WISDOM: A GIS-based supply demand mapping tool for woodfuel management

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Abstract

In this paper, it is argued that adequately assessing the implications of the current patterns of woodfuel production and use, and the sustainable potentials of woodfuel resources, requires a holistic view and a better knowledge of the spatial patterns of woodfuel supply and demand. There is a need to conduct multi-scale spatially explicit analyses of woodfuel supply and demand that are able to articulate local heterogeneity at the regional and national levels. Studies that provide full-country coverage and are based on consistent integration of data at lower geographical scales are woefully lacking. This paper describes the Woodfuel Integrated Supply/Demand Overview Mapping model (WISDOM). This is a GIS-based tool, aimed at analyzing woodfuel demand and supply spatial patterns from a new perspective that includes: (a) the assembling of existing but dispersed information into single data sets, (b) a modular integration of these data sets, based on the analysis of key variables associated with woodfuel demand and supply patterns, and (c) a multiple-scale and spatially explicit representation of the results, in order to rank or highlight areas in which several criteria of interest coincide. The final objective of WISDOM is to assess the sustainability of woodfuel as a renewable and widespread energy source, while supporting strategic planning and policy formulation. Three case studies for Mexico, Slovenia, and Senegal illustrate the practical implementation and innovative results of using WISDOM.

Keywords: Fuelwood priority areas; Fuelwood planning; Sustainability assessment; Data analysis; Mexico; Slovenia; Senegal

Abbreviations: ABF, Association Bois de Feu, Senegal; CDM, Clean Development Mechanism (UNFCCC); CHP, combined heat and power; CR, Rural Communities (counties of Senegal); CSE, Centre de Suivie Ecologique of Dakar, Senegal; CSE, EROS Center for Ecological Monitoring (USGS); DEM, digital elevation model; Digital Chart of the World, Environmental Systems Research Institute, Inc. (ESRI) product: http://www.maproom.psu.edu/dcw/ (Last visited on 19th December 2005); EROS, Earth Resources Observation & Science (USGS); FAO, Food and Agriculture Organization of the United Nations (UN); FPI, Fuelwood Priority Index; FRA RSS, Remote Sensing Survey of the Forest Resources Assessment (FAO); GHG, Greenhouse Gases; GIS, Geographic Information System; GTOPO 30, Global digital elevation model (DEM) with a horizontal grid spacing of 30 arc; IUCN, International Union for the Conservation of Nature; KO, Cadastral Communities (counties in Slovenia); LANDSAT, United States satellite used to acquire remotely sensed images of the Earth’s land surface and surrounding coastal regions; LCCS, Land Cover Classification System of the AFRICOVER Project (FAO); LPG, Liquefied Petroleum Gas; LU/LC, Land use/Land cover; PSACD, Programme Sectoriel d’Appui au Combustible Domestique (Senegal); SEMIS, Bureau d’étude Sénégalais, Dakar, Senegal; SFS, Slovenia Forest Service; SWEIS, Slovenia Wood Energy Information System; TREES II, Tropical Ecosystem Environment Observations by Satellite (II stands for second phase); UNFCCC, United Nations Framework Convention on Climate Change; USAID/DAT, Direction de l’Aménagement du Territoire, Dakar, Senegal, United States Agency for International Development (USAID); USGS, United States Geological Service; WISDOM, Woodfuel Integrated Supply/Demand Overview Mapping; WPI, Woodfuel Priority Index; WSC, woodfuel supply capacity

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1. Introduction

When used in a sustainable way, biomass represents a renewable energy source which is widely available. Bioenergy can play a major role in the expected worldwide transition to renewables, both in developed and developing countries [1,2]; and have significant positive impacts on climate change, by offsetting fossil fuel emissions. Estimates of the bioenergy production potential in 2050, reaches a maximum of 1.135 ZJ yr\(^{-1}\) [1,2]. For comparison, the global primary energy consumption in 2001 was 420 EJ [3]. One step that is needed in order to design national strategies for sustainable biomass energy use and exploitation is to understand in detail, the current spatial patterns of biomass demand and supply over a country. Currently, about 60% of the wood removed from around the world is used for energy purposes. For the group of developing countries this amount rises to 80% [4]. Woodfuel is one of the main forest products, in many situations, the major product [5]. For a comprehensive definition of the term “woodfuel”, please refer to FAO’s Unified Wood Energy Terminology [6]. Woodfuels satisfy 7% of the world primary energy consumption, and 15% when considering the group of developing countries [4]. The International Energy Agency estimated that approximately 2.4 billion people living in developing countries depend on woodfuels for cooking, heating, and boiling water [7]. FAO projections to 2030 predict a slow decline in the global annual fuelwood consumption from 1.611 km\(^3\) (2000) to 1.501 km\(^3\), whereas charcoal consumption is expected to grow from 46 Mt (2000) to 76 Mt in 2030 [8]. For comparison, 1 hm\(^3\) of wood (or 150 dam\(^3\) of charcoal obtained with poor techniques) corresponds to an area between 100 km\(^2\) and 200 km\(^2\) of a mid-density mature plantation. One hm\(^3\) of wood is equivalent to approximately 10 PJ. As seen by these numbers, woodfuel plays an indubitable role as an energy source; however, its patterns of demand and supply, and its associated social, economic and environmental impacts are still poorly understood.

Historically, reliance on very general and aggregated information on woodfuels has led to misleading conceptions about the effect of woodfuel use on the environment and its sustainability: from pointing to woodfuels as major direct causes of deforestation and forest degradation (e.g. “woodfuel crisis” approach [9–11]) [12–14], to the denial of any significant influence of woodfuel collection in these processes [15,16]. These types of assessments have also resulted in poor planning and ineffective implementation of projects. The research conducted in the last decade, including comprehensive field studies and projects have shown that woodfuels demand and supply patterns are rather complex and very site specific [17–25]. This characteristic has shifted the early thinking of a general fuelwood crisis to the understanding that critical areas vary from place to place [22,23,25]. Even in regions with an overall negative woodfuel demand/supply balance, not all the places face woodfuel scarcity, and similarly, regions with an overall positive balance may include deficit areas [22,23,25]. In this article, the terms woodfuel “supply” and woodfuel “production” are used synonymously, as are woodfuel “demand” and woodfuel “consumption”, since they are used in a technical—as opposed to an economic—sense.

