1. Introduction

The large and widespread utilization of woodfuels is associated to a host of environmental and socioeconomic impacts and benefits. For example, by creating local employment and income, the use of woodfuels supports rural development; also, when harvested sustainably, woodfuels allow the mitigation of greenhouse gas emissions. On the other hand, the indoor air pollution caused by smoky traditional stoves or the degradation of forests from intensive fuelwood harvesting are clear examples of negative impacts. The precise magnitude and likely trends of these impacts has been a controversial issue since the mid 1970`s, when fuelwood became a major item on the developing countries energy agenda. For example, regarding environmental impacts, widely cited studies still argue that woodfuel extraction is a major cause of deforestation and environmental degradation (Goldemberg & Johansson, 1995), while others state that the environmental impacts of fuelwood use are minor and circumscribed to specific locations (Del Amo, 2002).

The research conducted in the last decade, including comprehensive field studies and projects have shown that woodfuels demand and supply patterns are very site specific (Leach & Mearns, 1988; Arnold et al., 2003). Recognizing the site specificity of woodfuel use associated impacts has shifted the early thinking of a general fuelwood crisis to the understanding that critical areas vary from area to area (Arnold et al., 2003; Mahapatra & Mitchell, 1999; RWEDP, 1997 and 2000). Even in regions with an overall negative woodfuel demand/supply balance, not all the places face woodfuel scarcity, and, similarly, regions with overall positive balance may include deficit areas with serious impacts on natural resources (RWEDP, 2000).

However, no clear guidance has been developed so far that helps identifying these critical areas without having to rely on very expensive local fuelwood surveys. The problem is that national-level data are too aggregated to provide the sense of local variance, while local studies are too fragmented and discontinuous to convey the general picture. Also, obtaining exact measures of woodfuel deficits at the national level (i.e., like the studies conducted using the traditional fuelwood gap model (De Montalambert & Clement, 1983; Newcombe, 1984)) presents severe methodological and financial challenges, particularly considering the scarce resources normally allocated to this specific sector (ESMAP, 2001).

There is an urgent need for spatial explicit approaches that help in strategic planning and that follow a hierarchical analysis through multiple spatial scales: first identifying priority areas at the country level, and second, within each priority area, helping identify critical sites for the implementation of projects. In this manner, resources can be used more efficiently and policies can be more effectively directed and tailored to the specific characteristics of the sites.

To face these challenges, the Centre for Ecosystems Research (CIECO) of the National University of Mexico (UNAM), in cooperation with the Food and Agriculture Organization of the United Nations (FAO), has developed the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) (Masera *et al.*, 2003), a spatially explicit method for identifying woodfuel priority areas or "hot spots". WISDOM is based on geographic information system (GIS) technology, which offers new possibilities for integrating statistical information about production and consumption of woodfuels. WISDOM attempts to integrate existing information at different geographic scales and reduce the collection of costly new data.

In this article we apply the WISDOM approach to Mexico. Subsequently we explore the possibility of identifying concrete areas for intervention at the project level, based on an accessibility analysis within the Purhepecha Region of Michoacan State.

2. The WISDOM approach [1]

Assessing and strategic planning tool

The Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) is a spatial-explicit planning tool for highlighting and determining **woodfuel priority areas** or **woodfuel hot spots** (Masera, Drigo and Trossero, 2003). We recognize that woodfuels are connected to a set of interrelated environmental and socio-economic issues, and thus woodfuel hot spots can be defined in terms of its relevance for consumption patterns, production, and potential environmental impacts.

Woodfuel hot spots can be thus established according to a number of criteria set by the users. For example, in identifying areas with potential large social impacts, zoning can be done according to the number and density of woodfuel users and the scarcity of woodfuel resources. Studies looking at potential degradation caused by woodfuels use, will try to identify regions where woodfuel consumption is high, resilient, and increasing, where woodfuel supply is at risk, due to loss or degradation of natural vegetation, and where the demand-supply balance indicates a deficit or is likely to develop such condition in the near future.

WISDOM will not replace a detailed national biomass demand/supply balance analysis for operational planning but rather it is oriented to support a higher level of planning, i.e. strategic planning and policy formulation, through the integration and analysis of existing demand and supply related information and indicators. More than absolute and quantitative data, WISDOM is meant to provide relative/qualitative values such as risk zoning or criticality ranking, highlighting, at the highest possible spatial detail, the areas deserving urgent attention and, if needed, additional data collection. In other words, WISDOM should serve as an ASSESSING and STRATEGIC PLANNING tool to identify priority places for action.

WISDOM is based on:

- **Geo-referenced data bases**. A core feature of the approach is the spatial base on which the data is framed. The analysis and presentation of results for all modules is done with the help of a Geographic Information System (GIS).
- **Minimum spatial unit of analysis at sub-national level**. The spatial resolution is defined at the beginning of the study, on the basis of the wanted level of detail (national study, regional study) and as constrained by the main parameters or proxy variables that will be used to "spatialize" the information. In most cases the existing demographic data, such as census units, and land use/land cover data represent the main reference for the definition of the spatial base, which will be in all circumstances sub-national and preferably below state level.
- **Modular and open structure**. WISDOM consists of three basic modules: a demand module, a supply module, and an integration module. The first two modules require different competencies and data sources. Once the common spatial base of reporting is defined, each module is developed in total autonomy using existing information and analytical tools and is directed to the collection,

[1] This section presents a short summary of the WISDOM approach; refer to Masera, Drigo and Trossero (2003) for a complete description of the methodology.

harmonization, cross-referencing and geo-referencing of relevant information existing for the area of study.

- **Adaptable framework.** As mentioned before, the information of relevance to wood energy comes from multiple sources and is often fragmented and poorly documented, ranging from census data to local pilot studies or surveys, to projected estimates with unknown sources. Proxy variables may be used to "spatialize" discontinuous values. In synthesis, WISDOM tries to make all existing knowledge at work for a better understanding of woodfuel consumption and supply patterns.

The benefits of the WISDOM approach include:

- It provides a consistent and **holistic vision** of the wood energy sector over the entire country or region and helps to determine **priority areas** for intervention.
- It constitutes an **open framework** and a **flexible tool** meant to adapt to existing information related to woodfuels demand and supply patterns.
- It allows the **definition of critical data gaps** resulting from the thorough review and harmonization of wood energy data.
- It **promotes cooperation and synergies** among stakeholders and institutions (Forestry, Agricultural, Energy, Rural development, etc.). In this, WISDOM will combat the fragmentation (of information, of responsibility) that so heavily limits the development of the sector.
- It allows to concentrate the actions on **circumscribed targets** and thus to optimize the use of available resources (human, institutional, financial, etc.)[2]
- It enhances the **political recognition** of the real inter-sectoral role and priorities of the wood energy by policy makers.

WISDOM steps

The use of WISDOM involves five main steps (See Figure 1):

1. Definition of the minimum administrative spatial unit of analysis
2. Development of the DEMAND module
3. Development of the SUPPLY module
4. Development of the INTEGRATION module
5. Selection of the PRIORITY areas or "woodfuel hot spots"

[2] One of such actions would likely be the collection of up-to-date local data to confirm the results of national or regional analyses (which are always based on information of lower quality and resolution), and to build-up an information base for operational planning.

A detailed description of the WISDOM approach can be found in Masera, Drigo and Trossero, (2003). Below we give a short description of the different steps of the analysis.

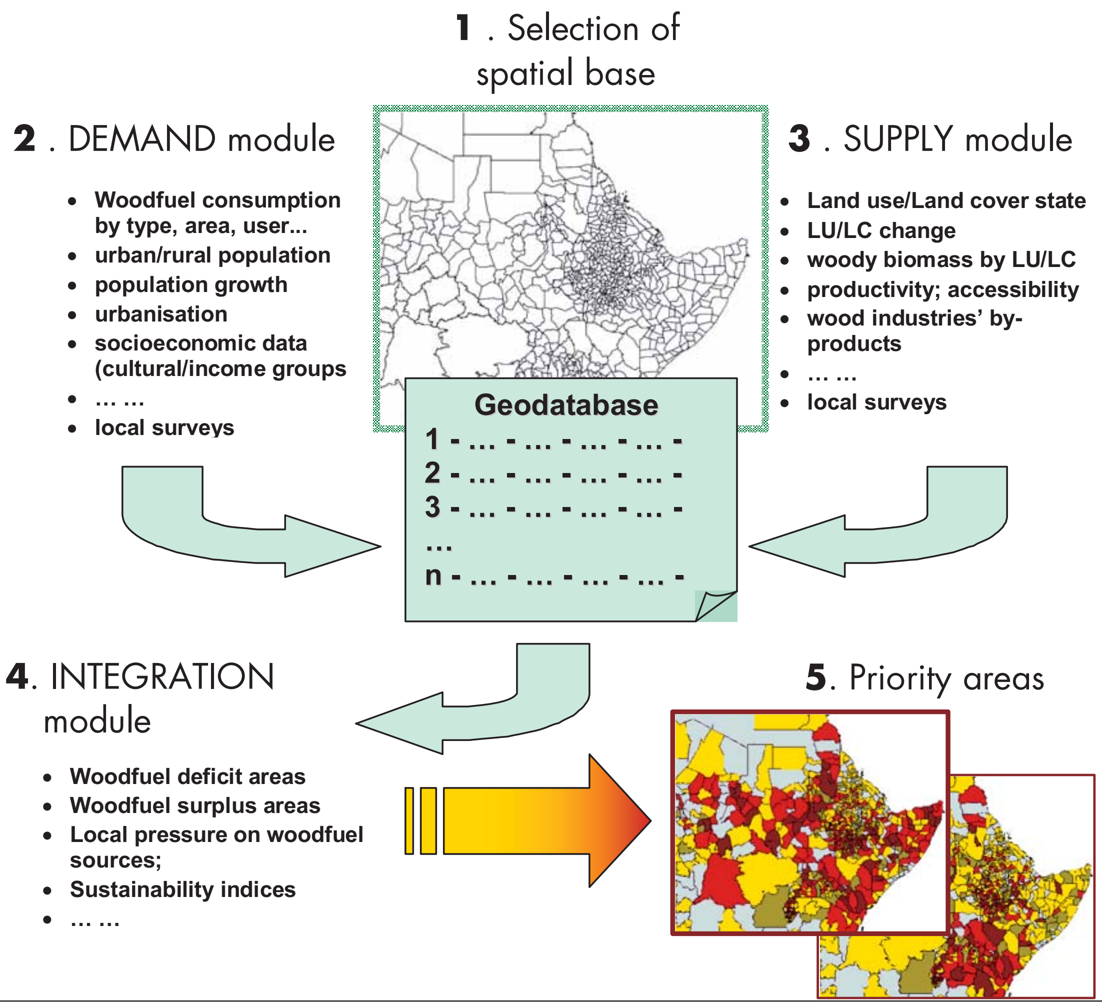


Figure 1. WISDOM Steps

1. Definition of the minimum administrative spatial unit of analysis

The analysis should be carried out at the lowest administrative level for which demographic, social and economic parameters are available. In this step, spatial and statistical data are linked through a "map attribute table", which has a database structure and contains the basic geographic attributes and identifiers of all individual elements of the digital map (identity codes and names, area, perimeter, coordinates, etc.). The table can be expanded as needed by the addition of thematic attributes referring to the same set of map elements.

2. Development of the DEMAND module

The main challenge of this module is to find either direct or proxy variables, available at the minimum sub-national unit selected, that can be used to estimate consumption levels and their spatial distribution. These variables should be disaggregated, if possible, by fuel type (fuelwood, charcoal, others), by sector of users (households, industrial, others) and by area (rural, urban), since each has a particular impact on sources and sustainability of supply, calling for separate lines of analysis.

3. Development of the SUPPLY module

This module provides a spatial representation of all woodfuel sources, their stocking capacity, their change over time, and their productivity. The main, and often the only, sources of information for developing this module are national forest inventories. A weak point of these data sources is that they do not differentiate woodfuels from other types of commercial or usable timber, overestimating the real woodfuel supply. Moreover, inferred data based on detailed surveys might be used regarding non forest land use classes, as forest inventories do not cover these areas. As mentioned earlier, the scope of WISDOM is not operational planning, for which quantitative precision is essential. Thus, with the scope of identifying priority areas where the demand-supply balance reveals a possible deficit, the supply module may concentrate mainly on land use and land use change, and may use indicative biomass productivity indices based on ecological characteristics.

4. Development of the INTEGRATION module

This module is used to integrate the information from the demand and supply modules. The integration is done through the combination of the variables related to woodfuel consumption and supply that have been systematized for each minimum administrative unit of analysis.

