LAND USE, LAND USE CHANGE AND FORESTRY RELATED GHG EMISSIONS IN LEBANON: ECONOMIC VALUATION AND POLICY OPTIONS

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Abstract. Global climate change has been one of the most challenging environmental concerns facing policy makers in the past decade. The characterization of the wide range of greenhouse gas (GHG) sources and sinks as well as the behavior of GHGs in the atmosphere remains an on-going activity in many countries. Lebanon, being a signatory to the Framework Convention on Climate Change, is required to submit and regularly update a national inventory of GHG emission sources and removals. Accordingly, an inventory of greenhouse gases from various sectors was conducted following the guidelines set by the United Nations Intergovernmental Panel on Climate Change. The inventory indicated that the land use, land use change, and forestry sector contributed about 1% to the total greenhouse gas emissions instead of acting as a sink. This article proposes mitigation scenarios to reduce these emissions and increase carbon sequestration in the Lebanese land use. Limitations in emission estimation, economic valuation, and policy options are also addressed.

Keywords: climate change, emission factors, forestry, greenhouse gas, IPCC, land use, Lebanon, mitigation

1. Introduction

Anthropogenic emissions of greenhouse gases (GHG) have led, over the past two centuries, to a considerable increase in the concentration of these gases in the atmosphere. For instance, the methane (CH4) concentration has more than doubled since pre-industrial times whereby it increased from about 0.7 ppmv to about 1.7 ppmv (1994 level) with a currently estimated annual growth rate of 0.008 ppmv. The carbon dioxide (CO2) concentration has also increased from about 280 ppmv in pre-industrial times to the current 365 ppmv, with an estimated annual growth rate at about 1.8 ppmv. Similarly, anthropogenic activities have contributed to a 10% increase in nitrous oxide (N2O) concentrations in the atmosphere over the last 200 yr. Trends in atmospheric levels of these three major GHGs are depicted in Figure 1.

GHG act as a blanket that retains solar heat in the atmosphere. Therefore, elevated concentrations of GHG cause increased atmospheric heat retention. This
creates higher global temperatures or what is more commonly known as global warming. This process is suspected to trigger adverse environmental consequences including coastal zones flooding and desertification. Both flooding and desertification are likely to affect the country of Lebanon since it is located at the border of desert regions and more than 60% of its economic activity lies in a narrow coastal plain along the Mediterranean sea (ERM, 1995).

Climate change from GHG emissions has been at the forefront of current research in the past decade (IPCC, 1995). The agenda for future climate change research was set at the earth summit in Rio de Janeiro as achieving ‘stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climatic system’ (UN, 1992). Earlier studies estimated the aggregated monetary damage due to climate change at 1.5–2% of world Gross Domestic Product (GDP) for a doubling in atmospheric CO₂ concentration from the pre-industrial level (Fankhauser and Tol, 1996).

The first step in the characterization of GHG emissions is the preparation of a national inventory of GHG emissions by sources and removals by sinks. Such an effort was recently undertaken in Lebanon in fulfillment of the Framework Convention on Climate Change (FCCC), ratified by the country in 1994 (Lebanon, 1999). The work included the development of an inventory, with 1994 as a base year, using the Intergovernmental Panel on Climate Change (IPCC) reference and sectoral approaches (IPCC, 1997).

The IPCC has prepared guidelines for building a worldwide inventory of GHG emissions. For this purpose, three methodologies of differing accuracy and refinement were developed. The last two cover countries that have collected, or have adequate resources to collect, the data needed to perform in-depth inventories. The first is the reference approach applied for situations where data is relatively lacking.
In the inventory for Lebanon, the reference and sectoral approaches were used to estimate GHG emissions. The GHGs considered are CO$_2$, CH$_4$, N$_2$O, carbon monoxide (CO), nitrogen oxides (NO$_x$), non-methane volatile organic compounds (NMVOCs), sulfur dioxide (SO$_2$) and hydrofluorocarbons (HFCs). Perfluorocarbons (PFCs) and sulfurhexafluoride (SF$_6$) are also emitted; however, their estimation was impeded by a lack of information about the emitting industries (Lebanon, 1999). Five economic sectors contributing to emission or removal of GHG were targeted namely, energy (including transport), industry, agriculture, land use change and forestry, and waste. Emissions from the usage of solvents and other products were not estimated in the inventory due to the lack of emission factors and their relatively low usage.

This article focuses on the land use, land use change, and forestry (LULUCF) sector and proposes mitigation scenarios to reduce net emissions from this sector by the year 2040 through increasing carbon sequestration. Economic valuation of these scenarios was conducted and uncertainty in emission factors used in the estimation process addressed. For this purpose, theoretical and experimental emission factors were used as alternatives to default factors recommended by the IPCC. The significance of the resulting relative deviations in emission estimation from the LULUCF is discussed. Finally, policy options aimed at increasing carbon sequestration and decreasing GHG emissions from this sector are presented. It should be noted that projections to the year 2040 may introduce uncertainties since predicting economic changes or governmental measures are at best uncertain. However, the relative benefit of applying mitigation measures should not vary considerably.