To cope with these problems, thorough local studies have been implemented (e.g. area-based woodfuel flows analysis: see [26] for the case of Mexico). The results of these local investigations are then expanded at national level to guide energy actions and interventions [23]. Although these approaches have proven the heterogeneity of local situations, and provide the information needed to understand wood energy situations at the local level, they are expensive and time consuming. They also tend to be limited to small areas, and to be sporadic, thus failing to convey the national perspective needed for the design of effective national policies, for completing national inventories for greenhouse gases, or for estimating the national potential of woodfuels as a renewable energy source. Moreover, obtaining exact measures of woodfuel deficits (as in studies conducted using the traditional fuelwood gap model [27,28]) presents severe methodological and financial challenges, particularly considering the scarce resources normally allocated to this specific sector [15]. Still little is known, for example, about the amounts, extent, geographical location and dynamics of wood supplies: from plantation strategies, to traditional wood collection and harvesting methods [29].

In this paper, it is argued that adequately assessing the implications of the current patterns of woodfuel production and use, and the sustainable potential of woodfuel resources, requires a holistic view and a better knowledge of the spatial patterns of woodfuel supply and demand. There is a critical need of planning tools that allow users to integrate data from various sectors and to conduct multi scale spatially explicit analyses of woodfuel supply and demand that are able to articulate the local heterogeneity into the regional and national levels. Studies that provide full-country coverage and are based on a consistent integration of data at lower geographical scales are woefully lacking. Such studies should be oriented to identify priority areas and hot spots within a country or a broad region. In a second step, more in-depth analyses can be conducted within priority areas, allowing a more efficient use of scarce available resources.

This paper introduces the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM), a spatially explicit method for determining woodfuel priority areas. WISDOM has been developed by FAO, in cooperation with the Center for Ecosystem Research of the National Autonomous University of Mexico (UNAM). WISDOM has been formulated as a planning tool and a methodology to provide country-wide synoptic views of local wood energy supply and demand patterns based on the consistent integration of forestry, energy and socio-economic data and information. We also summarize the results of the
application of WISDOM in three case studies in Mexico [30], Slovenia [31], and Senegal [32].

2. The WISDOM approach

Due to space limitations we show here the main elements of the WISDOM approach. Refer to Masera et al. 2003 [33] for a complete description of the methodology and for more details about its practical implementation, existing databases, and other relevant information. WISDOM is based on the integration of geographic information system (GIS) and database technologies (i.e. geodatabase), which offers new possibilities for combining, or integrating, statistical and spatial information about the production (supply side) and the consumption (demand side) of woodfuels. This accessible, user-friendly technology makes it possible to display the results of spatial analysis in easily understandable ways to public officials and private citizens as well as to the scientific community [34].

WISDOM is intended as a strategic planning tool, rather than an operational one. Therefore, rather than absolute and quantitative data, WISDOM is meant to provide relative/qualitative values such as risk zoning, criticality ranking or ranking by energy supply potentials, highlighting, at the highest possible spatial detail, the areas deserving urgent attention and, if needed, additional data collection.

To identify these critical areas or hot spots, relevant interactions over a set of socio-economic and environmental variables, directly or indirectly related to woodfuels use patterns are analyzed. WISDOM’s final objective is to assess the sustainable potential use of woodfuels as a renewable and widespread energy source, while supporting strategic planning and policy formulation.

3. WISDOM methodological structure

Conducting a WISDOM analysis involves five main steps (Fig. 1): (1) selection of the spatial base, (2) development of the demand module, (3) development of the supply module, (4) development of the integration module, and (5) identification of woodfuel hot spots.

3.1. Selection of the spatial base

WISDOM is flexible and can be used for studies at the national, regional or sub-regional level. For national-level studies, which are most useful for policy formulation, the analysis should be carried out at the lowest administrative level for which demographic, social and economic parameters are available (e.g. the municipality). The sub-national level of analysis is an essential feature of WISDOM as it helps to avoid aggregations and generalizations that have so negatively affected wood energy

![Fig. 1. WISDOM steps. Notes: The figure shows the five steps needed to complete a WISDOM analysis.](image)
studies in the past. Many countries have digital data sets for their administrative units, which facilitate the analysis. Census and other socio-economic information are increasingly provided in digital form. For regional (i.e. supra-national) or sub-regional studies, demographic information may be derived from the LandScan Global Population Database of Oak Ridge National Laboratory in the United States [35], which provides worldwide population density maps at 30' x 30' (arc-second) resolution.

In this step, spatial and statistical data are linked through a “map attribute table”. The table can be expanded as needed by the addition of thematic attributes referring to the same set of map elements or units of analysis, in order to include all available information directly or indirectly related to woodfuel demand and supply.

3.2. Demand module

The demand module portrays the spatial distribution of woodfuel consumption, disaggregated, if possible, by fuel type (e.g. fuelwood, charcoal), by sector of users (e.g. household, industrial), by type of demand (self-consumption, local market), and by area (e.g. rural, urban), since each has a different impact on sources and sustainability of supply, calling for separate lines of analysis. It is also used to identify those areas showing distinctive consumption dynamics (e.g. increasing woodfuel needs). Determining the actual and expected consumption of woodfuels is a complex task, as it is a function of socio-demographic, technical, environmental, cultural, and economic variables [21]. Table 1 shows potential variables that can be used in the analysis.