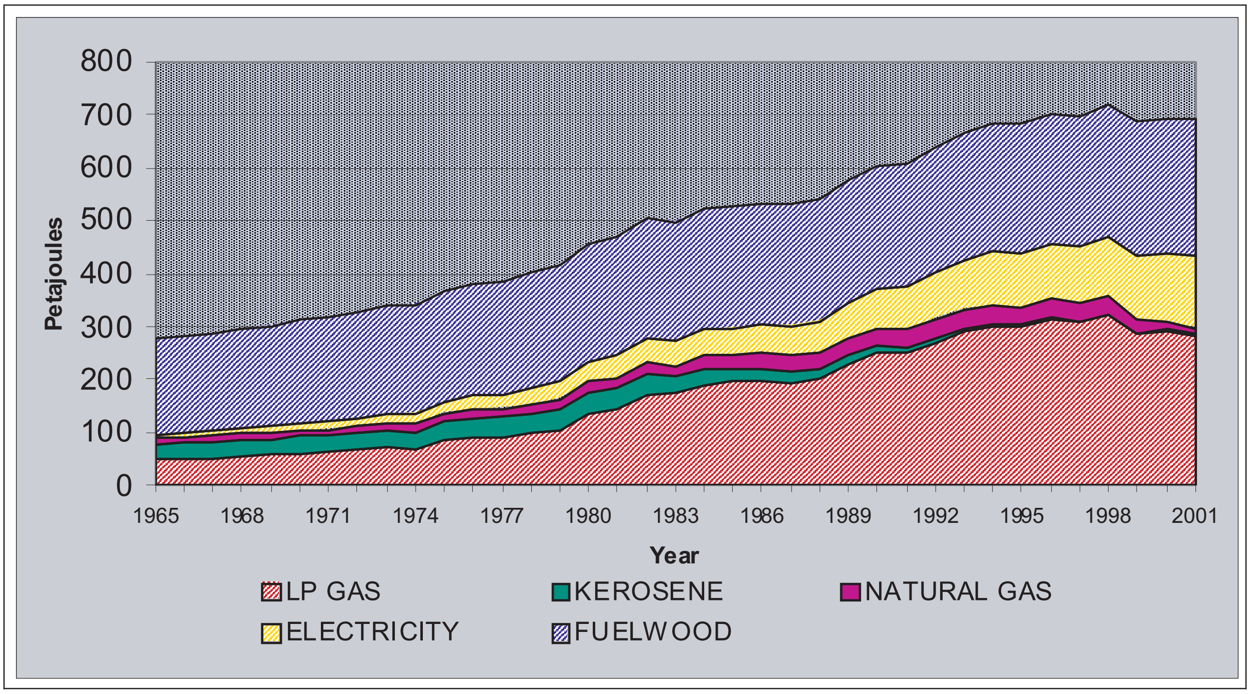
5. Selection of the PRIORITY areas or "woodfuel hot spots"

The last step of the methodology is the identification of those areas where action, or further investigation, is needed. This final objective may be achieved either by multivariate statistical procedures or by grouping some selected variables form the three modules into an overall index (Fuelwood Priority Index) which allows the priorization of each minimum administrative unit in terms of woodfuel demand, supply or both.

3. Identifying fuelwood "hot spots" at the national level

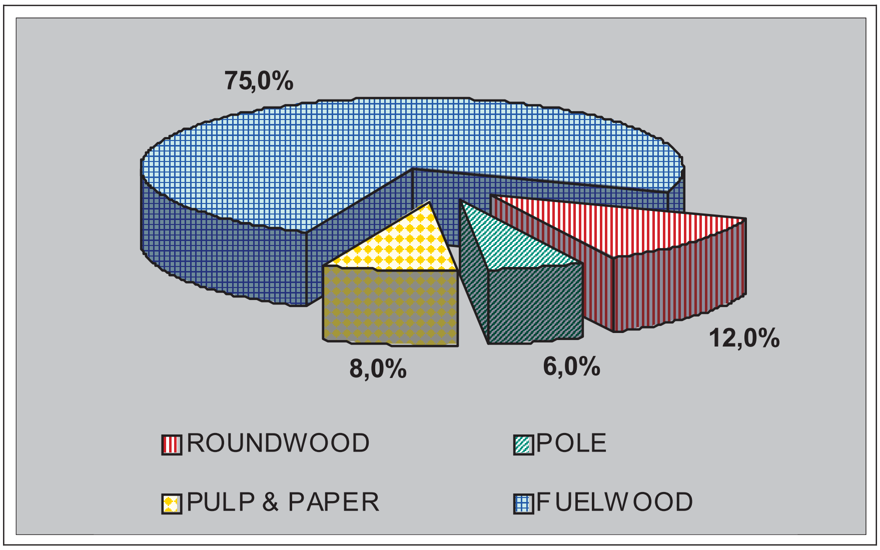
Mexico's current pattern of woodfuel use

Biofuels represent about 9% of total energy demand in Mexico, while fuelwood accounts for 37% of residential energy use (SENER, 2001) (Figure 2), and more than 80% of the energy demand in the rural sector (Masera, 1996b). The three main types of biofuels used in the country are: bagasse, which is used in the sugar cane industry, fuelwood and charcoal. Fuelwood is, by far, the dominant woodfuel, with charcoal being used mostly in food industries and for barbecues. Total fuelwood use accounts for three times the total commercial timber legally harvested in the country (Figure 3) (Masera 1996a).



Source: Secretaría de Energía del Gobierno de Mexico (SENER): National Energy Balance.
http://www.energia.gob.mx/work/secciones/192/imagenes/cons_res_com_pub.xls

Figure 2. Mexico's energy consumption in the residential sector (1965 - 2001)



Source: Masera (1996a)

Figure 3. Share of fuelwood on total wood demand in Mexico

Mexico fuelwood demand is concentrated on rural areas and small towns, and comes mostly from households. Approximately one out of four inhabitants (25 million people) uses fuelwood for cooking (Masera, 1996b). Fuelwood is also used in many small (cottage) industries, like pottery making, "tortilla" making, brick making, and several others; this demand is important within specific regions. Fuelwood is either collected or bought from local markets and comes from commercial and non commercial forest areas (including here all degraded lands and semi-arid forests), little from agricultural areas. Many of the species used are of no commercial value. The use of agricultural residues and dung is not widespread. (Masera, 1996a; Masera *et al*, 1997).

The patterns of fuelwood use are extremely diverse, with a high heterogeneity in terms of saturation and growth of users and potential environmental impacts across the country. Still critically lacking are studies that show the spatial patterns of fuelwood use, availability of woodfuel resources, and the identification of "woodfuel hot spots". The undertaking of WISDOM was thus a needed exercise.

WISDOM analysis for Mexico

The objective for conducting a WISDOM analysis for Mexico was to identify fuelwood priority areas or "hot spots" for the year 2000 at the national level. "Hot spots" are defined as those areas showing a high number of exclusive[3] fuelwood users; a high density and growth of exclusive fuelwood users at the

[3] The INEGI census does not distinguish mixed fuel users (i.e. users of fuelwood and LP gas), although they represent a significant percentage of total fuelwood users (31% in 1990 (Díaz, 2000)). As there is no reliable direct estimate of this group of users, this study accounts for the exclusive fuelwood users alone. Some underestimation of fuelwood demand should then be expected.

household level; a high percentage of houses that exclusively use fuelwood; a high resilience of fuelwood consumption (resistance to change to other fuels in terms of social and cultural aspects); and few or insufficient woodfuel resources from forests. Table 1 shows the main premises for the WISDOM case study in Mexico.

Table 1. Main characteristics of the case study in Mexico

Main features of woodfuel use in Mexico	▶ The demand for woodfuels is concentrated on fuelwood. ▶ Most demand comes from households. ▶ The majority of fuelwood comes from forest areas, relatively little from agricultural areas. ▶ The use of agricultural residues and dung is not widespread.
Objective and scope of the analysis	▶ To determine fuelwood "hot spots" in the country for the year 2000. ▶ The analysis focused on fuelwood, households and fuelwood exclusive users.
Minimum Administrative Spatial Unit of Analysis	▶ The unit chosen was the *Municipio* (county). The country had by the year 2000 a total of 2,436 *municipios* .
Demand Module	The two main sources for the development of the module were: ▶ The National Population Census 1990/2000. ▶ A comprehensive collection of local/regional/national surveys on energy use in the household sector.
Supply Module	▶ The basis of the module is the National Forest Inventory 2000, which was conducted at a 1/250,000 scale over the whole country. The original 69 Land-use land-cover classes were aggregated into seven major classes (Velázquez *et al.*, 2001). Average biomass productivities were assumed for each LU/LC class.
Integration Module and GIS system	▶ A GIS was created using an ArcGIS platform. ▶ The GIS database includes information on fuelwood demand and supply for each of the 2,436 *municipios* in the country. ▶ A new variable called "fuelwood balance" was created integrating supply and demand variables.
Priority zoning	▶ A set of six uncorrelated variables was selected. *Municipios* were grouped into five main categories: high; mid-high; mid; mid-low; and low. (e.g., high consumption, mid-high consumption, and so on), for each variable. ▶ A simple indexing of all the six variables and a further grouping was conducted to rank *municipios* into five categories or classes of priority.

STEP 1: Determining the minimum spatial unit of analysis: the "municipio"

The municipio (county) was selected as the minimum administrative unit of analysis for conducting the WISDOM (Figure 4). A geo-referenced data base that covers the whole country and is articulated into the state and national level is available from the Mexican National Bureau of Statistics (INEGI). A total of 2,436 units were identified and incorporated into a GIS. For each unit, basic information such as: coordinates, area, and perimeter are available. However, there are gaps in relevant data for some municipios due mainly to geostatistical changes at the bureaucratic level: new municipios are created frequently (INAFED, 2002). This usually leads to inconsistencies of the census data with these new municipios. For calculating some variables, (e.g. discrete average annual growth rate of exclusive fuelwood users population (1990-2000) only those municipios that could be tracked all the way during the twenty year period were used.

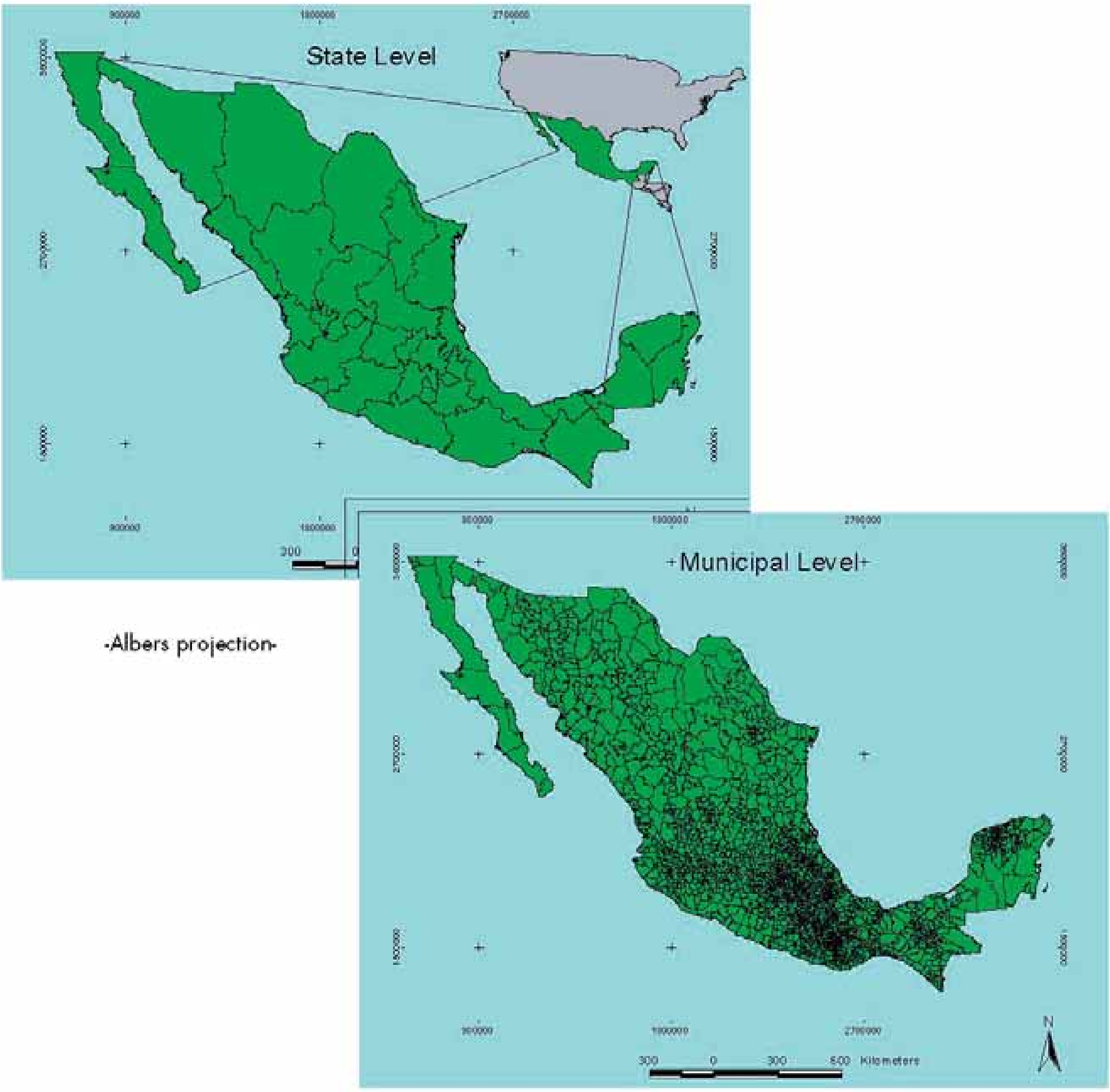


Figure 4. Spatial administrative units within Mexico

STEP 2: Development of the DEMAND module

The INEGI census (currently available electronically at the *municipio* level)[4] was used as the basic source of information for the module. The census includes general socio-demographic variables as well as variables related to the quality of living of the Mexican population. The average per capita fuelwood consumption by major ecological zone was estimated based on local surveys (Díaz, 2000)[5]. Besides these two sources of information new variables were calculated for the completion of the demand module (Table 2).

