lead to health risk comparable to those incurred by chronic smokers (Holdren, 1990; Smith, 1988). Epidemiological studies in Mexico also suggest that fuelwood use in three-stone fires might lead to a high incidence of respiratory illnesses (Onofre & Pérez, 1992; Selman, 1991).
d. Figures for unit and average emissions are shown only for illustrative purposes, because pollutant emissions per unit of energy very wide ranges of variation (up to 5 to 10 times), depending on the particular technology and the fuel characteristics. Average emissions have been calculated based on the following fuel consumption for electricity generation for 1989: coal 80 PJ, fuel oil and diesel 677 PJ; natural gas 113 PJ (SEMIP, 1990). A more accurate estimate of emissions from residential electricity use should take into account the specific demand by this sector (i.e its contribution to peak demand). Total annual emissions in Mexico are estimated as follows (in million tons) P 2.7; HC 1.2; NO_x 2.1; SO_x 0.5; and CO_2 58.7.
e. The specific amounts of greenhouse emissions from biomass or charcoal burning depends on the portion of fuelwood that is harvested on a non-renewable basis.

TABLE 5

ESTIMATED CONSUMPTION OF WOOD PRODUCTS IN MEXICO (1989)

Forest Resources	million m^3/year
Timber Production [a]	8.8
Fuels	23.5
Commercial use [a]	0.4
Fuelwood [b]	23.1
Total	32.3

Notes: It should be noted that timber and fuelwood consumption cannot be compared on the same basis. This is because fuelwood comes mostly from dead wood, branches, and shrubs (which are usually not considered as part of the commercial resource), while timber harvesting involves felling of living trees;
a. CNIF (1991);
b. Masera (1990) and Masera et al. (1991), it is assumed an average consumption of 2 kg/cap/day, 19 million of rural users, 0.6 ton/m$_3$ average wood density. Estimates on fuelwood use in the country range from 17 millions m^3/year (Castillo, 1989) to 32 millions m^3/year (Guzmán et al., 1985). Commercial fuelwood use corresponds essentially to charcoal production -an important share of which is exported.

TABLE 6-A
ENERGY SAVINGS POTENTIAL
IN THE MEXICAN RESIDENTIAL SECTOR

A. URBAN SECTOR

End use	Current Technology	Measures to save energy	Energy Saving Potential %
Cooking L.P.G.	stove 40-50% effic. (13.7 GJ/hh/year)	stove 70% effic.; electronic lighting; pressure cookers	20-60
Water heating L.P.G.	water heater 50% effic. (16.9 GJ/hh/year)	turn off pilots; insulate water heater; fix water temp. to no more than 48 °C; efficient boiler and showers; use cold water for washing; solar water heaters	30-70 50-100
Biomass	rustic water heater (39 GJ/hh/year)	efficient fuelwood water heater L.P. water heater solar water heater	20-70 50-100 50-100
Lighting	incandescent bulbs 8%-10% effic. (500 kWh/hh/year)	CFL 40% effic. automatic switches	20-30
Refrigeration	250 lt refrigerator (500 kWh/hh/year)	efficient refrigerators 1990: 350 kWh/year in Mexico; 240 kWh/year in Korea; 100 kWh/year in Denmark	30-80
Air conditioning	equip. with EER= 5-8 (1.6 MWh/hh/year)	equip. with EER= 10-15; better dwelling thermal insulation; passive solar designs	20-80
Television	50 W (B&W), 100-200W (color) (200 kWh/hh/year)	20-40 W (B&W) 50-80 W (color)	20-60 60-75
Clothes Care	washer (60 kWh/hh/year); gas dryer (4 GJ/hh/year)	Washer: cold wash; controls of water level and temperature; horizontal axis 30 kWh/hh/year; Dryer: effic. dryer of 3.2 GJ/hh/year; solar drying	20-70 20-100
Other Stereo, iron, small appliances	various wattages; imported appliances of larger wattage	more effic. appliances reduced size	n.d.

Note: Energy savings potential is defined here as the reduction in unit consumption that would result form replacing current technologies with efficient technologies commercially available in the market and penetration potential. Energy savings in residential demand depend on assumptions regarding saturation of each technology, and the penetration of efficiency measures. For lighting the number of light points economically viable was taken (around 1/4 of total points). EER = energy efficiency ratio (Millions of Btu/h/kW).
Sources: De Buen (1990), Dutt (1987 and 1989), Friedmann (1991), Schipper et al (1988), Shepard (1990), USDOE (1989a&b), Wilson, (1990)

TABLE 6-B
ENERGY SAVINGS POTENTIAL
IN THE MEXICAN RESIDENTIAL SECTOR

B. RURAL SECTOR

End use	Current Technology	Measures to save energy	Energy Saving Potential %
Cooking			
Fuelwood	three-stone fire; 17% effic. (60.1 GJ/hh/year)	improved stoves; biogas stoves; other modern biofuels fuel substitution to L.P.G.	30-50 60-80
L.P.G.	stove 40-50% effic. (15.9 GJ/hh/year)	gas stoves 70% effic., turn off pilots, pressure cookers	20-70
Kerosene	stove 40% effic. (19.9 GJ/hh/year)	substitution by effic. LPG stoves	30-80
Water heating			
Fuelwood	three-stone fire 17% effic. water heater (44.3 GJ/hh/year)	improved fuelwood water heater; substitution by solar water heater	30 100
L.P.G.	water heater 50% effic. (22.7 GJ/hh/year)	water heater 86% effic. and other measures Table 6-A substitution by solar water heater	30-70 100
Lighting			
Electricity	incandescent bulbs 8-10% effic. (300 kWh/hh/year)	CFL 40% effic.	20-40
Kerosene	home-made wicks and lamps (5.6 GJ/hh/year)	electrification with renewables; CFLs	90-100
Refrigeration	small refrigerator, 400 to 700 kWh/year; second-hand and very inefficient units	efficient refrig., 300 a 400 kWh/year	30-60
Television	50-200 W, most B&W (100 kWh/hh/year)	20-40 W (B&W) 50-80 W (color)	20-60 60-75
Other stereo, radio, iron	second-hand markets for appliances	avoid markets for junk technologies	maintain current CU