The development of the demand module usually implies the integration of consumption data from surveys—normally covering only part of the country, and using different methodologies/assumptions—with socio-demographic variables obtained from census information. The main challenge in this module is to find either direct or proxy variables, available at the national level, that can be used to estimate consumption levels and their spatial distribution. As WISDOM uses statistical information disaggregated by sub-national units, it is necessary to have complete data sets associated to these units in order to

<table>
<thead>
<tr>
<th>Variable</th>
<th>Desired breakdown</th>
<th>Possible sources of information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Woodfuel consumption by households</strong></td>
<td>Fuel type (fuelwood, charcoal)</td>
<td>Household energy surveys</td>
</tr>
<tr>
<td>● Woodfuel use per capita</td>
<td>End use (cooking, boiling water, heating)</td>
<td>Estimates are available at national level, rarely at sub-national level; often based on project level data. Estimates may differ from source to source</td>
</tr>
<tr>
<td>● Number of users at time $t$</td>
<td>Urban/rural population</td>
<td>National census and/or LandScan® population density map 1998/2000</td>
</tr>
<tr>
<td>● Combination of fuels</td>
<td>Minimum administrative unit of analysis</td>
<td></td>
</tr>
<tr>
<td><strong>Woodfuel consumption by industrial users</strong></td>
<td>Type (and size) of industries</td>
<td>Estimates usually based on project or survey level data</td>
</tr>
<tr>
<td>● Woodfuel use per unit of product</td>
<td>Minimum administrative unit of analysis</td>
<td>National census/surveys for industries (rarely comprehensive for industries belonging to the informal sector)</td>
</tr>
<tr>
<td>● Number of users at time $t$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Density of users</strong></td>
<td>Urban/rural</td>
<td>National census and/or indirectly through surveys</td>
</tr>
<tr>
<td>● Saturation (% of users)</td>
<td>Household/industrial</td>
<td>National census could be assessed through GIS analysis</td>
</tr>
<tr>
<td>● Users by km$^2$</td>
<td>Woodfuel exclusive/multiple fuel users</td>
<td></td>
</tr>
<tr>
<td><strong>Average annual growth rate of consumption/users</strong></td>
<td>Urban/rural</td>
<td>National Census and country population projections</td>
</tr>
<tr>
<td>● Household/industrial</td>
<td>Household/industrial</td>
<td>UN population projections are available at national level only. Sub-national time series from national statistical services. Population growth maps (from LandScan) are expected to be developed shortly</td>
</tr>
<tr>
<td>● Woodfuel exclusive/multiple fuel users</td>
<td>Woodfuel exclusive/multiple fuel users</td>
<td></td>
</tr>
<tr>
<td><strong>Resilience of consumption</strong></td>
<td>Ethnic groups</td>
<td>National census</td>
</tr>
<tr>
<td>● Relevant social/cultural groups</td>
<td>Income groups within urban/rural population</td>
<td>Income–expense national household surveys</td>
</tr>
<tr>
<td>● Income levels</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: Adapted from Masera et al. [33].

*Global Population Database produced by the LandScan Global Population Project of Oak Ridge National Laboratory, which is a worldwide population database at 30' x 30' (arc-second) resolution.*
“spatialize” the information over the maps. Gaps in the data may be filled in three ways: (1) by the use of proxy variables to “spatialize” discontinuous values (e.g. using rural population as a proxy for woodfuel users); (2) by extrapolating information available at the project level, to the entire study region (i.e. to extrapolate fuelwood consumption per capita). This procedure may be valid in cases where data does not need to be highly accurate or where woodfuel consumption estimates cover at least representative regions or situations within the study area; and (3) by filling specific or critical data gaps with new data coming from field surveys. This option could be very expensive, so the surveys need to be carefully designed, to minimize the cost and effort for a given precision level. Different woodfuel survey methodologies can be used for these purposes [25,36].

Several criteria can be set to determine priority areas in terms of woodfuel demand. For example, one might be interested in areas that show: (a) high woodfuel consumption; (b) high density of woodfuel users; (c) high growth rates of woodfuel consumption or users, either by households or industrial users; (d) high resilience of woodfuel demand (in terms of cultural attachment to fuelwood use, represented for example by the percentage of ethnic population).

The precise criteria, and the corresponding prioritization of areas, will depend on the specific objective of the study. For example, the study may be intended to identify places with large potential market opportunities for new technologies or places with major health impacts associated with the use of open fires for cooking.

3.3. Supply module

Having access to reliable data on woodfuel supply has been historically one of the main challenges in wood energy analysis. For this reason we will be more explicit in this section. To the extent allowed by the existing information, the supply module should provide a spatial representation of all natural and planted woodfuel sources, their current stock (volume of biomass), their change over time and their productive capacities. Thus the analysis is not restricted to natural forests, but also encompasses plantations, trees outside forest, woodlands, shrubs, live hedges and any other main source of woodfuels. The main, and often the only, sources of information for developing this module are national forest inventories, since detailed surveys of biomass stocking and productivity covering non-forest land-use classes are still rare events. In most cases, stocking and productivity for non-forest woodfuel sources (shrubs, agricultural plantations, agro-forestry practices, etc.) will be inferred or guesstimated. Given the paucity of data on non-forest classes, the development of this module will usually rely on local studies, even if of limited coverage, and experts’ opinions.

As with the demand module, it is essential to use disaggregated statistics referring to small spatial units of analysis rather than aggregated averages. Table 2 shows the potential variables to be used for the development of the supply module. In general terms, it may be assumed that the woodfuel supply capacity (WSC) of an area is a function of several factors which include, among others: (a) land use/land cover and relative changes; (b) biomass stocking and productivity of trees, shrub and herbaceous species; and (c) accessibility.

Detailed land use/land cover inventories are still scarce but increasingly available at the national and international level. An interesting example is the FAO AFRICOVER Project over East and Central Africa countries. Promising features of AFRICOVER products are the wall-to-wall coverage of all countries at a good level of detail (scale 1:100,000–1:200,000) and the associated Land Cover Classification System (LCCS), which represents well the wide variety of low-density vegetation types characteristics of African landscapes, and offers a good basis for the estimation of woody biomass stocking [37].

Concerning land cover change, national deforestation rates are available in countries that regularly conduct monitoring studies. However, only few tropical countries undertake regular monitoring studies from which sub-national change patterns can be derived (India, Brazil limited to Legal Amazon have some, but there are none for Africa for example). Richer information on land cover changes was produced for the tropical belt, by region and main ecological zones. Other sources of information include the Remote Sensing Survey of the Forest Resources Assessment (FRA RSS) carried out during the 1990 Assessment, and continued in the 2000 Assessment [38–40,42]. This study produced highly consistent information on the land cover change processes and trends for the periods 1980–1990 and 1990–2000 through the analysis of satellite time series over a 10% statistical sample of tropical land. Important information from this study is the biomass flux diagram, which provides a useful indication on the loss or gain of woody biomass associated with each change in land cover. The FRA RSS analyzed 117 sampling units, each of them covering an entire Landsat scene (185 × 185 km). Additional evidence on the change in land cover occurring in the humid tropical regions over the period 1990–1997 has recently been produced by the TREES II Project of the European Joint Research Center on the basis of a statistical sample of high-resolution satellite images covering the dense forest formations of the humid tropics [37,41]. The TREES High Resolution Study analyzed 93 sampling units, 39 of which covering full Landsat scenes and 54 covering quarter scenes (approximately 100 × 100 km). Neither of the two studies produced country-level results, but each of the sampling units analyzed in these surveys, which vary in size between 10,000 and 34,225 km², may contribute some interesting insights into the local patterns of change.