Table 2. Variables used in the demand module

Original Variables from the Census (1980/1990/2000)	► Population (urban, rural, total). ► Total number of households. ► Number of households that use exclusively fuelwood. ► Number of exclusive fuelwood users. ► Percentage of population belonging to an ethnic group. ► Socioeconomic index.
Original Parameters from Surveys	► Average per capita fuelwood consumption by major ecological zone (temperate, tropical dry, tropical humid, semi-arid and wetlands).
New variables calculated	► **Density of fuelwood users (A)** (exclusive fuelwood users per km^2, using the total municipality area). ► Density of fuelwood users (B) (exclusive fuelwood users per km^2, using the forest municipality area). ► Average annual growth rate of exclusive fuelwood users (1990-2000). ► **Saturation of fuelwood users** (percentage of exclusive fuelwood household users). ► Annual fuelwood consumption (estimated as per capita fuelwood consumption times number of exclusive fuelwood users). ► Annual fuelwood consumption coming from forests (estimated as per capita fuelwood consumption coming from forest times number of exclusive fuelwood users).

Note: All these variables are disaggregated at the *municipio* level. In bold are the variables selected for the determination of "woodfuel hot spots".

As appears in Table 2, the amount of fuelwood that is harvested within forest areas (annual fuelwood consumption coming from forest areas) was calculated as the total fuelwood demand minus the proportion of fuelwood coming from non-forest areas. This last factor was obtained from local surveys conducted over the different ecological zones (temperate, tropical humid, tropical dry, semi arid and wetlands). For tropical regions of Mexico for example, about 20% of fuelwood consumption comes from non forest areas, which may include farmland trees, abandoned or regrowth areas due to shifting cultivation practices, and

[4] Mexican National Bureau of Statistics (INEGI), http://www.inegi.gob.mx

[5] This paper gives a compilation of data from several local surveys conducted within Mexico.

other places. More detailed surveys covering all the ecological zones need to be conducted in order to obtain a more precise estimate of these proportions.

Table 3. Average per capita fuelwood consumption coming from forest areas.

Major Ecological Zone	Per capita biofuel consumption kg/cap/day **(A)**	Per capita fuelwood consumption* kg/cap/day **(B)**	Percentage of fuelwood consumption coming from forest areas **(C)**	Per capita fuelwood consumption coming from forest areas kg/cap/day (B * C)
Temperate	2.0	1.98	82%	1.62
Tropical Dry	2.5	2.47	68%	1.68
Tropical Humid	3.0	2.97	82%	2.44
Semiarid	1.5	1.48	80%	1.12
Wetlands	2.5	2.47	80%	1.98

Source: Own estimates based on a review of existing studies. See Díaz (2000) for a comprehensive review of case studies and surveys in Mexico.

* Non-fuelwood consumption is represented mainly by crop field residues and dung, estimated here as 1% of total biomass fuel consumption (A * 1% = B). All the agro industrial by-products (i.e. residues produced in the processing, like sugar-cane bagasse; coconut shells, etc.) are used as fuel almost exclusively by industries but not by households.

STEP 3: Construction of the SUPPLY module

The supply module was based on the cartography derived from the latest Mexican National Forest Inventory (Palacio *et al.*, 2000). It was conducted over a period of a year and was based upon data from INEGI and Landsat ETM-7 imagery. The procedure followed the interdependent interpretation method (FAO, 1996), which chiefly includes visual up-dating of the classes modified between the reference data base (Serie II) and the current image (Landsat ETM-7 from 2000). The legend is hierarchical with four levels, namely, vegetation formations, vegetation types, vegetation communities and vegetation sub-communities, giving a total of 75 classes (Velázquez *et al.*, 2001). The inventory was subjected to a reliability assessment with the aid of digital aerial photography (scale ±1:15,000) (Mas *et al.*, 2001).

For the purpose of the present work, a simplified legend was derived with the following general LC/LU vegetation classes: 1) agriculture/pasture; 2) urban areas; 3) and 4) temperate forests (primary and secondary); 5) lakes; 6) scrublands; 7) mangroves; 8) other vegetation; 9) and 10) tropical deciduous forests (primary and secondary); 10) and 11) tropical evergreen forests (primary and secondary). Table 4 shows the detailed description of the original LU/LC incorporated into the more general classification used in our analysis and Figure 5 shows the vegetation map for Mexico.

Table 4. Land use and land cover classes used in the Mexican case study

Formation	Vegetation Types	Simplified legend for the present analysis
Temperate forest	Conifers	Temperate Primary Forests
	Conifers & broad-leaved	
	Broad-leaved	
	Mountain cloud forest	
	Conifers (with herbaceous and shrubby secondary vegetation)	Temperate Secondary Forests
	Conifers & broad-leaved (with herbaceous and shrubby secondary vegetation)	
	Broad-leaved (with herbaceous and shrubby secondary vegetation)	
	Mountain cloud forest (with herbaceous and shrubby secondary vegetation)	
Tropical forest	Perennial & sub-perennial rainforest	Tropical Evergreen Primary Forests
	Perennial & sub-perennial rainforest (with herbaceous and shrubby secondary vegetation)	Tropical Evergreen Secondary Forests
	Deciduous & sub-deciduous forests	Tropical Deciduous Primary Forests
	Deciduous & sub-deciduous forests (with herbaceous and shrubby secondary vegetation)	Tropical Deciduous Secondary Forests
Scrubland	"Mezquital"	Scrubland
	Xerophytic scrubland	
Hygrophilous vegetation	Hygrophilous vegetation	Mangroves
Other vegetation types	Other vegetation types	Other vegetation types
Man made grassland	Cultivated grassland	Agriculture/Pasture
	Induced grassland	
Natural open grassland	Alpine grassland and Natural grassland	Other vegetation types
Cropland	Cropland (irrigation & humid)	Agriculture/Pasture
	Cropland (rainfed)	
	Forest cropland	
	Open grassland	
Other coverage types	Human settlements	Urban areas
	Water reservoir	Lakes

Adapted from Velázquez *et al.* (2001).

Figure 5. Simplified vegetation map for Mexico, 2000

To estimate the total woody biomass production from Mexican forests, average biomass productivities (in ton/ha/yr) for each of the major forest types was assumed and incorporated into the supply module (Table 5). Figure 6 shows the distribution of the resulting biomass forest productivities within the country. A more detailed analysis of forest productivities, for example, using climate and soil conditions will be needed for a more accurate estimate of total biomass production at the *municipio* level.

Table 5. Average aboveground biomass production by main forest type

Forest Type	ton/ha/yr
Temperate Primary forests	3.0
Temperate Secondary forests	2.0
Tropical Primary Evergreen forests	5.0
Tropical Secondary Evergreen forests	5.0
Tropical Primary Deciduous rainforests	4.0
Tropical Secondary Deciduous forests	4.0
Mangroves	5.0
Scrublands	1.5
Other vegetation types	1.5

Source: Own estimates based on a comprehensive review of literature.

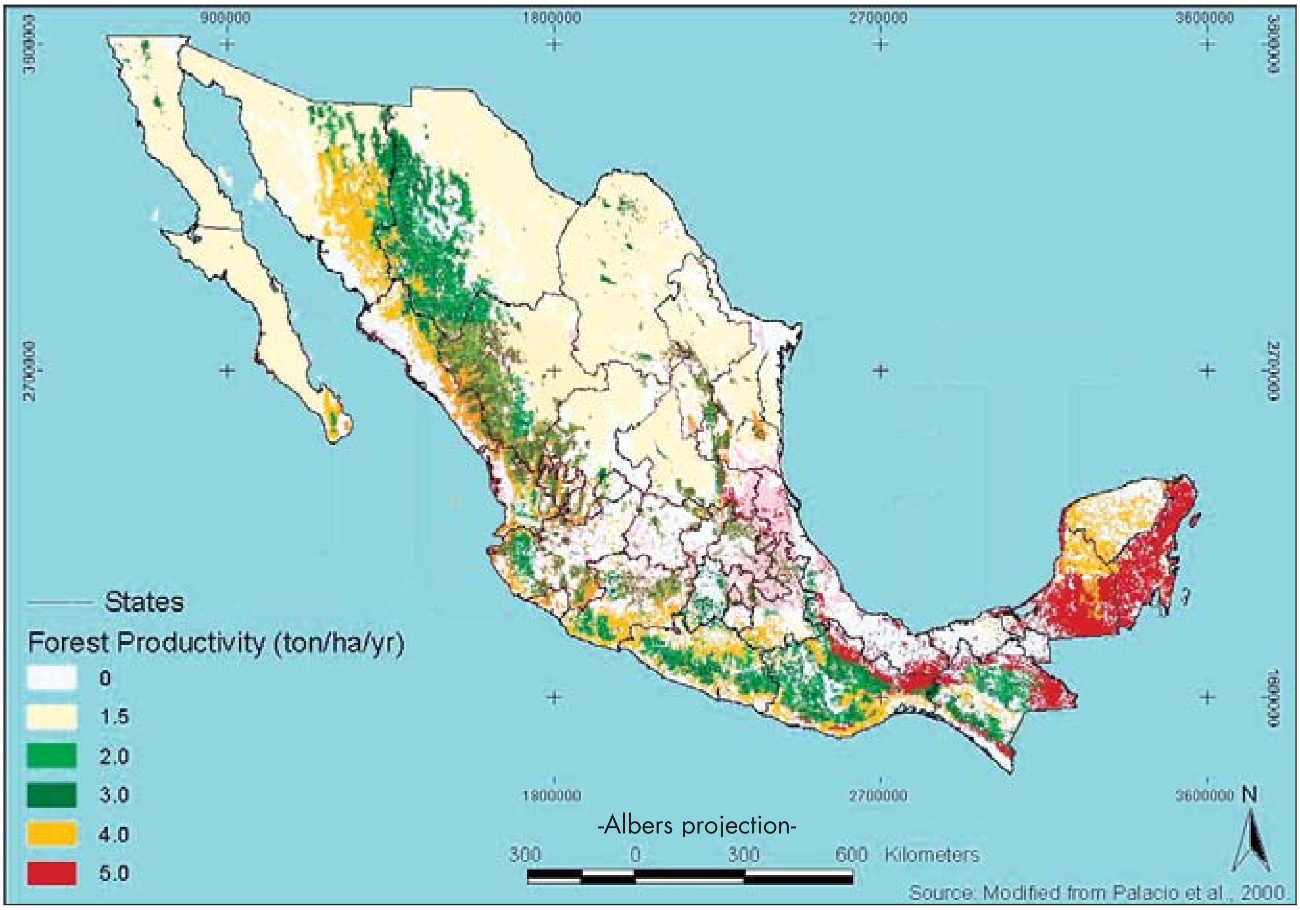


Figure 6. Assumed biomass productivities for Mexican forests, 2000

Table 6 shows the different variables used to construct the woodfuel supply module.

Table 6. Variables used in the supply module

Variables	Description
Original Variables from the National Forest Inventory (2000)	Area by each LU/LC class (ha).
Original Parameters from Surveys	Total aboveground biomass productivity by forest class (ton/ha/yr).
New variables calculated	Total forest area (ha); includes temperate, tropical, scrubs, mangroves and other forests. Aboveground biomass production from forests (ton/yr).

Note: All these variables are disaggregated at the *municipio* level. None of these variables were selected for the determination of "woodfuel hot spots". See the Integration Module.

STEP 4: Integration module

The information gathered in the supply and demand modules was combined to get a series of new variables, or indicators. This procedure was done iteratively during the development of WISDOM, as some demand variables depend on variables from the supply module (e.g., per capita fuelwood use) and vice versa.

Two main integrated variables of interest at the *municipio* level derived were:

- **Fuelwood Balance** (forest biomass productivity - fuelwood demand coming from forests) in ton/yr.
- **Pressure on Forest Resources** (fuelwood demand coming from forests / total forest area) in ton/ha/yr.

Only the Fuelwood Balance was selected for the determination of "woodfuel hot spots".

STEP 5: Identification of Mexican fuelwood "hot spots" at the municipio *level*

The last step of the analysis was the determination of the fuelwood "hot spots". Four main sub-steps were necessary for achieving this task:

1. Selection of a robust set of variables associated to fuelwood consumption and supply by *municipio* to be used in setting priority municipalities.
2. Ranking of *municipios* in 5 groups in terms of each of the individual variables.
3. Construction of an integrated fuelwood priority index by *municipio* (FPI).
4. Ranking of *municipios* in 5 groups according to the FPI.

1) Selection of a final set of variables

A correlation matrix was built with the different potential variables associated to the demand and supply of fuelwood. The matrix and the subsequent analysis allowed the selection of a smaller set of uncorrelated variables for the setting of a priority ranking of municipalities within the country. The objective of the priority ranking was to find municipalities that show high fuelwood demand, high density and growth of fuelwood users, resistance to change to other fuels (due to social and cultural aspects), and few or insufficient woodfuel resources. It was clear from the analysis that several variables were closely correlated. For example, there was a close correlation between fuelwood consumption and fuelwood users and between the income level and the saturation of fuelwood users. Table 7 shows the correlation analysis.

Based on this statistical analysis a final set was chosen with the following six uncorrelated, or loosely correlated, variables:

- Total number of exclusive fuelwood users.
- User density (number of exclusive fuelwood users / total municipality area).
- Discrete annual growth rate of exclusive fuelwood users (1990-2000).
- Saturation of fuelwood users (proportion of households that use exclusively fuelwood).
- Percentage of people belonging to an ethnic group.
- Fuelwood balance (total forest productivity - annual fuelwood consumption coming from forest areas).