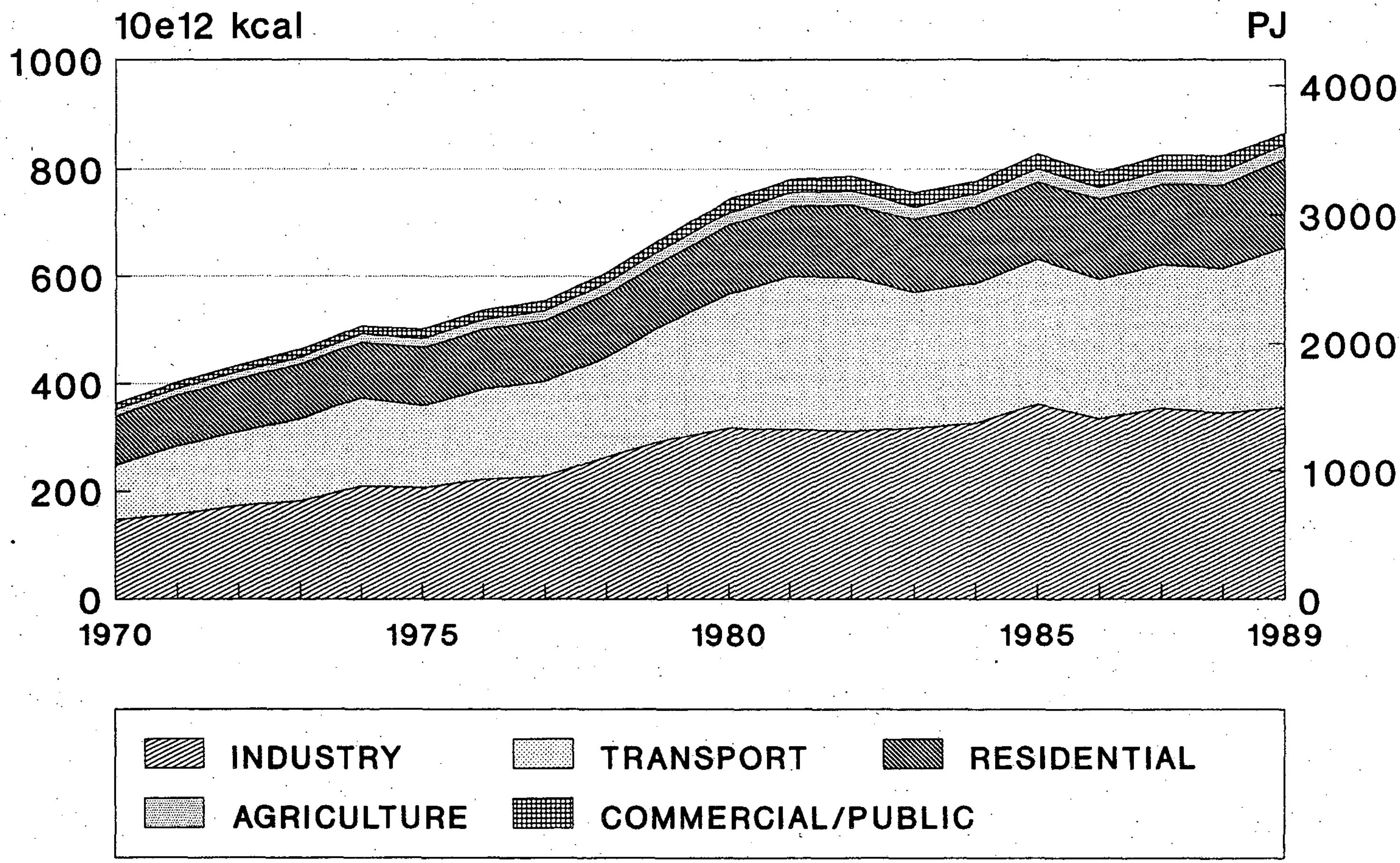
Nota: See notes to Table 6-A.

TABLE 7
ENERGY EFFICIENCY AND RENEWABLES
ACTORS, BARRIERS AND SOLUTIONS

BARRIERS	SOLUTIONS
User	
Lack of information on devices, savings potential, benefits and costs of savings. Subsidized energy. Limited access to efficient (high-capital cost) devices. Difficulties to get financing and to insure investment. Non-economic factors: fashion, lifestyles, and inertia. High-income: energy is low percentage of expenditures and/or income. Poor: limited income forces to recur to secondary markets; high discount rates.	Inform/educate. Labels and efficiency standards. Financing at low rates to reduce capital costs of devices. Promote industry of efficiency/renewables and energy services. True-cost energy prices.
Manufacturer/Supplier	
Minimizes production costs and retail prices. Avoids changes that modify production line. Depends on foreigners for new technology. Produces for a captive market. Does not care for operation costs of devices. Lacks information on efficient devices.	Labels and efficiency standards. Financing given according to efficiency. Support information, R&D, and marketing.
Energy Producer / Distributor (CFE, CLFC, PEMEX)	
Budget, profits and prestige depends on total sales. Money saved returns to government. Prefers centralized resources, easy to control and to administrate. Supply monopoly under present administration. Current paradigm: supply energy (as opposed to energy services) for economic development.	Change goal to service-oriented firms. Budget and profits determined by services. Least-cost planning, including decentralized energy sources. Provide incentives to independent energy producers and/or distributors.
Government (SEMIP, SECOFI, SH, SARH, SEDUE)	
Lacks understanding of potential, costs and benefits of renewables and efficiency. Current system created interest groups opposed to change. Energy prices are fixed regarding political considerations. Energy is seen as key "engine" of economy; energy costs are minimized with subsidies. Agency that promotes efficiency or renewables does not have power within current institutional set-up. Lack of communication/coordination among government agencies.	Least-cost planning, including decentralized energy sources. Price policies based on long-term marginal costs. Agency for renewables and efficiency should be under direct mandate of maximum political authority. Coordinate policies among state agencies to avoid counterproductive/contradictory measures.
International Actors	
Multinationals lobby aid agencies to support projects that increase supply. Interested in getting rid of obsolete technology in industrialized countries, monopolize R&D in new technology. Support projects instead of programs, that result in centralized technologies, easier to control from the financial center. Lack of institutional capacity and trained personnel in recipient country gives excuse to support centralized projects and to insist in rapid results.	Limit technology transfer to most efficient and appropriate. Demand assistance in technology evaluation. Promote technology leap-frogging. Emphasize local programs and participation. Promote initiation, establishment, and reinforcing of local capabilities to perform analysis and energy planning and to develop new technologies.