Information on biomass stockings and productivity of natural forests and plantations may be derived through the integration of land cover information with conventional
forest inventory data (volume and yield) [43]. For instance, the LCCS applied in several African countries, which is based on classifiers independently describing three vegetation layers (trees, shrubs, and herbaceous), may be combined with local volume and yield estimates to produce biomass density maps. Rarer are stocking and productivity estimates for non-forest formations such as scrublands, homestead gardens, windbreaks, roadside trees, farmland trees, etc., which may represent important woodfuel sources for the rural population [24,43–45]. Usually this aspect will need to be covered by inference and extrapolation from detailed studies conducted at the project or micro-regional level.

Access to woodfuels must be considered when calculating the WSC of an area [30,40]. As with other variables, accessibility results should be disaggregated by minimum units of analysis, following each scale of analysis (Table 2). Physical accessibility may be defined in a Geographic Information System (GIS) through the use of slope information from terrain models (e.g. GTOPO 30; Digital Chart of the World-derived products), using a buffer analysis based on road networks and settlements distribution, and other parameters. Different assumptions or access thresholds should be taken into account by type of extraction practice (e.g. considering fuelwood: gatherers using vehicles, draught animals, or none of these) and by final use (e.g. selling and trade in local markets, self-consumption). For example, from a national perspective, access to areas with woody vegetation could be calculated from broad buffer zones around clusters of localities with high woodfuel consumption. When dealing with local or micro-regional accessibility patterns, more detailed studies using high-resolution digital elevation models (DEMs) and local route maps are recommended. General assumptions for accessibility studies should be based on local survey data. Legal accessibility will identify the areas where wood extraction is forbidden, such as national parks or just private lands. These areas may be derived from national or international maps, such as the IUCN map of protected areas, and from cadastral databases.

The quantitative WSC value is extremely difficult to determine with precision since it depends on the capacity (potential) of an area to produce biomass which may vary widely [15]. Moreover, the majority of research on this area as noted above has concentrated on establishing the amounts of usable timber produced by commercial tree

Table 2
Potential variables to be used in the supply module

<table>
<thead>
<tr>
<th>Variable</th>
<th>Desired breakdown</th>
<th>Possible sources of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use/land cover class</td>
<td>All land use/land cover classes must be considered (including both forest and non-forest classes)</td>
<td>National Forest Inventories, e.g. AFRICOVER mapping in Africa using FAO’s Land Cover Classification System [37]</td>
</tr>
<tr>
<td>Land use/land cover change</td>
<td>Crude deforestation rates should be avoided; land cover transitions (i.e. using land use transition matrices) are well suited for this type of analysis</td>
<td>National monitoring studies; large-scale studies such as FAO’s Global Forest Resources Assessment remote-sensing survey [38–40]; TREES II high-resolution survey [41]</td>
</tr>
<tr>
<td>Woody biomass stocking by land use/land cover</td>
<td>Biomass stocking for all land use/land cover classes including croplands, shrublands, etc.</td>
<td>Forest inventory data (volume expanded to total biomass); inference and extrapolation from detailed studies to include non-commercial species used as woodfuels</td>
</tr>
<tr>
<td>Average biomass production by land use/land cover class</td>
<td>Productivity indices for all land use/land cover classes</td>
<td>Forest inventory data (yield expanded to total biomass); non-forest biomass surveys (still rare); inference and extrapolation from detailed studies; agro-ecological zoning</td>
</tr>
<tr>
<td>By-products of primary and secondary wood processing industries</td>
<td>Type and quantity of by-products (residues) produced by main industrial processes (by unit of processed main product)</td>
<td>National statistics on industrial production. Chamber of commerce data on size and distribution of wood processing industries</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Adjust total area by legal reasons (e.g. protected areas), for physical reasons (e.g. slope, distance, natural barriers) and for economic reasons (e.g. tenure fragmentation making the extraction uneconomic)</td>
<td>Legal access: national or international maps of protected areas, such as those of the World Conservation Union (IUCN)</td>
</tr>
</tbody>
</table>

Source: Adapted from Masera et al. [33].

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species (i.e. annual increment of stems), which is not of interest for the rural woodfuel supply [44]. On the other hand, estimating the woodfuel supply of non-forest areas is particularly complicated because of the high degree of variability in the woody cover and productivity of these areas. In many instances, the capacity of agricultural farming systems to produce woodfuels depends on the level of demand (e.g. population density [46]) and accessibility of alternative sources, which might bring their production to a higher or lower priority level, with respect to other products [22]. However, as mentioned earlier, the scope of WISDOM is not operational planning, for which quantitative precision is essential and definitely more demanding.

In this context and within the scope of identifying priority areas where the demand/supply balance indicates 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. For example, if the aim is to identify areas with potential woodfuel shortages, then the study could look for areas that show: (a) rapid depletion rates of forests and woodlands as a result of land-use changes or high pressure; (b) change in land use patterns such as increased field size and associated loss of hedges; (c) low biomass productivity; (d) poor accessibility. Alternatively, areas with larger potential for sustainable woodfuel production will be those showing accessible woody vegetation with good stocking and productivity.

### 3.4. Integration module

The main scope of the integration module is to analyze relevant interactions between the demand and supply modules in order to derive new variables that can potentially be used to prioritize areas of concern. One of the main challenges for this module is achieving a consistent integration of databases, given that demand and supply estimates come from very different sources (e.g. demand estimates are usually done by the Energy Ministry, whereas supply estimates come usually from the Forestry or Agriculture Ministries).