2) Grouping of *municipios* for each variable

For each of the variables selected, *municipios* were grouped and ranked into 5 categories, reflecting the acuteness (or priority) of the problem. The ranking was done by dividing each of the six selected variables in five intervals or "natural groups":

Group 1 = low priority

Group 2 = mid-low priority

Group 3 = medium priority

Group 4 = mid-high priority

Group 5 = high priority

The thresholds for defining each group are shown in Table 8. For example, regarding the proportion of fuelwood users, low priority municipalities are those with low saturation and high priority those showing high saturation of users (Table 8 and Figure 10). Each index might be used independently when considering or aiming at highlighting different situations.

Table 7. Correlation coefficients for the full set of fuelwood related variables

Correlation coefficients
Marked correlations are significant at p < .05000
N=2401 (Casewise deletion of missing data)

Variable	Income Level	Number of Exclusive Fuelwood Users	User Density (A)	User Density (B)	Growth Rate of Fuelwood Users	Annual fuelwood Consumption Coming From Forest	Saturation of Fuelwood Users	% Indigenous Population	Fuelwood Balance	Pressure on Forest
Income Level	1	-0.14	-0.22	0.04	-0.24	-0.15	-0.84	-0.50	0.15	0.03
Number of Exclusive Fuelwood Users	-0.14	1	0.17	-0.01	0.25	0.97	0.13	0.07	0.05	-0.01
User Density (A)	-0.22	0.17	1	0.11	0.14	0.18	0.25	0.29	-0.15	0.06
User Density (B)	0.04	-0.01	0.11	1	0.02	-0.02	-0.02	-0.01	-0.02	0.98
Growth Rate of Fuelwood Users	-0.24	0.25	0.14	0.02	1	0.25	0.32	0.21	-0.08	0.02
Annual Fuelwood Consumption Coming From Forest	-0.15	0.97	0.18	-0.02	0.25	1	0.15	0.10	0.04	-0.01
Saturation of Fuelwood Users	-0.84	0.13	0.25	-0.02	0.32	0.15	1	0.64	-0.14	-0.02
% Indigenous Population	-0.50	0.07	0.29	-0.01	0.21	0.10	0.64	1	-0.10	-0.01
Fuelwood Balance	0.15	0.05	-0.15	-0.02	-0.08	0.04	-0.14	-0.10	1	-0.01
Pressure on Forest	0.03	-0.01	0.06	0.98	0.02	-0.01	-0.02	-0.01	-0.01	1

Note: In red are those coefficients that are statistically significant at 95% confidence level.

Table 8. Variables selected and threshold values for the construction of the indexes

Index	Variable associated	Threshold values used in the construction of the index
I 1	Number of exclusive fuelwood users.	1. <2,000 2. 2,000 to 4,000 3. 4,000 to 7,000 4. 7,000 to 15,000 5. >15,000
I 2	User density (number of exclusive fuelwood users / total municipality area)	1. < 0.07 2. 0.07 to 0.15 3. 0.15 to 0.3 4. 0.3 to 0.6 5. >0.6
I 3	Annual growth rate of exclusive fuelwood users (1990-2000)	1. <-0.03 2. -0.03 to -0.01 3. -0.01 to 0.005 4. 0.005 to 0.02 5. >0.02
I 4	Saturation of fuelwood users (proportion of households that use exclusively fuelwood over total number of households)	1. <0.2 2. 0.2 to 0.4 3. 0.4 to 0.7 4. 0.7 to 0.9 5. >0.9
I 5	Percentage of people belonging to an ethnic group	1. < 0.5% 2. 0.5% to 1.5% 3. 1.5% to 7% 4. 7% to 40% 5. >40%
I 6	Fuelwood balance (total forest productivity - annual fuelwood consumption coming from forest areas (ton/yr))	1. >120,000 2. 30,000 to 120,000 3. 12,000 to. 30,000 4. 1,000 to 12,000 5. <1,000

3) Construction of an integrated Fuelwood Priority Index (FPI)

The third step of the analysis was the development of an overall "priority index" for each *municipio* that integrates the six variables identified in the final set. In order to perform this analysis, each *municipio* was given a numerical value for each variable, from 1 to 5 according to its degree of priority (low priority = 1; high priority = 5).

Then, an overall fuelwood priority index was obtained as follows:

$$FPI_j = \sum_{1}^{6} I_{ij} * P_i$$

where,

FPI_j = woodfuel priority index for each *municipio* "j"

i_{ij} = index for each variable "i" used in the analysis (6 in total), ranging from 1 to 5.

p_i = weights assigned to each variable, set to 1 in our case.

4) Ranking of *municipios* in 5 groups according to the FPI: defining "hot spots" municipalities

With each *municipio* being assigned a numerical index that integrates the different concerns regarding fuelwood consumption and availability of resources, the final step was a regrouping into the five categories defined in the previous section: from low priority to high priority (Figures 16, 17 and 18)

The analysis of 2,401 (out of 2,436) *municipios* used to calculate the FPI produced the following results:

262 *municipios* → High priority
389 *municipios* → Mid-high priority
461 *municipios* → Medium priority
676 *municipios* → Mid-low priority
613 *municipios* → Low priority

Statistical analysis

A statistical analysis was conducted to corroborate the significance of the previous mentioned groups. An overall ANOVA confirmed that these five groups were statistically different at a 95% confidence level for the six variables used to calculate the FPI (Tables 9 and 10).

Table 9. Values of the FPI by group of priority *municipios*

Group	FPI threshold values	Average FPI	Number of municipios
1. High priority	> 24	25.6 (1.4)	262
2. Mid-high priority	21 - 24	22.0 (0.8)	389
3. Medium priority	18 - 21	19.0 (0.8)	461
4. Mid-low priority	13 - 18	15.1 (1.4)	676
5. Low priority	< 13	9.3 (1.9)	613
Global		16.6 (5.6)	2,401

Note: Differences are significant at $p< 0.05$; Standard deviation values are shown in brackets.

Table 10. Analysis of variance of the six dependent variables of the FPI

Analysis of Variance for the variables in the fuelwood priority index
Marked effects are significant at $p < .05000$

Variable	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	P
Fuelwood user	447270E5	4	111818E5	239954E6	2397	100106E3	111.6986	0.00000
User density	199	4	50	451	2397	0	264.8270	0.00000
Growth Rate of Fuelwood Users	1	4	0	4	2397	0	165.7476	0.00000
Saturation of fuelwood users	121	4	30	142	2397	0	510.3282	0.00000
Percentage indigenous population	1078830	4	269708	1414990	2397	590	456.8857	0.00000
Fuelwood balance	928128E8	4	232031E8	15684E11	2397	654333E6	35.4608	0.00000

The differences among all groups are statistically significant for most groups and variables, as can be seen from a box-plot analysis showing averages and standard errors for each group graphically (Figure 7).

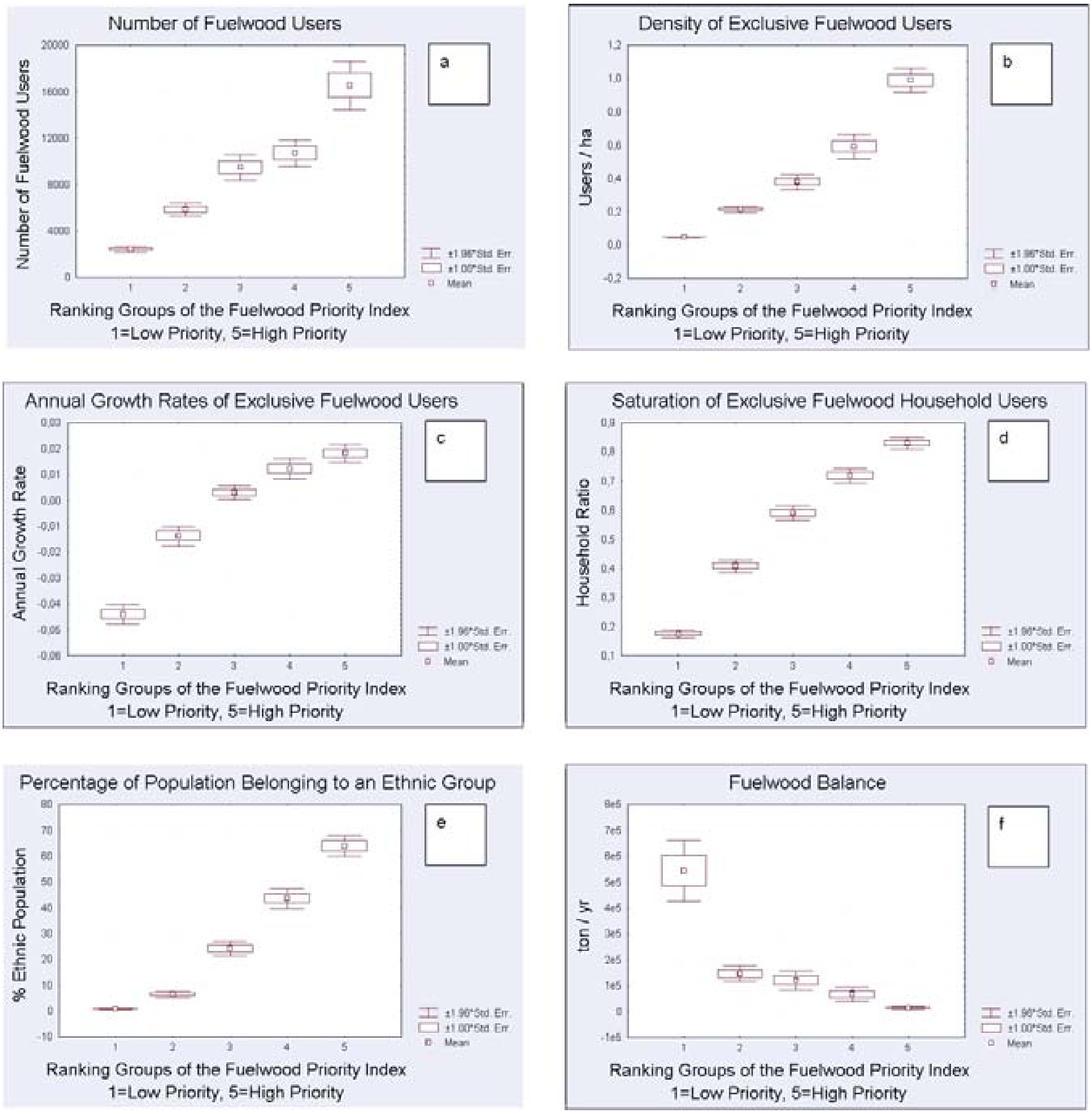


Figure 7. Statistical differences among groups of *municipios* according to selected variables

Overall results

Results for each variable used to construct the FPI

The FPI combines six variables in one ranking or priorization of *municipios*. However, useful results can be obtained by examining each of the variables independently. For example, we might be interested in the geographic distribution of fuelwood users from a health perspective, such as indoor air pollution, while an environmental analysis will focus on those municipalities where fuelwood extraction is not sustainable (i.e. when consumption surpasses fuelwood production). Moreover, a public policy analysis might need to link some fuelwood supply/demand variables with the average income level for each *municipio*. In other words, WISDOM is a flexible tool for focusing actions on different perspectives.

Thematic maps were prepared for each of the six variables used in the construction of the FPI index, illustrating the diverse aspects of fuelwood use patterns in Mexico (Figures 8 to 13). The five colours in all legends correspond to the five groups of priority, from green to red in increasing order of priority. Note the uneven geographical distribution of the different groups of *municipios* regarding the different criteria.

Figure 8 shows the distribution of fuelwood users in Mexico. Red areas correspond to those *municipios* with more than 15,000 exclusive fuelwood users. Note that their distribution is heavily biased towards Central and Southern Mexico. Because of their small size, municipalities from the state of Oaxaca are seldom red (high priority).