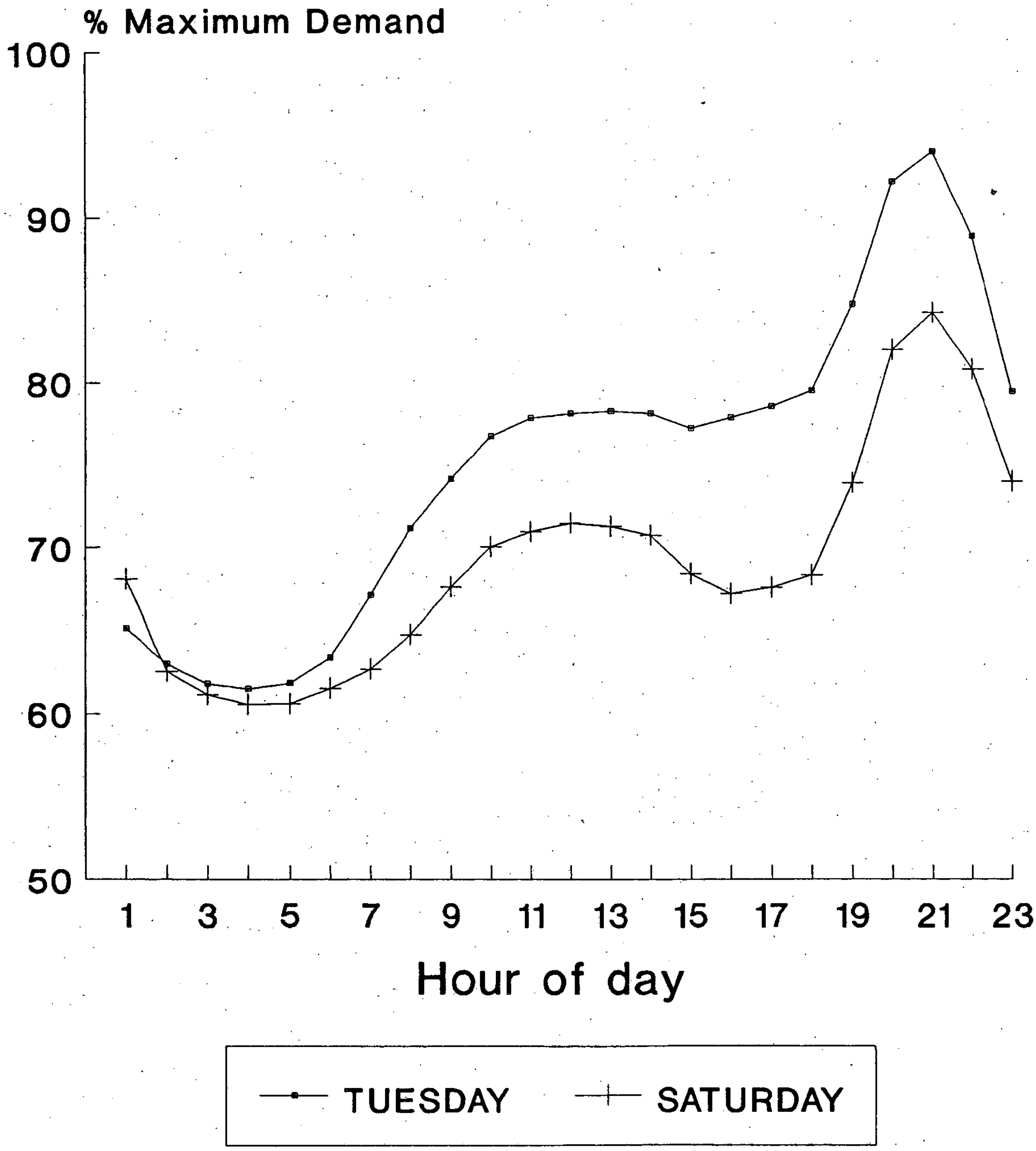
Sources: Kempton (1987), Lovins (1988ayb), Nadel (1991), Reddy (1990b), Schipper (1991), Stern (1984).

Figure 1: EVOLUTION OF FINAL ENERGY DEMAND IN MEXICO (by Sector 1970-89)