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. Several variables or indicators can be designed to analyze the combined impact of woodfuel supply and demand. A necessary first step is to derive estimates of the woodfuel demand coming from different LU/LC classes. The woodfuel sources to be considered will include natural sources such as forests, other wooded lands (shrubs, shifting cultivations, etc.) and man-made sources such as forestry and agricultural plantations, agro-forestry, windbreaks, etc. Detailed information on these aspects come from local surveys, which are usually conducted over specific ecological regions, and need to be adapted to the national context using for example, wood extraction coefficients by LU/LC class.

The selection of indicators is decided case by case, depending on the availability and accuracy of the data. Potential indicators include:

- **woodfuel deficit** = \[\text{woodfuel supply} - \text{woodfuel demand}\] \(<0\);
- **potential pressure on woodfuel sources** = \(\frac{\text{woodfuel demand}}{\text{total accessible woodfuel sources}}\);
- **CO₂ net emissions** = \(f\) [woodfuel deficit].

Strictly speaking, woodfuel deficit areas are those with negative values, and should include of course, demand and supply from non-forest areas. However, since it is difficult to obtain precise information on both supply and demand, different thresholds could be defined so that woodfuel deficit areas could include those with a range of values around zero.

Potential pressure on woodfuel sources is given in metric tons (t) (or cubic meters (m³)) per hectare per year and thus gives an idea of the average local wood productivity needed to cope with the existing woodfuel demand. If the demand is higher than the wood productivity in the area, then a deficit, or unsustainable situation, may be assumed.

Net CO₂ emissions will be registered in those areas where woodfuel extraction remains unsustainable. Estimates of total Greenhouse Gases (GHG) emissions coming from woodfuels can also be derived using emission factors for the most common end-use technologies, such as open fires [47,48]. As the estimates come from a detailed spatialization of data (Fig. 2), they are much more precise than the current figures available at the National Greenhouse Inventories submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The spatial analysis of woodfuel GHG emissions can also be useful for deriving regional baselines on Clean Development Mechanisms (CDM) projects.

### 3.5. Identification of woodfuel hot spots

The final step in the WISDOM approach is the identification of those areas where action is urgently needed in terms of demand, supply or both (i.e. highlighting woodfuel hot spots). Departing from old approaches, like the fuelwood gap model, where the identification of hot spots was based entirely on a quantitative estimates of woodfuel deficits, WISDOM aims at identifying areas showing a distinctive woodfuel situation and dynamics. To do so, common multivariate statistical procedures—data grouping techniques, factor analysis, cluster analysis, indexing and others—could be used. Alternatively, the final grouping of sub-national areas, in terms of their priority, could be done using an overall woodfuel priority index that reflects the key aspects of the areas of analysis in terms of woodfuel demand, supply and integration variables [30].
One proposed procedure for constructing the woodfuel priority index involves four sub-steps (next section provides examples of priority indexing using the WISDOM approach): (a) Selection of a robust set of variables associated with woodfuel consumption and supply, extracted from the demand, supply and/or integration modules. The selection of final set of variables needs to consider the integration of different concerns regarding woodfuel consumption and availability of resources. (b) Allocating each spatial unit of analysis to a category in terms of each of the individual variables selected in the previous step (a). (c) Construction of an integrated woodfuel priority index by unit of analysis: based on the ranking of each spatial unit of analysis for each of the variables selected. The construction of an integrated index may need multi-criteria analysis, particularly when trying to integrate variables from different fields (e.g. social/economic/environmental, qualitative/quantitative). (d) Allocating each spatial unit of analysis to a particular group according to the integrated woodfuel priority index calculated in the sub-step (c). This final step involves a re-grouping of administrative units into categories (from low priority to high priority), along the integrated woodfuel priority index.

According to a pre-defined set of criteria, WISDOM helps in rating the units of analysis, at any one scale, into priority categories. Further ratings can be conducted through successive scales of analysis (i.e. over different sets of units of analysis—state, county, community, etc.). For example, if the identification of areas with potentially large social impacts is important at the national level (e.g. health problems associated to indoor air pollution), zoning can be done according to the number and density of woodfuel users, the availability of alternative fuel sources, and the socio-economic situation of woodfuel users. Studies looking at potential forest or land degradation caused by woodfuels, will try to identify regions where woodfuel consumption is high, resilient, and increasing. They will also look at cases where woodfuel supply is at risk, due to loss or degradation of natural vegetation and where the demand/supply balances indicates a deficit or where a deficit is likely to develop in the near future.

4. WISDOM case studies

So far, three case studies have been conducted using the WISDOM approach. These case studies are all at the country level and involve Mexico, Slovenia, and Senegal. They represent contrasting situations in terms of overall woodfuel dynamics, ecological and socio-economic contexts and policy implications. In this section, we present a short discussion of the most relevant features and findings for each case study; more detailed information regarding the methods used and the results obtained is available on the respective publications (Mexico [30]; Slovenia [31]; Senegal [32]).
4.1. Mexico case study

In Mexico, approximately one fourth of the population cooks with fuelwood, either alone or in combination with LPG [49,50]. The residential fuelwood demand for the year 2000 was 320 PJ [51], equivalent to 32 hm$^3$ of wood, a volume three times higher to the total commercial timber legally harvested in the country per year [52] (Fig. 3). Fuelwood consumption accounts for half of total residential energy demand in Mexico. Therefore, assessing the country’s sustainable wood energy potential and viable options for the use of woodfuels deserve urgent attention. Fuelwood use in Mexico responds to the so-called “traditional pattern”, characterized by: (a) its spatial heterogeneity, (b) being focused on the rural and household sector, (c) the widespread use of traditional technologies, and (d) a very diverse array of extraction practices (oak re-growth management, abandoned crop-plots management, selective extraction, random extraction, etc.). Fuelwood in Mexico is mostly collected or bought from local markets. Although diverse sources of fuelwood exist, it is estimated that most of it comes from forest commercial and non-commercial areas, abandoned farming plots under re-growth, and arid regions with shrub cover [26,53]. Preferred species for fuelwood are not necessary the same as those of commercial value [51,53,54]. This represents a key problem when trying to assess the potential production of biomass as the majority of research on this area has concentrated on establishing the amounts of usable timber produced by commercial tree species (i.e. annual increment of stems) [44].