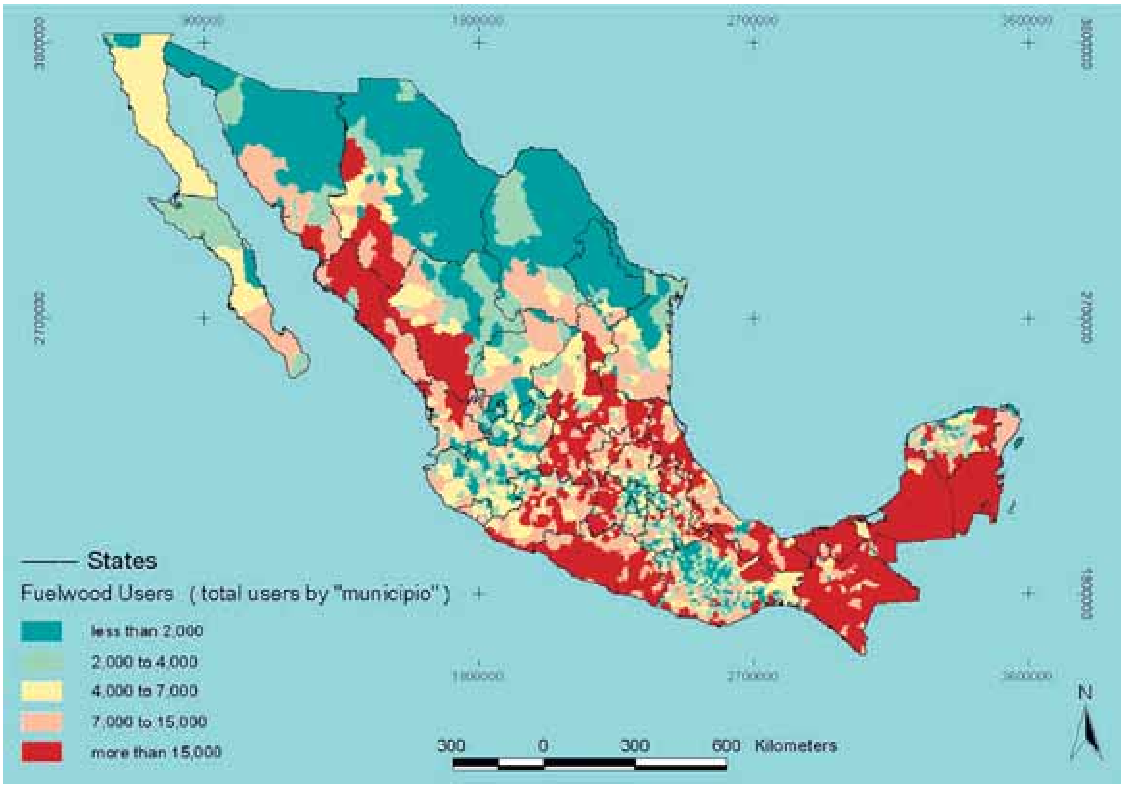


Figure 8. Number of fuelwood users, Mexico 2000

Figure 9 shows the distribution of densities of fuelwood users within Mexico. Red areas, corresponding to *municipios* with over 0.6 users per hectare, are mainly distributed within the states of Estado de Mexico (33.5% of its area); Puebla (27.8%); Veracruz (18.4%); and Hidalgo (17.9%).

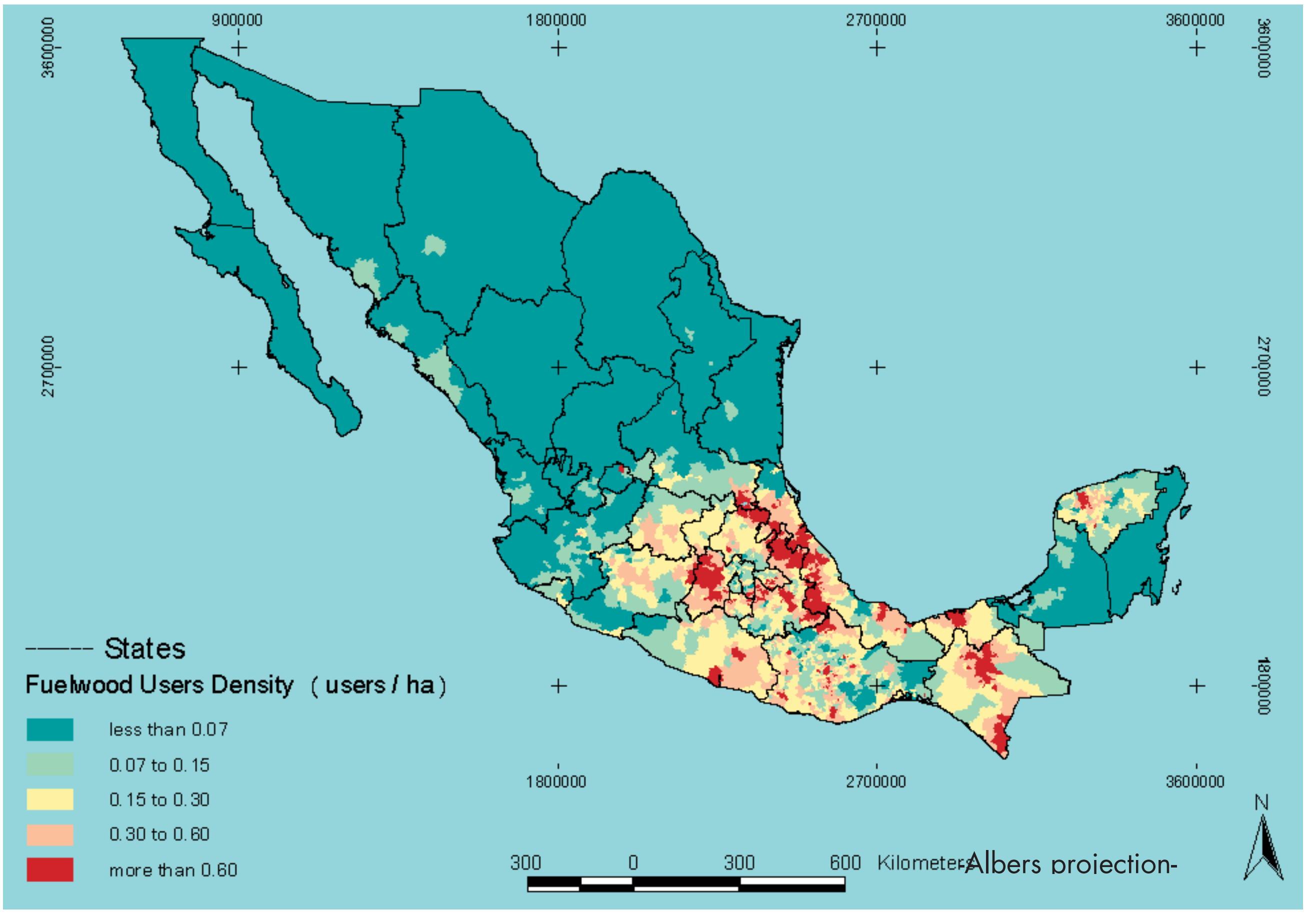


Figure 9. Density of fuelwood users, Mexico 2000

The spatial distribution of the growth rate of fuelwood users in Mexico (Figure 10) shows that a major proportion of *municipios* with high values (red) are distributed in the states of Yucatan, Quintana Roo, Tabasco and the coasts of Guerrero, Michoacan and Nayarit.

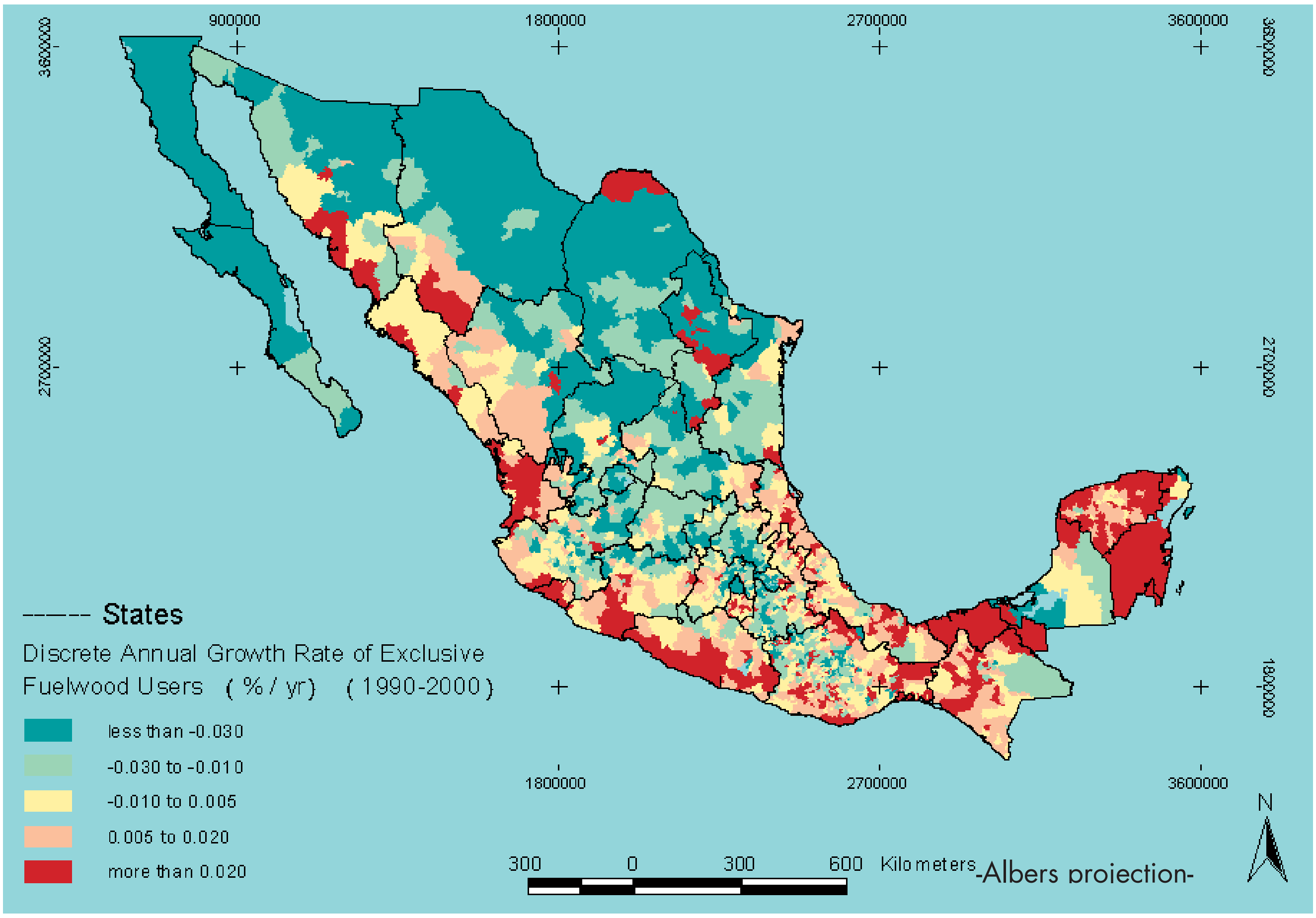


Figure 10. Growth of fuelwood users, Mexico 1990-2000

The percentage of households that use fuelwood for cooking is illustrated in Figure 11. As seen in the map, Oaxaca is the most critical state for this indicator. Approximately 43% of the State land area is covered by *municipios* where the percentage of households that use exclusively fuelwood for their domestic requirements rise to 90% of total population or more (red areas on the map).

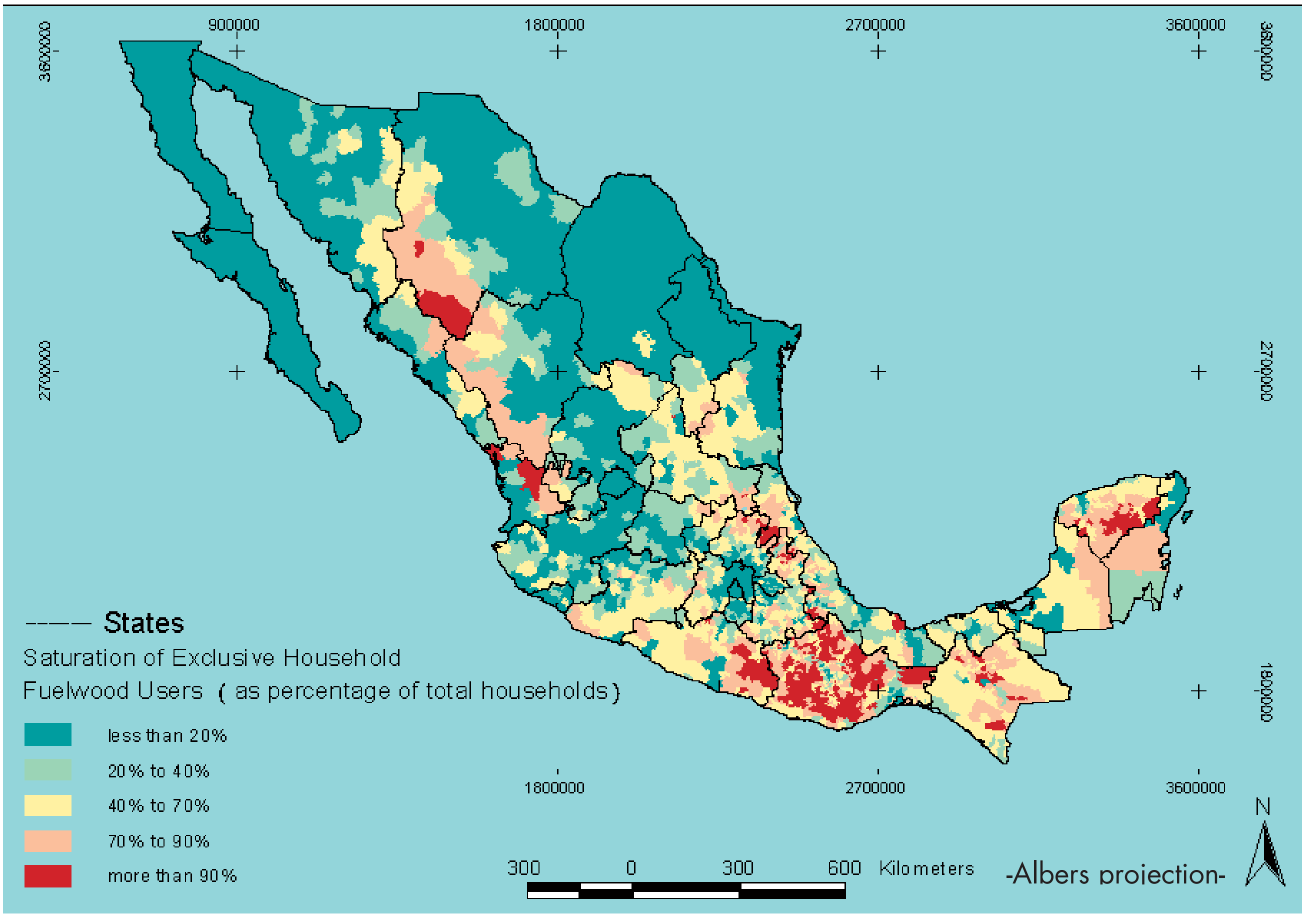


Figure 11. Saturation of fuelwood users, Mexico 2000

The distribution of people belonging to an ethnic group (speakers of native tongues) shown in Figure 12, is consistent with the results published by Toledo *et al.* (2001) and also mostly concentrated in the Southern States of Mexico.