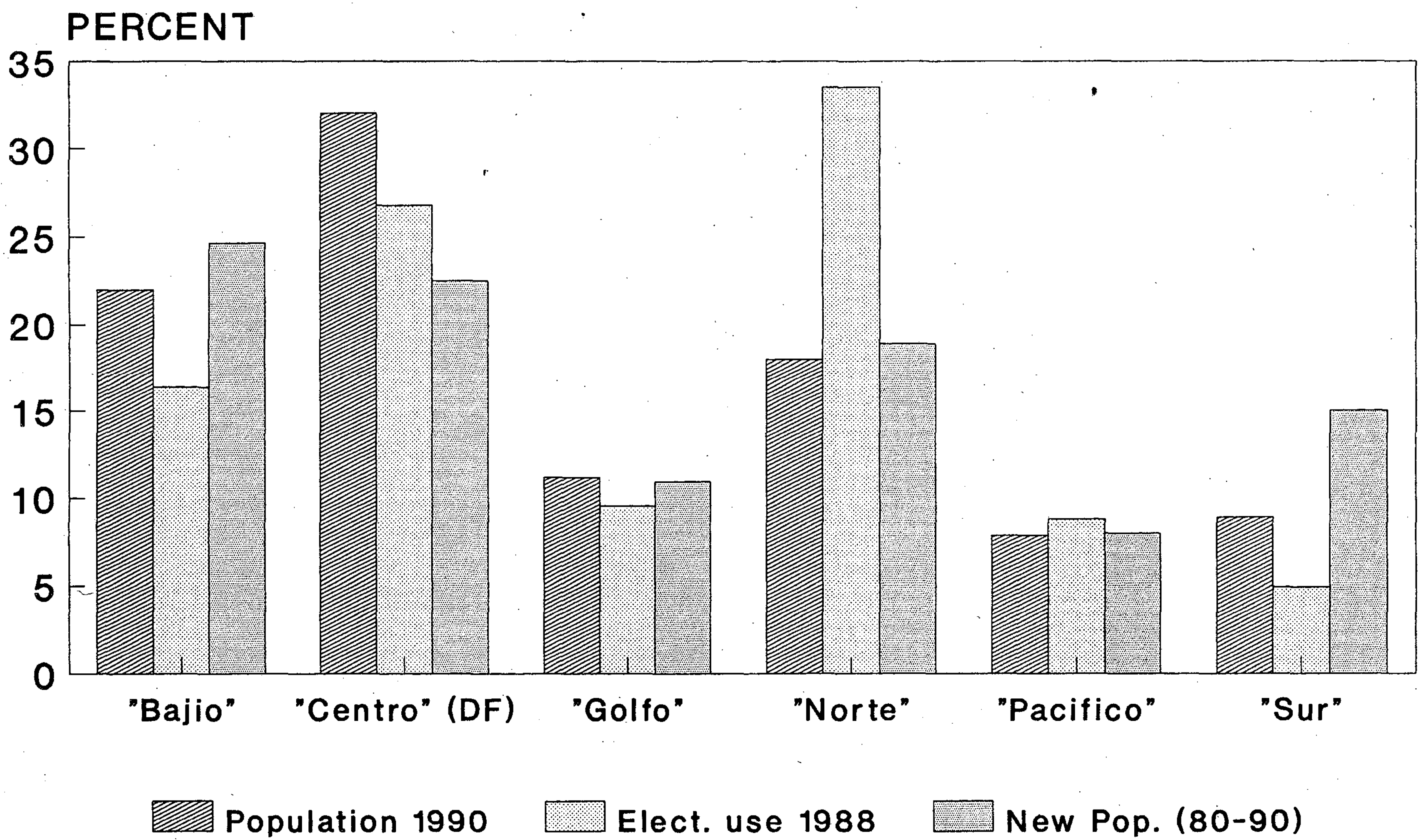
Source: SEMIP, Balances de Energia.
The industrial sector includes
basic petrochemical activities

Figure 2: MAXIMUM COINCIDENT DEMAND
NATIONAL INTERCONNECTED SYSTEM
MEXICO 1987



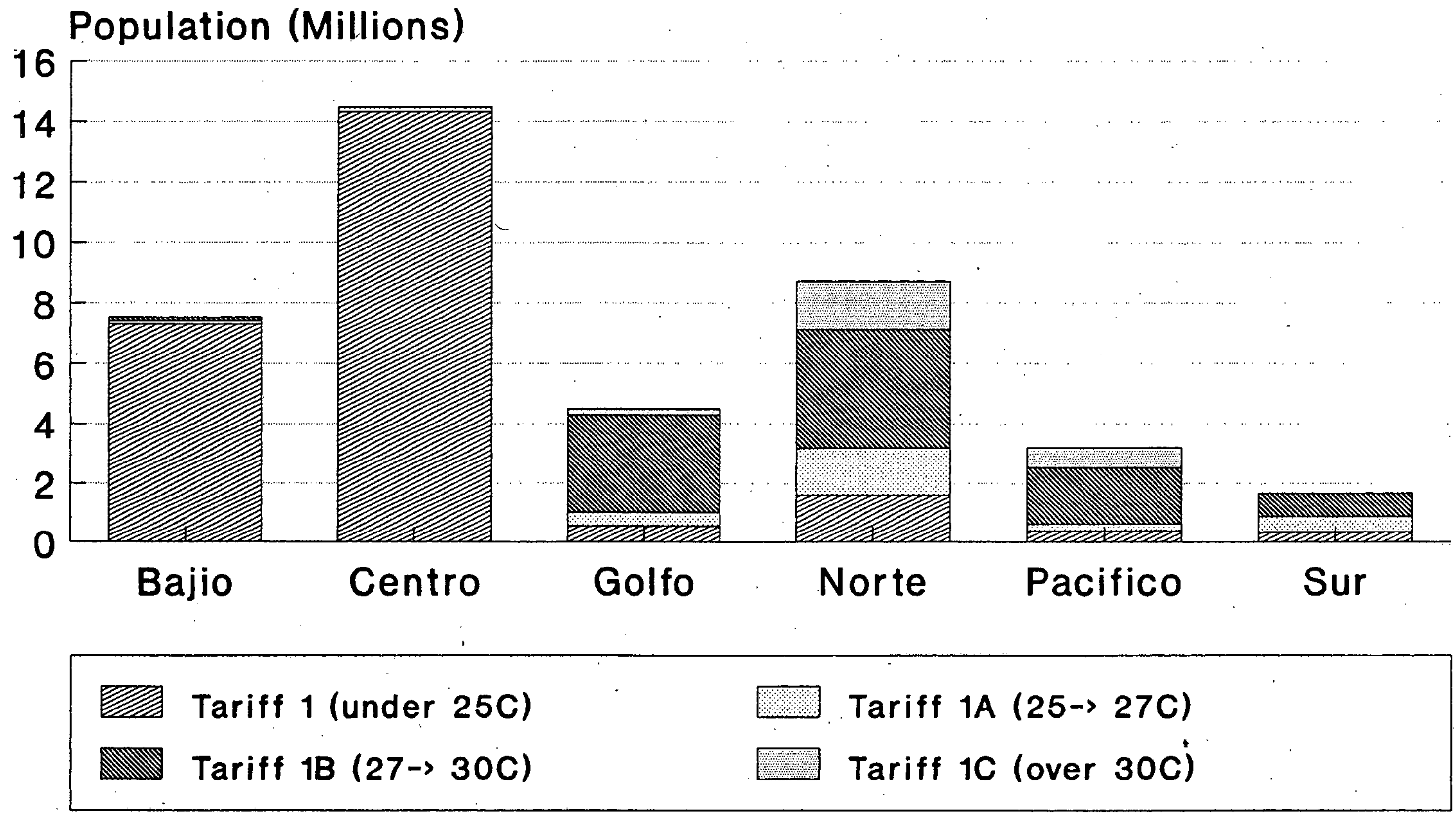
Source: CFE, 1988.