The WISDOM case study conducted in Mexico [30] was directed to determine fuelwood hot spots for the year 2000 (Table 3). The analysis was based in the integration of national geo-referenced multi-temporal databases that cover comprehensive information on fuelwood associated variables, for 2401 municipalities or counties (out of a country total of 2436). The main data sources were (a) the last National Forest Inventory [55], with 69 land-use land-cover classes (1:250,000); (b) an extensive review of the literature and case studies in order to estimate fuelwood productivities by LU/LC class, and per capita fuelwood use by macro-ecological zone; and (c) the National Population Censuses for the years 1990 and 2000, in which data about number and distribution of fuelwood users is available. At the national level, municipalities were ranked based on (a) the number of fuelwood users; (b) the percentage of households that use fuelwood; (c) the density and (d) growth of fuelwood users; (e) the cultural resilience of fuelwood consumption (i.e. percentage of ethnic population), and (f) the magnitude of woodfuel forest resources.

The WISDOM analysis confirmed the high heterogeneity of fuelwood situations within Mexico, allowing the identification of 267 high-priority municipalities, distributed over 16 hot spots, where action to assure the sustainability of fuelwood use is urgently needed (Fig. 4).
The area covered by high priority municipalities accounts for approximately 10% of the country. WISDOM also allowed producing thematic maps of policy and scientific relevance, such as net CO$_2$ emissions derived from fuelwood use (Fig. 2). Following a multi-scale approach, a first exercise was conducted over one hot spot in Central Mexico, in order to identify specific potential areas for establishing bioenergy plantations and improved wood-burning cookstoves. The results showed that 37% (1481 km$^2$) of the total forest area within the hot spot is accessible to walking fuelwood gatherers (Fig. 5).

The main policy impacts of the WISDOM Mexico case study include so far: (a) a consistent and comprehensive geodatabase with detailed multi-temporal information on fuelwood supply and demand patterns for each of the 2401 municipalities within Mexico, which will be soon available on the Internet; (b) the identification of priority municipalities where to conduct improved woodburning...
cookstove programs and multi-purpose energy plantations, to be undertaken by the National Forestry Commission; and (c) a revision of previous GHG emission estimates coming from woodfuel burning, that has served to update and improve the Mexican National GHG Emission Inventory.

Before the WISDOM analysis was conducted, Mexican data about fuelwood consumption and supply belonged to the forestry, energy and census agencies separately. The information was neither integrated together nor shown in a spatially explicit way. WISDOM results allowed a new perspective about fuelwood use patterns in Mexico, not only because of the integration and processing of all related fuelwood data into single data sets, but because of the possibility to select specific areas of interest, according to certain criteria (i.e. fuelwood consumption, CO2 emissions, and fuelwood priority areas).

4.2. Slovenia case study

Slovenia is a biomass rich country. Forests cover approximately 60% of the country and are accompanied by other land uses which are often rich of woody biomass and by consistent areas of abandoned farmland which revert to forest. The demand for woodfuels is concentrated on fuelwood (the production and use of charcoal being marginal) and on rural areas. A large part of the fuelwood trade is informal as wood is either collected by farmers from their own lands and forests or bought locally. There is a consistent wood processing industry composed of numerous small and medium units. The proportion of fuelwood coming from non-forest areas is larger than 20%. Most demand comes from households for heating purposes. Other uses such as district heating and combined heat and power plants (CHP) are still marginal but may grow as viable energy policy alternatives.

In spite of an increased interest on biomass resources and on their role as renewable energy sources, biomass goes largely unrecorded in both forestry and energy sectors and official statistics provide only generic and contradictory information. In addition, the geopolitical transformations of the last decade opened up new forest management issues related primarily to the marked fragmentation of forest ownership.

In this context, the Slovenia Forest Service (SFS) requested FAO assistance to conduct a WISDOM analysis in the country. The project’s overall objective was increasing Slovenia’s capacity to formulate adequate wood energy policies and plans compatible with the sustainable management of forests (Table 4). Specifically, WISDOM

Fig. 4. Fuelwood hot spots in Mexico, 2000. Notes: (A) Hot spots correspond to clusters of high priority municipalities (counties in red). Priorization of counties was made using a Fuelwood Priority Index (FPI). The FPI was constructed using six variables: (a) number of fuelwood users; (b) percentage of households that use fuelwood; (c) density of fuelwood users; (d) growth of fuelwood users; (e) cultural resilience of fuelwood consumption (i.e. percentage of population belonging to indigenous groups), and (f) balance between demand and supply of fuelwood. (B) Detail for central Mexico showing the States of Estado de Mexico, Veracruz, Morelos, Hidalgo and Puebla. It can readily be seen that most hot spots are located in central and southern Mexico, and that they follow specific patterns, rather than being uniformly distributed over the country area.
was directed to integrate the information relevant to wood energy planning in a comprehensive spatially explicit data set and to identify the priority areas for the implementation of wood energy projects.

The WISDOM analysis allowed constructing a Slovenia Geodatabase that presents a first holistic vision of fuel-wood demand and supply parameters and their spatial relation. The database provides, for each of the 2696 Cadastral Communities (KO) in the country, all variables relevant to the household wood energy sector that could be so far assembled and/or estimated. Those aspects related with wood industries are still under analysis. A total of 120 parameters are associated with each KO, therefore a wide variety of thematic maps can be produced.

As meaningful examples of the WISDOM case study, Fig. 6 shows the spatial pattern of today’s fuelwood production/consumption situation, which has a balance close to zero, and Fig. 7 shows the distribution of available surplus resources according to current allowable cut, which is estimated at some 1.1 hm$^3$. A priority zoning was also conducted, combining three aspects that are of particular relevance in future forestry planning of woodfuel production: (i) high surplus of non-timber assortments suitable for energy use, (ii) high fragmentation of forest properties, and (iii) high proportion of forest stands at thinning stage (Fig. 8). The areas identified are critical from a sustainable forest management viewpoint: in these areas forest owner associations could be promoted that would achieve an acceptable profit level and at the same time undertake the needed silvicultural treatments that are otherwise neglected. In these contexts, energy offers good opportunities, with benefit for the society and for the forest ecosystem.

4.3. Senegal case study

Senegal was selected as the first African WISDOM case study in view of the importance of its wood energy sector and the extensive use of charcoal. Until recent years, woodfuel consumption in Senegal was characterized by a strong demand for charcoal in Dakar and other main urban areas and by fuelwood dominating in villages and rural areas. However, the use of LPG is rapidly replacing charcoal in urban areas (apparently lowering the pressure on the resources) but at the same time charcoal is becoming a preferred fuel by village dwellers due to the increasing distance of stocked woodlands that limit self-gathering and other socio-economic factors. Production areas are often over 500 km far from consumption sites.