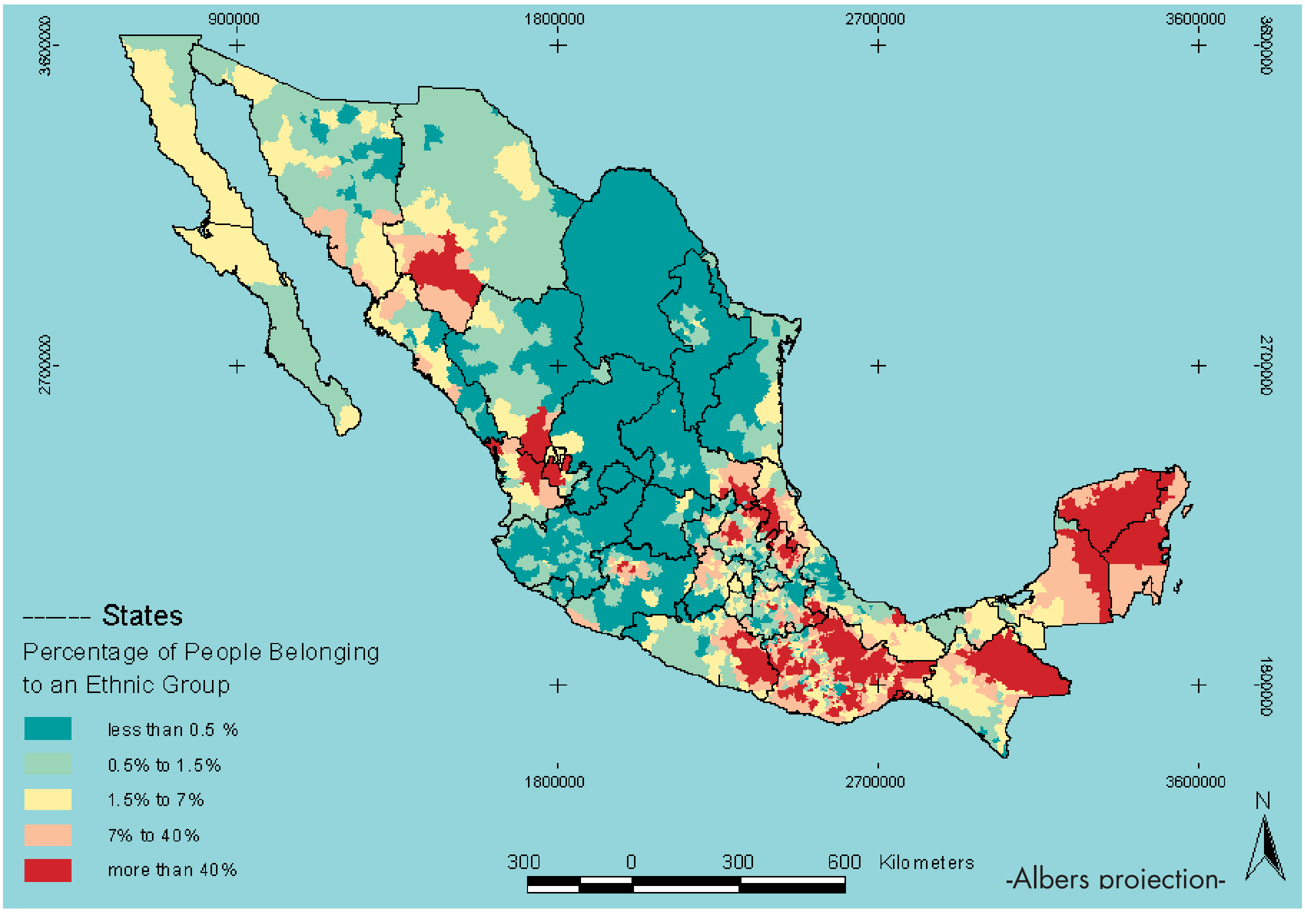


Figure 12. Percentage of indigenous population, Mexico 2000

Figure 13 illustrates the fuelwood balance in Mexico. As in Figure 8 above, the lowest availability of fuelwood is concentrated on the Mexican Gulf coast and central region. The three most critical states are again Veracruz (with 32.6% of its area covered by *municipios* ranked as "very low availability" of fuelwood), Tlaxcala (30.4%) and Estado de Mexico (22.3%). See Figure 7 for comparison.

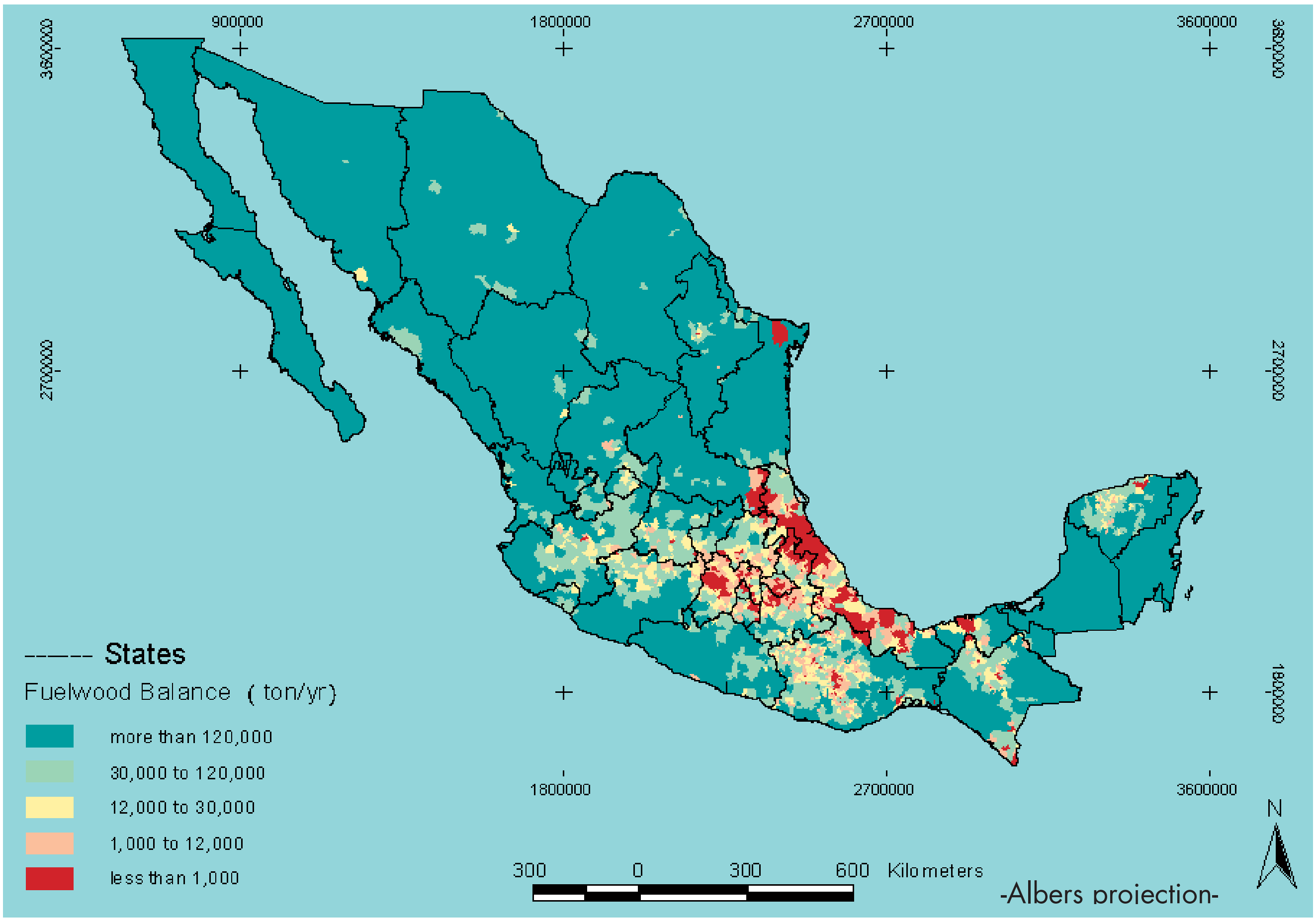


Figure 13. Fuelwood balance, Mexico 2000

Concerning another integrated variable, (not used in the FPI), Figure 14 illustrates the distribution of the potential pressure on forest resources from the use of fuelwood. Red areas are those *municipios* showing the highest pressure from fuelwood harvesting (> 2 ton/ha/yr). The map illustrates that the highest pressure on forest is concentrated on the Mexican Gulf coast and in the Central region. The three most critical states for this indicator are Veracruz (with 38.8% of its area covered by *municipios* ranked as "very high pressure", or more than 2 tons per hectare per year), Tlaxcala (27.1%) and Estado de Mexico (20.1%).

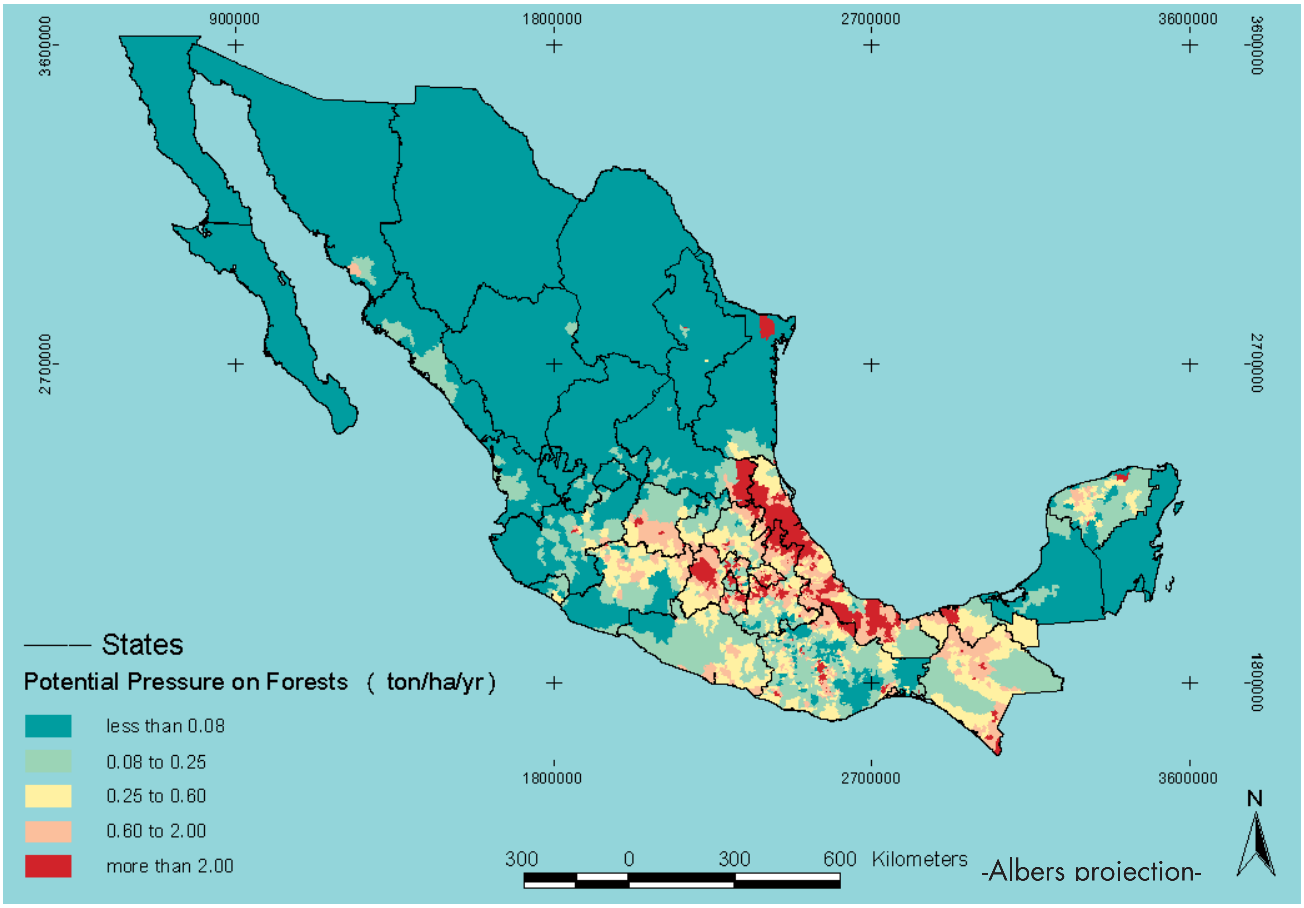


Figure 14. Potential pressure on local forests from the extraction of fuelwood, Mexico 2000

Results from the priorization of *municipios*

Conducting a WISDOM analysis for Mexico allowed the categorization of 2,401 *municipios* (out of 2,436) in five groups according to their level of priority. As stated above, the *municipios* ranked as high priority were those at the top of the Fuelwood Priority Index (FPI) ranking. The variables used in the construction of the FPI were: the number of fuelwood exclusive users; the percentage of houses that exclusively use fuelwood; the density and growth of exclusive fuelwood users at the household level; the resilience of fuelwood consumption (resistance to change to other fuels in terms of social and cultural aspects); and woodfuel resources from forests.