Figure 3: POPULATION DISTRIBUTION AND RESIDENTIAL ELECTRICITY USE IN MEXICO (by Region)



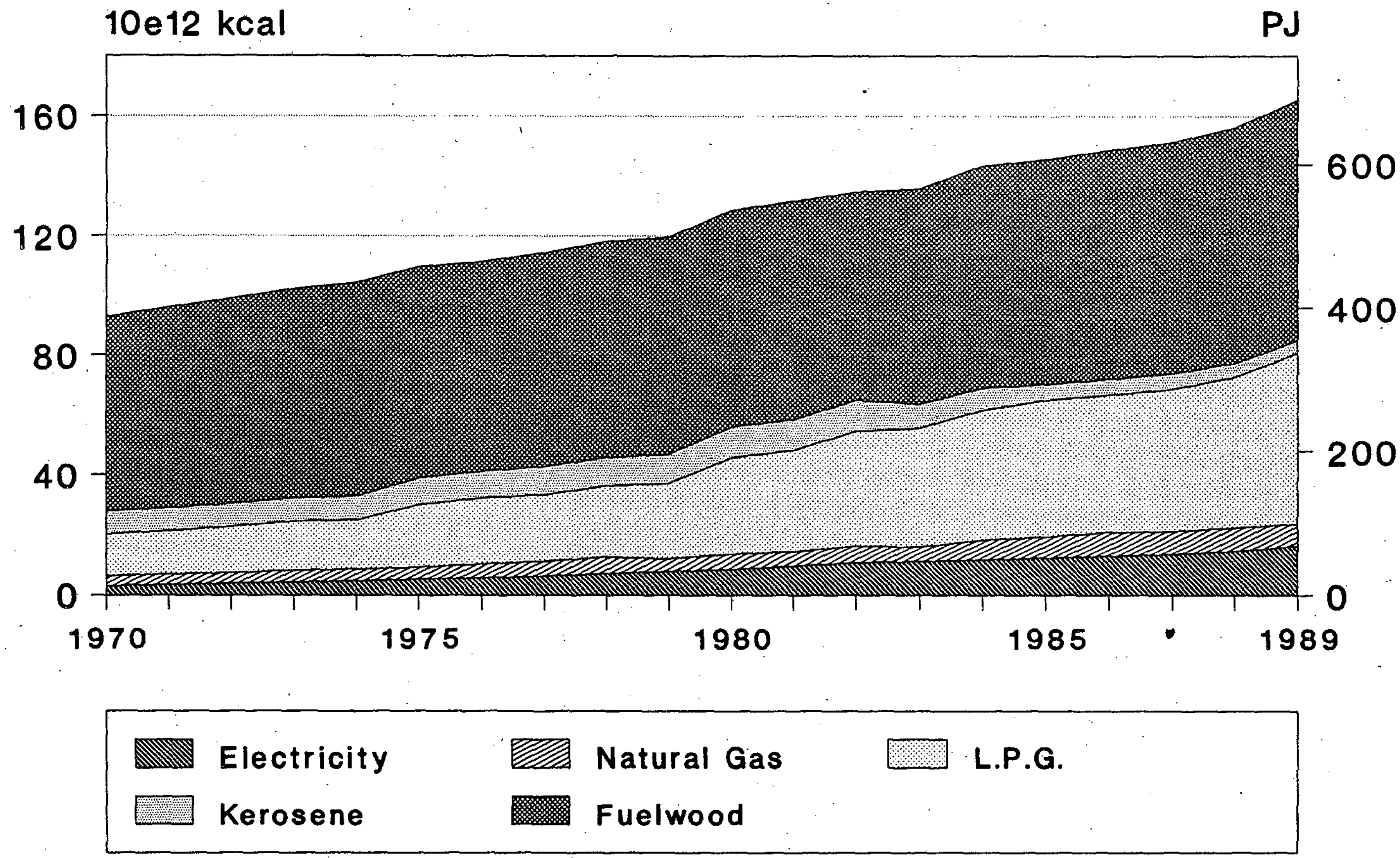
Sources: INEGI 1985 and 1991; CFE 1989a.

Figure 4: POPULATION DISTRIBUTION BY ELECTRICITY TARIFFS IN MEXICO (Cities › 10e5 people)



Sources: INEGI 1991, CFE 1989a.
Tariff depends on the temperature of two hottest summer months (as given above)