The WISDOM study for Senegal was undertaken on the initiative of the FAO Wood Energy Programme with the
The main scope of WISDOM analysis was to carry out a first-level evaluation of Senegal’s woodfuels consumption and production patterns based on the information provided by the CSE, integrated with other information from available documentation and web sources (Table 5). The analysis allowed constructing a database that integrated information from a Senegal vegetation map—with biomass stocking and productivity estimates for the 30 LU/LC classes—with woodfuel demand parameters for each of the 321 Rural Communities (CR) in the country.

Two additional objectives were developing future scenarios on the likely supply/demand ratios for each CR in the year 2010 and providing a priority zoning of these CRs based on current woodfuel use patterns and the scenarios to 2010. The scenarios were based on two recent energy surveys, which were carried out in 1992 and 1996 that estimated consumption and substitution rates among different fuels. One scenario considered only the consumption pattern reported in the last survey (A: static scenario),

<table>
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<th>Table 4</th>
<th>Summarized features of the WISDOM analysis in Slovenia</th>
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| **Main features of woodfuel use in Slovenia** | • Approximately 60% of Slovenia is forested; other land uses are often rich of woody biomass  
• The demand for woodfuels is concentrated on fuelwood for household consumption in rural areas  
• Large part of fuelwood trade is informal. Over 20% of total household consumption comes from non-forest-areas  
• Industrial consumption, such as district heating systems, combined heat and power plants (CHP) and other industrial use depend mainly on byproducts (residue) from wood processing industries  
• Non-household uses are rather marginal but may grow as viable energy policy alternatives |
| **Objectives of Slovenia WISDOM** | • To integrate relevant information for wood energy planning available in Slovenia in a spatially explicit data set and to fill critical information gaps  
• To understand the actual potential of wood energy as an economically and environmentally sound alternative or complement to fossil fuels  
• To identify priority zones suitable to the development and implementation of wood energy projects |
| **Minimum administrative spatial unit of analysis** | • The spatial base was developed on cadastral communities (KO), which represent the basis of Slovenia territorial structure. The 2,696 KO units may be aggregated at municipality level and at any other reporting level. Additional layers are settlements (5997 points) |
| **Demand module data sources** | • National census data on dwellings that use fuelwood for 2002  
• Estimated energy requirements for heating and other domestic uses  
• Industrial consumption (partial data on 65 biomass systems) |
| **Supply module data sources** | • A comprehensive Slovenia Forest Service database on forest compartments (over 65,000) and its new digital map, with information on stocking, annual increment, assortments production including fuelwood, actually cut quantities, management phases, ownership data, etc., all at KO level  
• A specific survey was carried out for non-forest fuelwood sources  
• Forest area changes 1975–2000 by KO  
• Distribution of wood processing industries |
| **Integration module** | • A GIS and a geodatabase were created including all available consumption and supply parameters for each of the 2696 KO and other point data  
• Additional set of variables were created such as various balances of production/consumption values to indicate the pressure on fuelwood resources and potential surplus of fuelwood for advanced wood energy initiatives |
| **Priority zoning** | • Included fuelwood production potential, property fragmentation and overstocked young forests at thinning stages  
• Further grouping can be conducted to rank KO into various categories and priority levels according to planners’ need |
| **Other results** | • Slovenia Wood Energy Information System (SWEIS), which provides the first coherent wood energy balance of the country  
• The current data set will serve to support the preparation of a new National Programme and Action Plan for use of wood biomass, which should be prepared by the end of 2005 |

Source: Adapted from Drigo [31].
Fig. 6. Current fuelwood balance in Slovenia, 2002. Notes: The map shows the spatial pattern of current fuelwood balance between production and consumption. The balance is defined as the difference between the estimated fuelwood actually extracted from Slovenia forests and non-forest areas and fuelwood consumption for domestic heating and cooking.

Fig. 7. Potential fuelwood balance in Slovenia, 2002. Notes: The map shows the spatial pattern of potential fuelwood production/consumption balance between current non-timber allowable cut plus the estimated non-forest productivity and household consumption. Overall balance is estimated to be over 1.1 hm$^3$. The darker green areas indicate the locations with highest woody biomass surplus. In these areas, for instance, new wood energy systems could be located.
projected using population growth in rural and urban areas. The second scenario considered also the 1992–1996 fuel substitution rates (B: dynamic scenario). In this case there is a reduction of fuelwood and charcoal consumption in urban areas in favor of LPG and a significant shift from fuelwood to charcoal in rural areas, which appeared as the potentially most critical factor, setting an unprecedented strain on the country’s limited wood resources. If the trends assumed in scenario B become real, one of the important effects of the changing consumption patterns is the likely spreading of charcoal production to respond to a more diffuse local demand. This may cause a sudden increase of charcoal-making in areas previously undisturbed (at least for this specific use), making the pressure on local wood resources more ubiquitous and more difficult to control and manage. Figs. 9 and 10 show, respectively, the supply/demand balance at year 2010 according to the static scenario (A) and to the “dynamic” scenario (B).

A preliminary Woodfuel Priority Index (WPI) was developed using several indices based on the possible levels of consumption at year 2010, on the consequent local supply/demand balance and on socio-economic parameters that represent the poverty level (CSE poverty index). Fig. 11 shows the result of this process, highlighting the Rural Communities that deserve particular attention in view of their combined levels of consumption and balance (according to the “dynamic” scenario) and of access to basic social services and infrastructures, defined by the CSE’s poverty index.

5. Conclusions and future research directions

The WISDOM approach allows constructing an integrated and comprehensive perspective of wood energy systems that catalyzes the dialogue between forestry and energy agencies and that facilitates the definition of sound policies and strategies.