Figures 15 to 18 show *municipios* ranked in five final groups according to their FPI index. The red areas represent the 262 hot spots, or those *municipios* of highest priority in terms of the six variables selected for the construction of the FPI index.

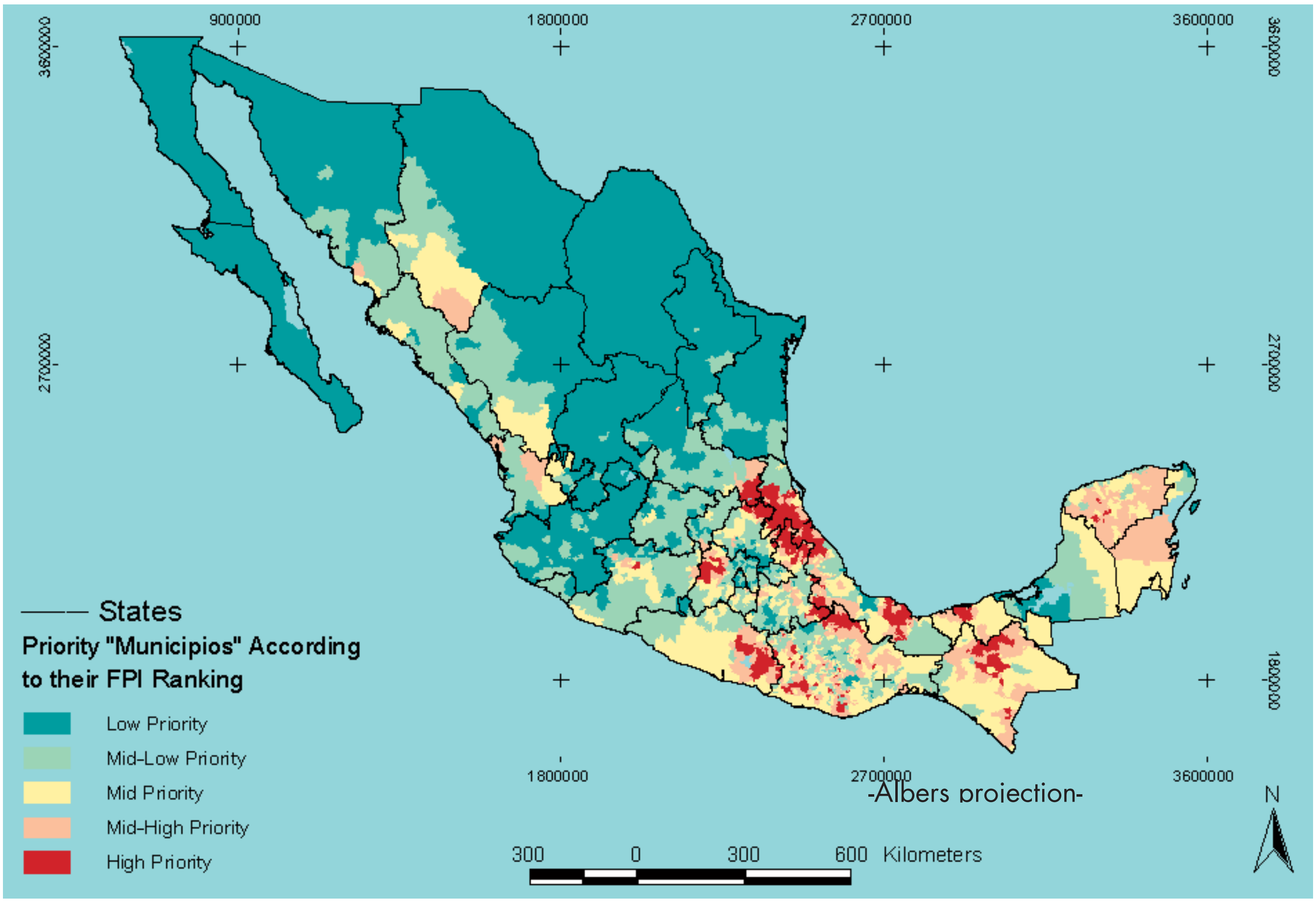


Figure 15. Priority *municipios* in terms of fuelwood use and availability of fuelwood resources, Mexico 2000

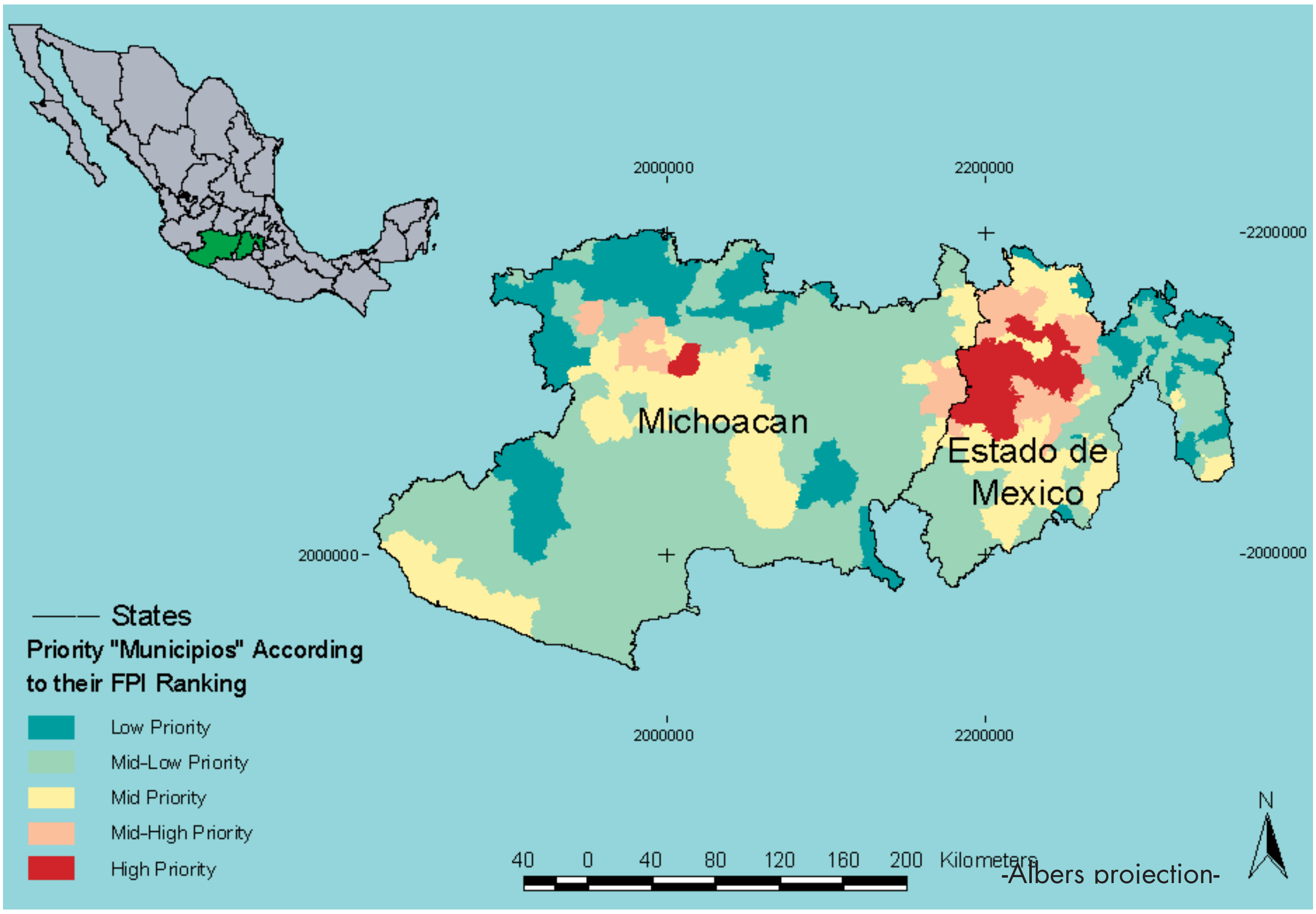


Figure 16. Priority *municipios* in terms of fuelwood use and availability of fuelwood resources, Mexico 2000. Detail for the Central Region

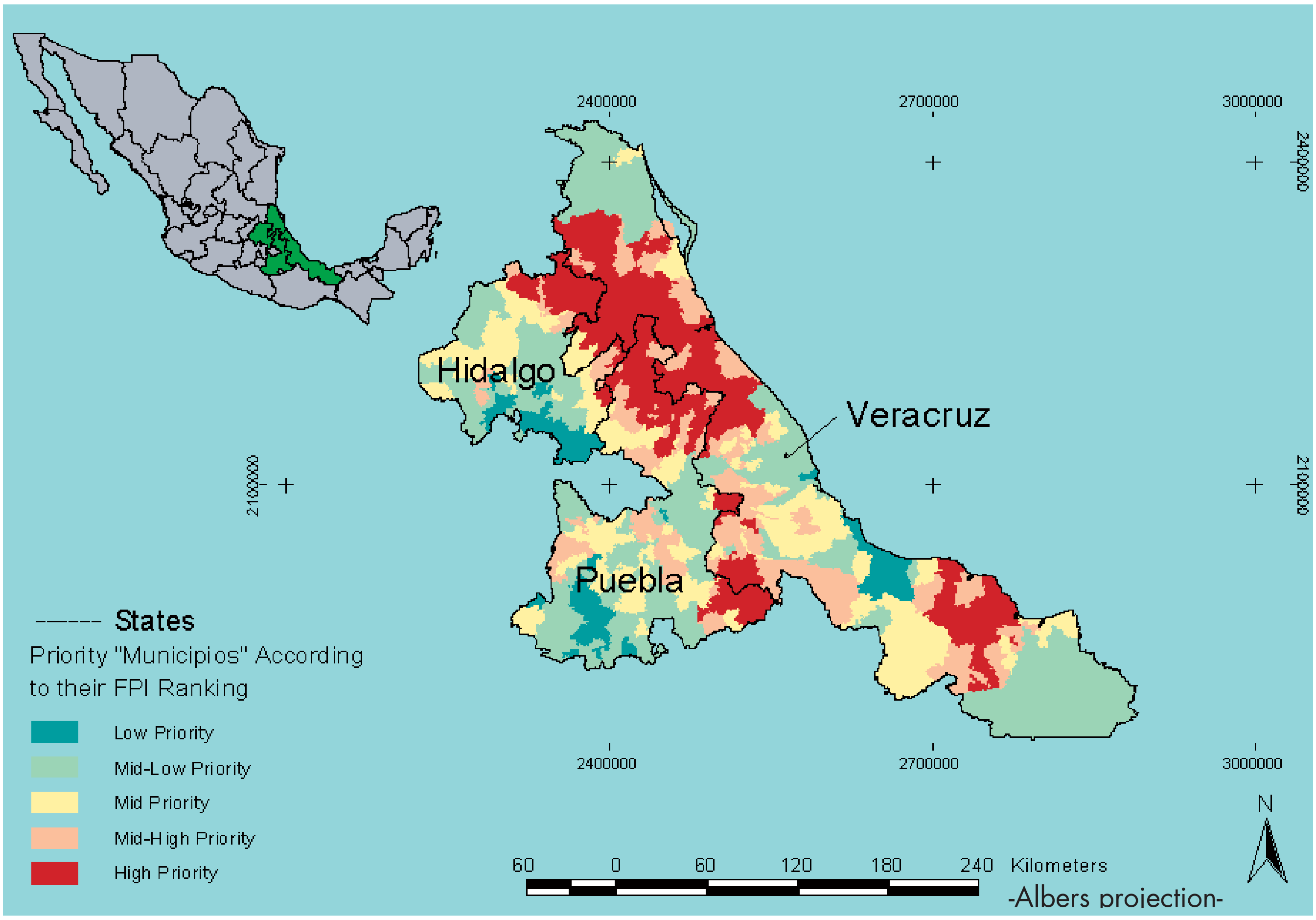


Figure 17. Priority *municipios* in terms of fuelwood use and availability of fuelwood resources, Mexico 2000. Detail for the Central Gulf Region