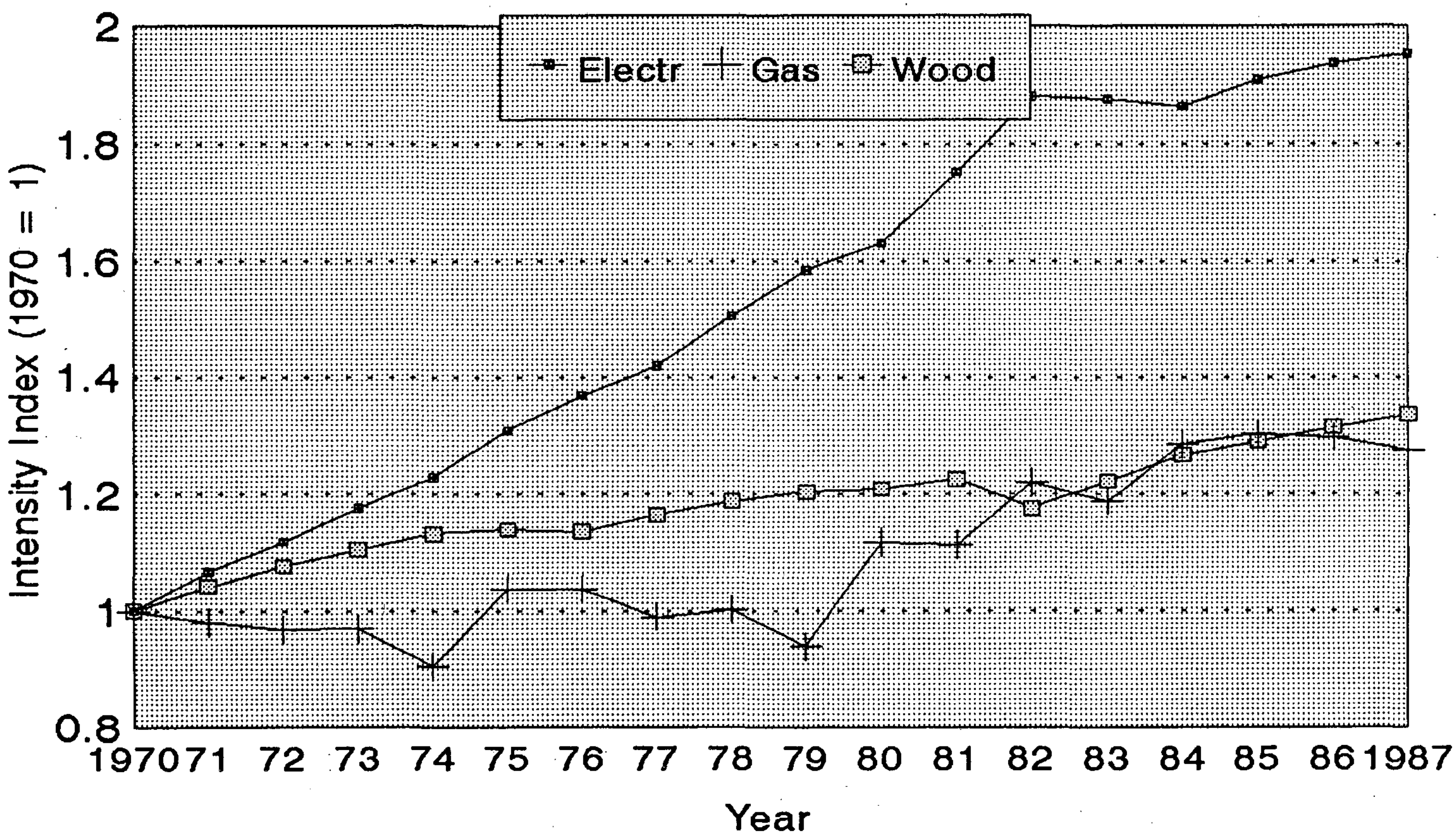
Figure 5: EVOLUTION OF RESIDENTIAL ENERGY DEMAND IN MEXICO 1970-89 (by Fuels)



Source: SEMIP, Balances de Energia

Figure 6: HISTORIC EVOLUTION FUEL INTENSITIES MEXICAN RESIDENTIAL SECTOR 1970-87

(consumption per capita)



Source: Calculated based on SEMIP, Energy Balances and INEGI (1985;1991)