The main benefits of using WISDOM include:

- It allows a holistic vision of the wood energy sector over an entire country or region; while identifying circumscribed priority target areas, where action should be concentrated in order to optimize the use of available human, institutional, and financial resources.
- It can be used to promote the development of wood energy as a locally available and environmentally friendly source of energy.
- It helps to clarify the true role of forestry and agricultural sectors in supplying woodfuels, and it is hoped that, in doing this, it will favor a clearer allocation of responsibilities and promote synergies.
- Within the context of climate change, WISDOM is a useful tool for helping in developing National GHG Inventories.
A detailed spatial representation of the woodfuel situation is clearly one of the prerequisites for promoting the sustainable use of these fuels within developing countries. A spatial analysis constitutes also a powerful tool for strategic planning: it helps both achieve a better understanding of the current wood energy situation and its future trends as well as helping to direct scarce financial and human resources to those areas needing most attention. Combined with other energy planning tools, the WISDOM approach can help in the design of robust policies and more effective actions. It should be emphasized that WISDOM does not reduce the need to collect local data but rather it stresses this need since its reliability is influenced by the quantity and quality of the data available and it helps to define the critical information gaps that really disrupt the analysis. WISDOM can also be improved over the years to progressively enhance the consistency of wood energy analysis.

A long road is still ahead in terms of further methodological development and potential applications of WISDOM. First of all, the approach needs to be tested against more case studies characterizing a diverse and

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### Table 5
Summarized features of the WISDOM analysis in Senegal

<table>
<thead>
<tr>
<th>Main features of woodfuel use in Senegal</th>
<th>Intensive use of woodfuels, including charcoal</th>
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<td></td>
<td>In recent years LPG is rapidly replacing charcoal in urban areas but at the same time charcoal is becoming a preferred fuel by village dwellers due to the increasing distance of stocked woodlands that limit self-gathering and other socio-economic factors</td>
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<td>Production areas often over 500 km far from consumption sites</td>
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<tr>
<th>Objectives of Senegal WISDOM</th>
<th>To review, harmonize and integrate, the available information related to production and consumption of fuelwood and charcoal at the level of Rural Communities (CR) in a spatial explicit format</th>
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<td></td>
<td>To review possible scenarios to the year 2010</td>
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<th>Minimum administrative spatial unit of analysis</th>
<th>The base layer consists of 321 Rural Communities (CR)</th>
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<td></td>
<td>Additional map layers included the distribution of rural villages (13,211 villages), the road network (8 categories) and protected areas</td>
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<tr>
<th>Demand module data sources</th>
<th>Urban and rural population data by CR and 1990-2010 time series</th>
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<td></td>
<td>Saturation of fuelwood, charcoal and LPG by urban and rural users and by Region and estimated per-capita consumption rates</td>
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<td></td>
<td>Socio-economic parameters (access to drinking water, health services, market, roads and school) for 13,000 villages and summarized by CR</td>
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<td></td>
<td>Time series of household urban and rural consumption 1990-2010 by CR were developed, according to two different scenarios:</td>
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<td>o Scenario A. 1996 consumption pattern (Semis survey) projected using urban/rural population growth rates</td>
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<tr>
<th>Supply module data sources</th>
<th>Senegal vegetation map (based on USAID/DAT 1982) with stocking and productivity for each of the 30 classes of the map (derived from PSACD 1998)</th>
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<tr>
<td></td>
<td>Map of Senegal Protected areas with 5 categories</td>
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<td></td>
<td>Estimated exploitable fraction of wood resources according to protection categories and distance from roads and villages</td>
</tr>
<tr>
<td></td>
<td>Time series of wood stocking and productivity (total and accessible fraction) by CR according to two change scenarios:</td>
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<tr>
<td></td>
<td>o EROS = stocking and productivity reduced in time according to the land use change estimated by EROS/USGS-CSE over the period 1965-2000 [56]</td>
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<td></td>
<td>o FRA = stocking and productivity reduced in time according to the forest area change estimated by FAO FRA 2000 [40].</td>
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| Integration module | Time series (1990-2010) of balance between household fuelwood and charcoal consumptions and total/accessible wood resources (scenarios EROS and FRA). The balance analysis represents the first level of integration of supply and demand variables |

<table>
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<tr>
<th>Priority zoning</th>
<th>A simple Woodfuel Priority Index (WPI) was developed using several indices, for each Rural Community, based on three main elements:</th>
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<tr>
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<td>o the possible levels of charcoal consumption at year 2010 according to scenario B</td>
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<td></td>
<td>o the local balance between total demand of wood for energy (fuelwood and wood for charcoal) and the estimated accessible and exploitable wood growth</td>
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<td>o socioeconomic parameters that represent the poverty level (CSE poverty index)</td>
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Source: Adapted from Drigo [32]. Please refer to the list of abbreviations for a better understanding of the special terms used in this table.
Fig. 9. Fuelwood balance scenario in Senegal for the year 2010-A. Notes: The map shows the balance between household woodfuel consumption (fuelwood and wood for charcoal) and estimated sustainable productivity according to the “static” scenario (A) (see text), which used the 1996 consumption survey data projected according to population growth rates in urban and rural areas.

Fig. 10. Fuelwood balance scenario in Senegal for the year 2010-B. Notes: The map shows the balance between household woodfuel consumption (fuelwood and wood for charcoal) and estimated sustainable productivity according to the “dynamic” scenario (B) which used the 1996 consumption survey data but projected the consumption according to the 1992–1996 trends and to population growth rates. Also shown are the “traditional” charcoal production areas.
contrasting set of circumstances. Case studies that deserve attention include situations were a large fraction of woodfuels come from agricultural areas or from non-woody biomass. The new challenges coming from these case-studies will serve to make the methodology more robust and adaptable to the variety of circumstances that may be found in different countries.

Moreover, clear linkages between the WISDOM analysis at the national/regional level and interventions at the local level must be developed. Having identified the woodfuel hot spots at a national/sub-national level, a more detailed spatial analysis needs to be conducted within each of the priority areas or hot spots [30]. For this purpose, a better understanding of the local woodfuel system (i.e. the different ways in which wood resources are produced, harvested, transformed and converted finally to energy, taking into account the larger context of forest resources) is needed. Masera et al. [30] shows an example of this type of analysis for a region in Central Mexico. The analysis of the local woodfuel system will allow the identification of concrete topics and issues for actual interventions. Thus, a logical chain of actions—from national planning to local intervention—can be established. It should be noted that this last step will need additional planning and implementation tools as well as a participatory approach that effectively incorporates the local population.

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