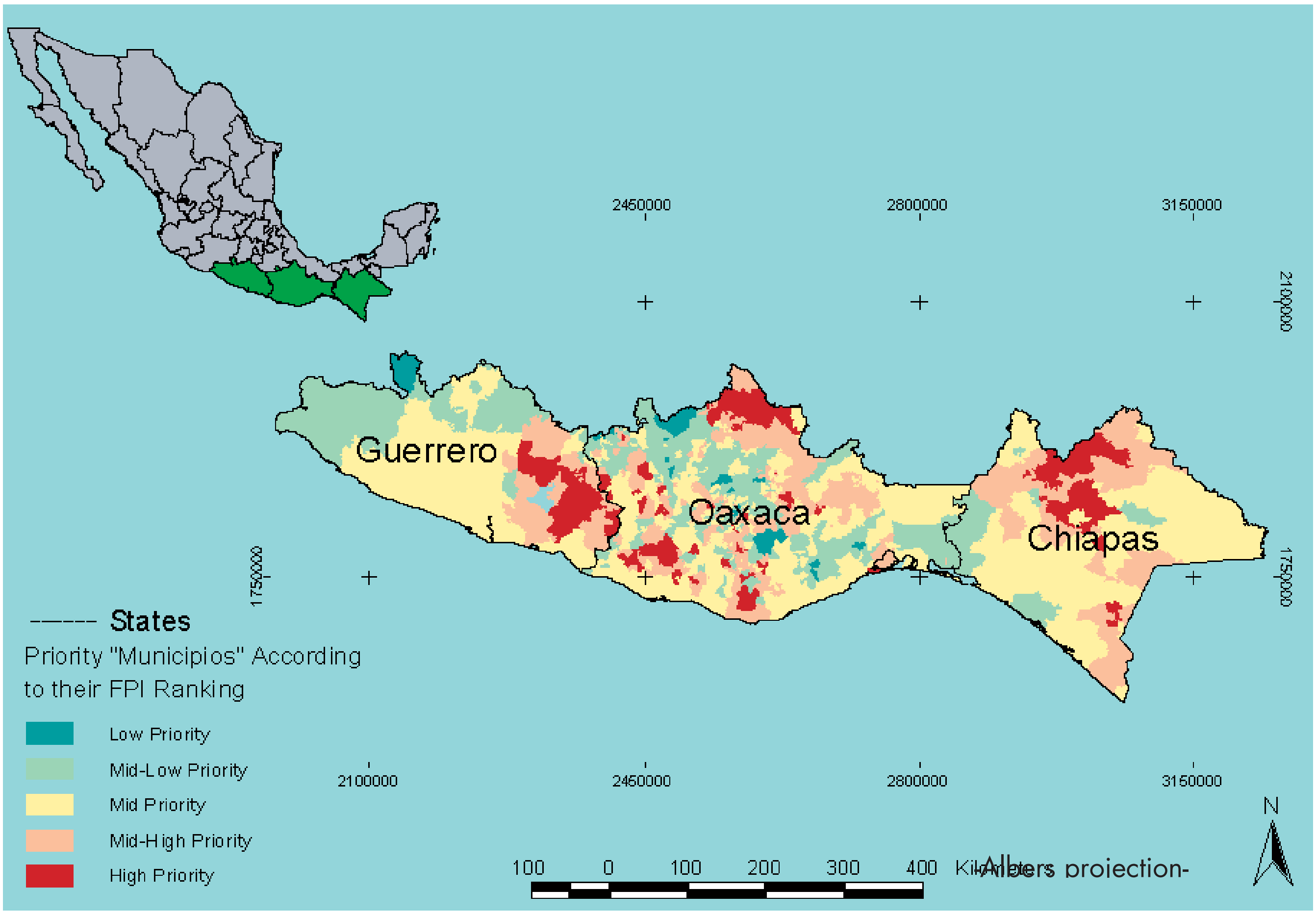


Figure 18. Priority *municipios* in terms of fuelwood use and availability of fuelwood resources, Mexico 2000. Detail for the South Pacific Region

The most critical states according to the percentage of their area covered by high priority (red) *municipios* are Veracruz (60 *municipios*; 26.4% of its area); Puebla (53 *municipios*; 19.1% of its area); Hidalgo (14 *municipios*; 15.3% of its area); and Estado de Mexico (10 *municipios*; 14.9% of its area). The number of *municipios* ranked as “high priority” on the state of Oaxaca rises to 63, but they represent only 9.3% of the total area. It is interesting to note that many priority *municipios* are located within larger clusters.

Tables 11 and 12 show the average and standard error values of selected variables of interest according to the five groups of *municipios* defined by the FPI index.

Table 11. Characteristics of each priority group according to the six variables used in the FPI

FPI Groups	Number of fuelwood exclusive users	Saturation of fuelwood users (%)	Fuelwood users density (A)(users/km2)	Indigenous population (%)	Growth rate of fuelwood users (% / yr)	Fuelwood balance (ton/yr)
High priority	16,539 (1,055)	83.0 (1.0)	0.99 (0.04)	63.9 (2.0)	1.8 (0.2)	13,632 (2,179)
Mid-High priority	10,734 (599)	71.8 (1.3)	0.59 (0.04)	43.7 (1.9)	1.2 (0.2)	67,999 (13,928)
Medium priority	9,451 (569)	58.9 (1.3)	0.38 (0.02)	24.2 (1.4)	0.3 (0.1)	118,911 (18,525)
Mid-Low priority	5,850 (280)	40.9 (1.1)	0.22 (0.01)	6.4 (0.6)	-1.4 (0.2)	145,812 (15,675)
Low priority	2,435 (118)	17,4 (0.7)	0.05 (0.00)	0.82 (0.1)	-4.5 (0.2)	543,633 (60,076)

Note: Standard error values are shown in brackets. Smallest "n" for any variable: 2401.

Table 12. Characteristics of each priority group according to selected variables of importance

FPI Groups	Welfare INEGI code* (1 to 7)	Consumption (ton/yr)	Forest area by municipio (ha)	Forest productivity (ton/yr)
High priority	1.83 (0.06)	11,633 (791)	8,079 (738)	25,265 (2,311)
Mid-High priority	2.67 (0.08)	7,002 (415)	20,749 (4,028)	75,001 (14,086)
Medium priority	3.16 (0.08)	5,846 (372)	35,938 (5,130)	124,757 (18,717)
Mid-Low priority	3.95 (0.07)	3,409 (170)	40,376 (4,131)	149,222 (15,763)
Low priority	5.07 (0.06)	1,296 (67)	132,217 (13,411)	544,929 (60,080)

Note: Standard error values are shown in brackets. Smallest "n" for any variable: 2,401.
*This variable, from the INEGI census, summarizes more than 20 socioeconomic other variables. The lower level of welfare is "1", while the highest is "7".

Net CO_2 emissions from fuelwood non-sustainable use by the residential sector

Non renewable use of fuelwood (i.e., when the amount burned exceeds the growth rate of the living biomass sources)[6] contributes to net CO_2 emissions. On the contrary, when harvested and used sustainably, woodfuels represent a major alternative for greenhouse gas mitigation (ISBSRD, 2003). In any case, quantifying the net CO_2 emissions from fuelwood use at the national level represents a key step towards promoting the sustainable use of this resource.

It is currently accepted that woodfuels are mostly used in a sustainable way (RWEDP, 1997 and 2000), however, there may be still specific sites within countries where it is not. When considering those areas where fuelwood extraction surpasses forest woody productivity, net CO_2 emissions from fuelwood use can be estimated. However, getting this type of information is very difficult (Díaz, 2000). In the Mexican case, estimates of net CO_2 emissions from fuelwood use remain very coarse, and they depend on assumptions about the overall degree of renewability of fuelwood extraction patterns (Díaz, 2000).

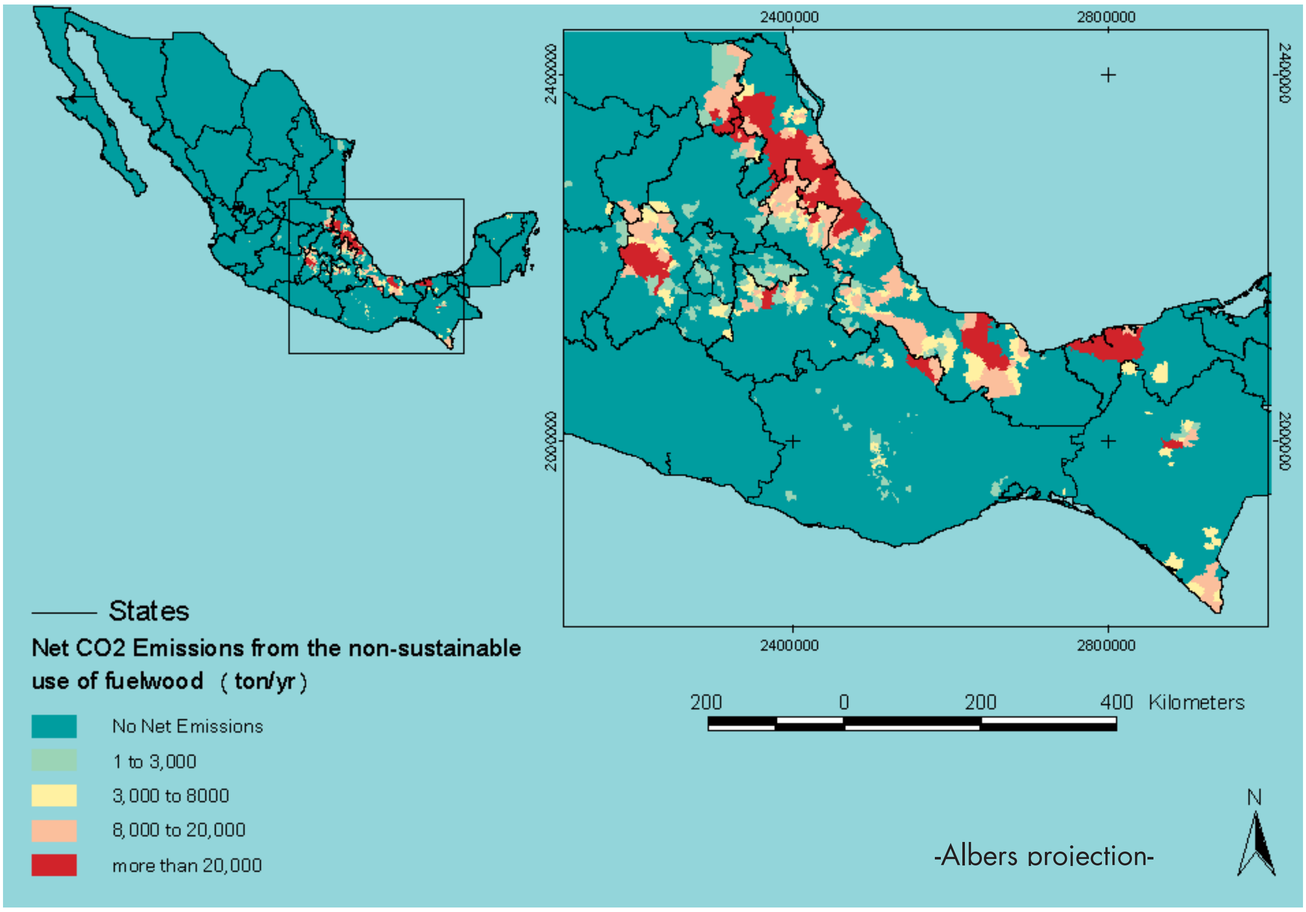
Based on our WISDOM results for Mexico, we can now get a relatively more precise estimate of the net CO_2 emissions from fuelwood use at the country level. To do this, we consider those *municipios* with a negative fuelwood balance between consumption and supply values. This analysis assumes that a) all the fuelwood demand from a *municipio* is covered by fuelwood coming from the same *municipio*, b) fuelwood extraction is homogeneously distributed within each *municipio*, and c) that all the forest biomass productivity is used for fuelwood. Criterion a) is mostly true in Mexico, while criteria b) and c) lead to underestimate the impacts of fuelwood use, particularly within large *municipios* or *municipios* with large commercial demand for timber.

Figure 19 and Table 13 show the estimated CO_2 emissions for Mexico in the year 2000 using the precedent assumptions. Considering only the fuelwood used within the residential sector, emissions reached from 1.90 $MtCO_2$/yr (0.52 MtC/yr) to 3.8 $MtCO_2$/yr (1.04 MtC/yr), depending if all forested areas within each *municipio* or only those forests actually accessible (estimated in 40% of the total forest area) are considered, respectively. These estimates are lower than the 4.3 to 10.2 $MtCO_2$/yr of emissions coming from fuelwood use obtained by Díaz (2000), using information aggregated at the state level.

Our estimates represents from 0.43% - 0.85% of total CO_2 emissions for Mexico (444.5 $MtCO_2$/yr (SEMARNAP, 1997)) and from 1.72% - 3.43% of total emissions from land use change and forestry (110.7 $MtCO_2$/yr (Masera *et al.*, 2001)). In other words, fuelwood is a minor contributor to carbon emissions within Mexico.

More detailed analyses are needed that take into account the actual fuelwood supply by *municipio*. As we will show in the next section, accessibility analysis may prove a valuable tool in this direction.

[6] Even when extracted on a renewable basis, fuelwood is not a 100% greenhouse gas emission neutral. This is because fuelwood combustion in traditional cookstoves or open fires is associated to net emissions of methane, non-methanogenic organic compounds (TNMOC), carbon monoxide and other gases. The relative contribution of these gases to total emissions depends largely on the type of technology used, the conditions of the fuel, and other factors. No reliable emission factors of these other greenhouse gases still exist for Mexico to make a reliable national assessment.



Note: Only forests accessible to fuelwood users are considered in the analysis.

Figure 19. Estimated Net Emissions of CO2 from the non-sustainable use of fuelwood, Mexico 2000.

Table 13. Net CO_2 emissions from the non-sustainable use of fuelwood by the residential sector, disaggregated by representative *municipios*:

Region	Net CO_2 emissions ($MtonCO_2$/yr)	As a percentage of total	Net CO_2 emissions from accessible forests only ($MtonCO_2$/yr)	As a percentage of total
Total Mexico	1.90	100%	3.80	100%
Veracruz	0.82	43.4%	1.51	39.7%
Puebla	0.27	14.4%	0.60	15.8%
Estado de Mexico	0.26	13.9%	0.48	12.6%
Oaxaca	0.08	4.4%	0.18	4.7%
Tabasco	0.08	4.1%	0.17	4.5%
Tlaxcala	0.05	2.7%	0.07	1.8%