Figure 7: STRUCTURAL COMPOSITION OF ELECTRICITY DEMAND GROWTH IN MEXICO 1970 - 1989

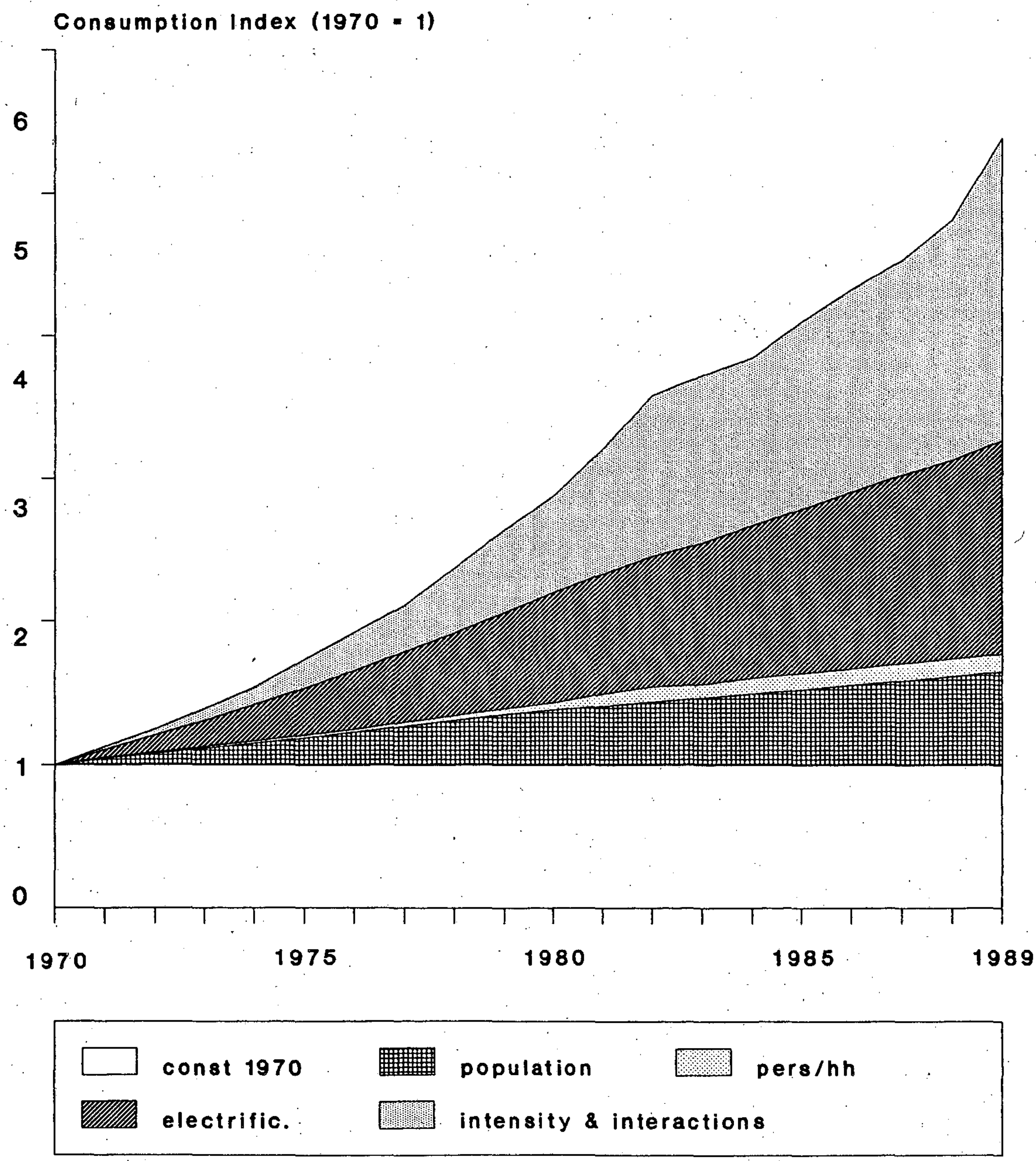
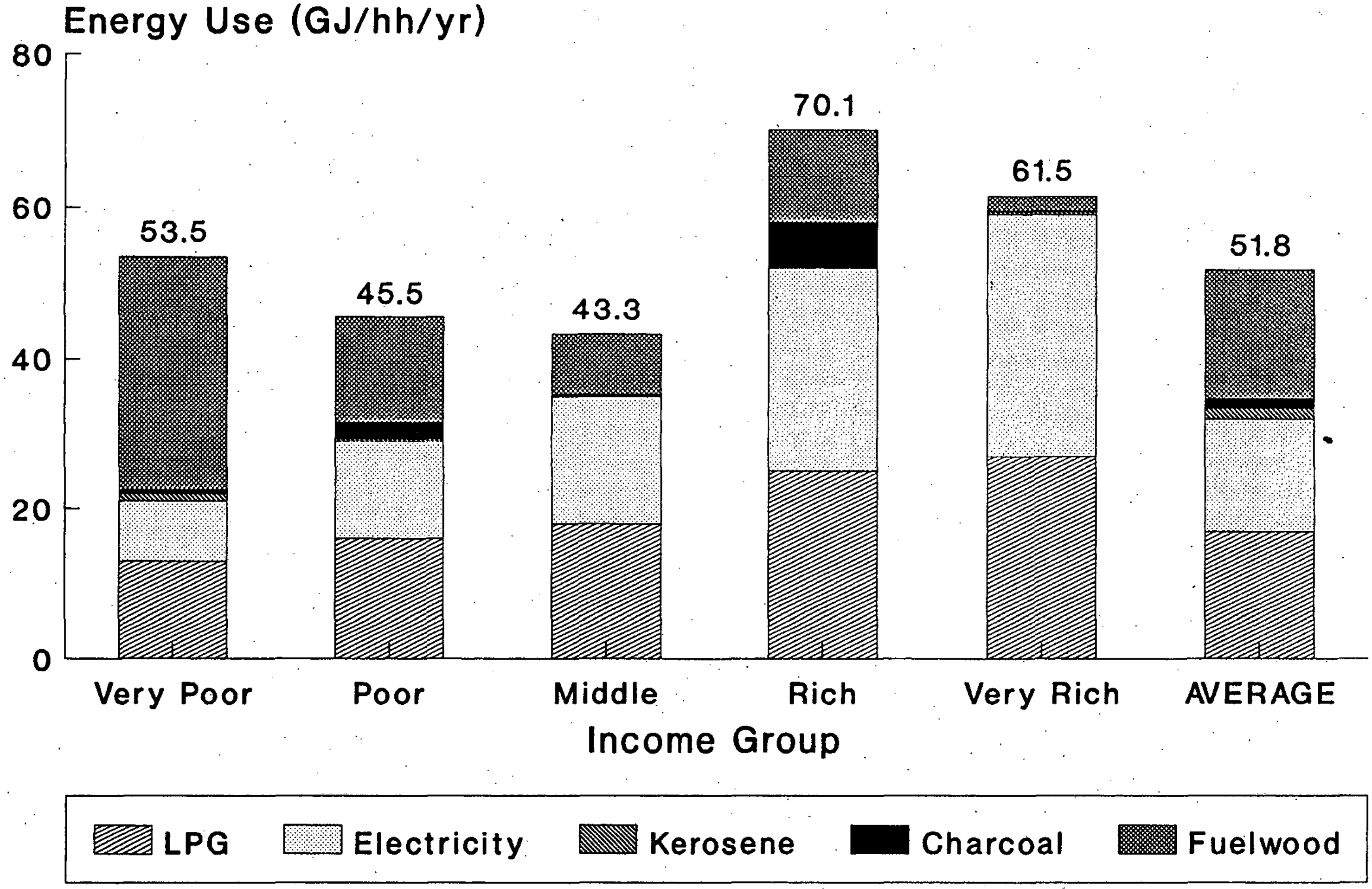
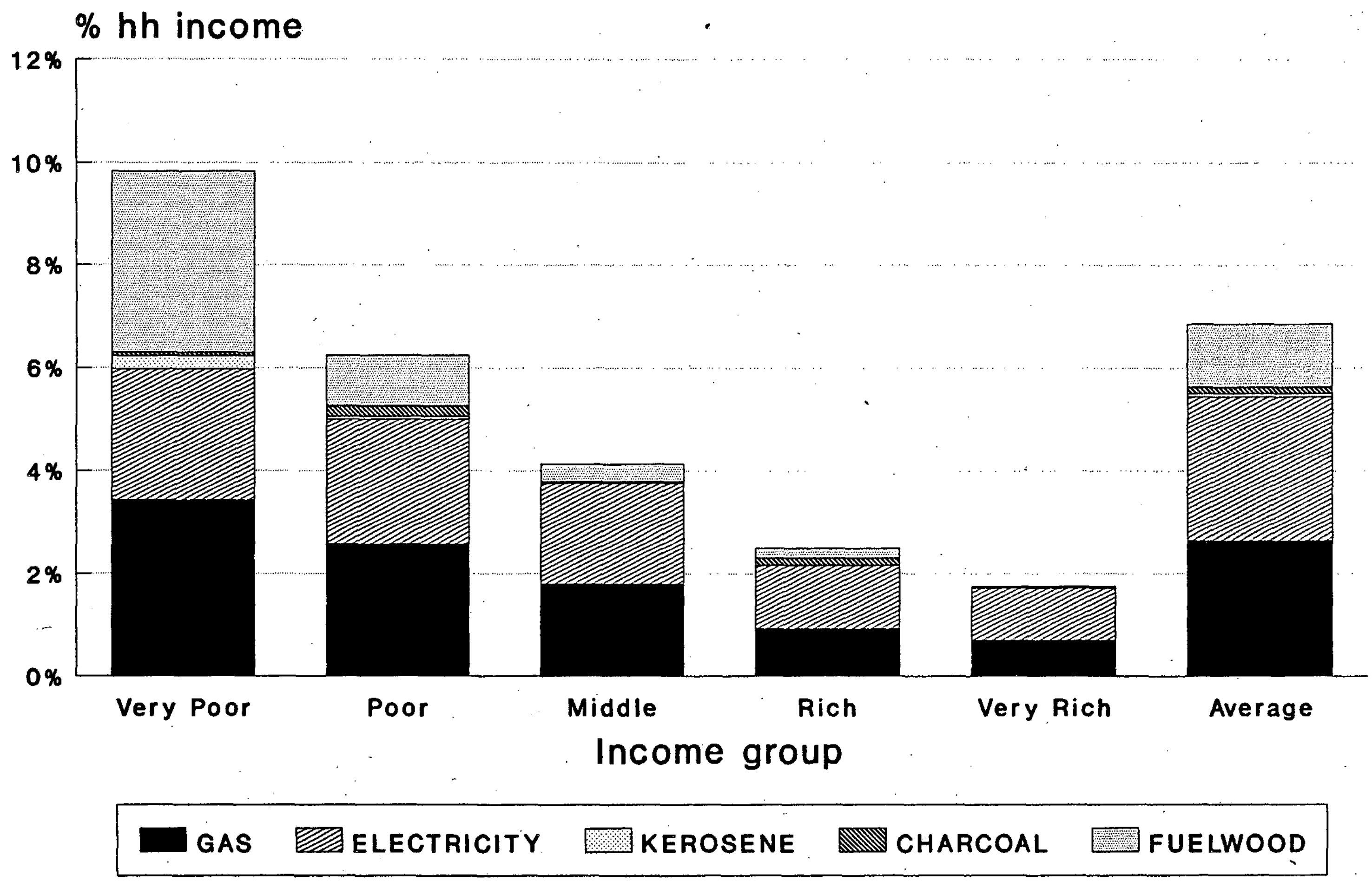


FIGURE 8: RESIDENTIAL ENERGY USE BY INCOME LEVEL IN MEXICO 1986



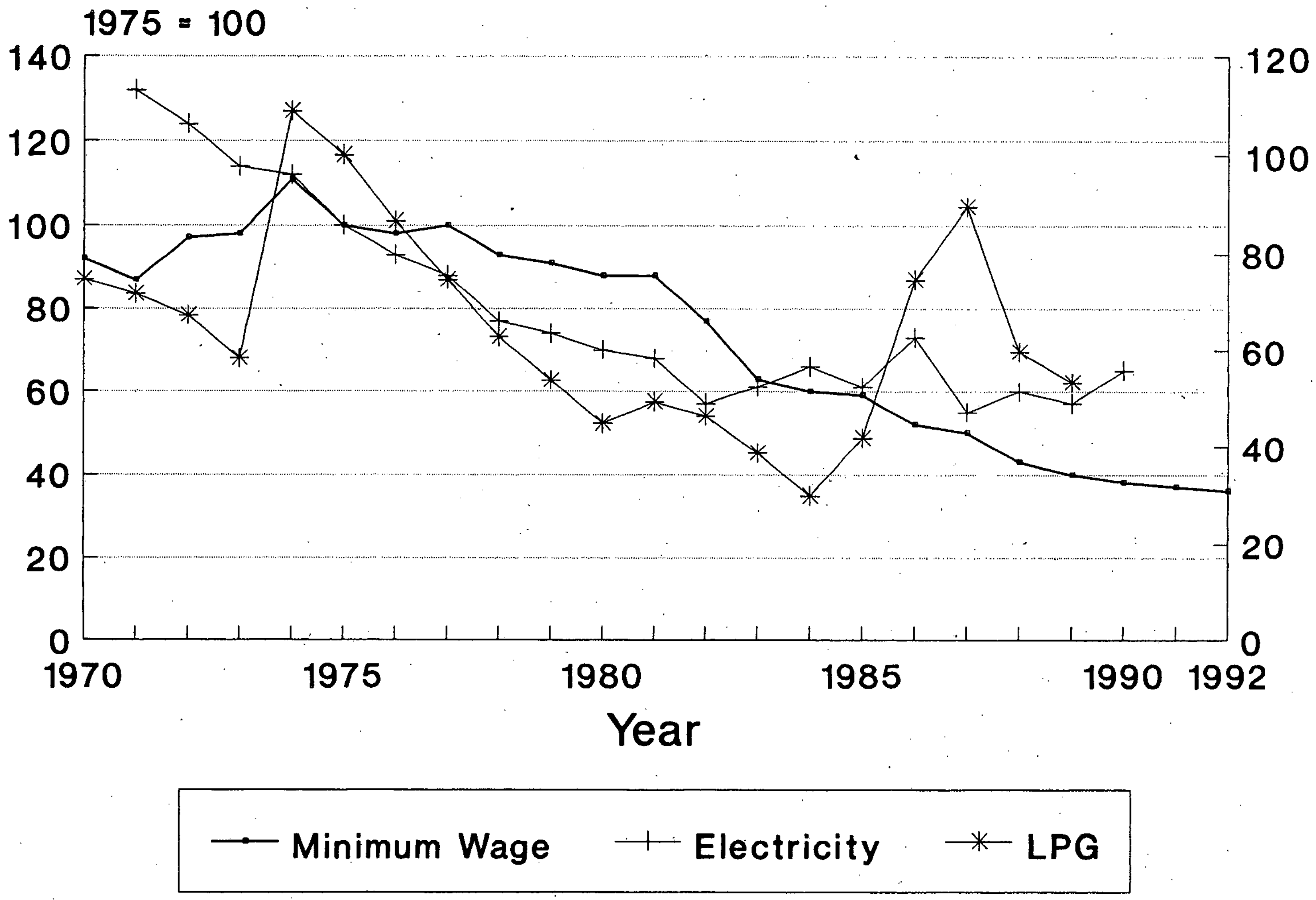
Adapted from IMP (1987)
Income groups based on composite index of various social indicators

Figure 9: ROLE OF ENERGY EXPENDITURES BY INCOME CLASS IN MEXICO 1986



Adapted from IMP (1987)
Income groups based on composite index
of various social indicators

Figure 10: REAL ENERGY PRICES VS MINIMUM WAGES IN MEXICO 1970 - 90



LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720