2. LULUCF Related Emissions

Forests are a carbon sink due to the carbon uptake that occurs during tree growth. On the other hand, they are a carbon source when for example, the woody biomass is cut and used as fuel or when it is burned in forest fires. Global CO$_2$ emissions from deforestation range from 600 to 2800 Mt of carbon constituting the second largest source of CO$_2$ emissions after fossil-fuel combustion, cement manufacturing, and natural gas burning (Smith et al., 1993; Houghton, 1991). The latter, combined, account for approximately 6000 Mt of carbon emissions.

Tree planting projects appear to be the most cost-effective way of decreasing the extent of net CO$_2$ emissions through increasing terrestrial carbon storage and have been commonly reported to provide a low cost net GHG emission reduction (Plattinga, 1997; Moffat, 1997; Solberg, 1997; Callaway and McCarl, 1996; Parks and Hardie, 1995; Richards et al., 1993; Adams et al., 1993). In this context, assessment of silvicultural practices in 40 nations showed that forest thinning, fertilization, weeding and modified harvesting were the most efficient carbon conservation and sequestration techniques for mid and high latitude forests (Dixon, 1997). Many countries are considering or have already implemented tree planting programs as
TABLE I
Mitigation scenarios to manage LULUCF carbon sequestration (Dixon et al., 1993; Kinsman and Trexler, 1993; Binkley et al., 1997; Parks et al., 1997)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintaining existing C stocks</td>
<td>The objective of maintaining existing C stocks is to conserve C pools in forests. The major components of this option include reducing deforestation, protecting forests in reserves, changing harvesting regimes, and controlling fires and pests outbreaks. Most deforestation occurs in order to satisfy the needs for grazing lands and wood products, which are in turn the result of rapid demographic growth. Thus, the success of a deforestation program is highly dependent on a comprehensive agricultural and demographic policy.</td>
</tr>
<tr>
<td>Expanding C pools</td>
<td>The principle behind this alternative is to maximize the amount of carbon stored in vegetation (living, above and below ground biomass), soil (litter, dead wood, mineral soil and peat) and durable wood products. Different approaches are adopted to reach this objective including: a) reforestation (replanting and/or enhancing regeneration of deforested areas); b) afforestation (planting forests on bare lands); c) enhanced regeneration (increasing the biomass density of existing degraded and under stocked forests); and d) agroforestry (planting forest trees on agricultural land in order to produce agricultural and forest products).</td>
</tr>
<tr>
<td>Substitution effects</td>
<td>Substitution strategies focus on the transfer of biomass into products that substitute for, or lessen the use of fossil fuel. Substitution could be: a) direct involving the use of biomass fuels from plantations instead of fossil fuels (e.g., woody biomass crops are harvested every 5–12 yr and the harvested material can be used directly as boiler fuel, converted into biofuels, such as ethanol and methanol, or gasified); or b) indirect referring to cases where wood products replace other products that are more energy intensive such as steel.</td>
</tr>
</tbody>
</table>

One remediation technique. Forestry mitigation options refer to those measures and policies that can lead to a net reduction in the emission of GHGs primarily through avoidance of deforestation-degradation, increased carbon sequestration in forests, long term wood products, and other tree vegetation. These are based on three main principles, namely 1) the maintenance of existing C stocks; 2) the expansion of carbon sinks; and 3) management for substitution. Practices falling under these principles to manage LULUCF carbon sequestration have been detailed in the literature and are summarized in Table I.

The applicability of each mitigation option depends on site-specific factors such as forest productivity and the efficiency of material harvest and use. In fact, when these efficiencies are low, afforestation programs have an advantage over substitution programs in terms of CO₂ emission reduction (Marland and Schlamadinger,
1995). On the other hand, when the crop growth rate is high and is harvested and used efficiently, substitution of other sources of energy-demanding products by the woody crops proves to be more successful than afforestation in terms of atmospheric CO$_2$ reduction. In summary, forestation projects appear to have the potential to significantly offset emissions of carbon dioxide from fossil fuel and other sources. However, the decision to implement such projects must be based on the cost of the program relative to other emission reduction strategies.

3. The Lebanon Context

Lebanese forests cover an area of 70,000 ha which represents 7% of the total country area. The plant cover of the country is rich and diversified but has long suffered from neglect and abuse and hence, is facing several threats. The most significant include:

- **Abusive tree cutting**: in the absence of any administrative control, forest trees are excessively cut mainly for bioenergy purposes;
- **Overgrazing** which accelerates soil erosion and inhibits natural regeneration of forests due to the uprooting of forest vegetation;
- **Deforestation**: the lack of any form of authority during nearly two decades of civil unrest (1975–1990), allowed the farmers to convert nearby forest areas into agricultural land;
- **Wildfires** which result in economic losses, sociological damage, as well as, the loss of certain tree species that are easily flammable.

These practices have led over the years to partial and sometimes total degradation of forestland. Forests were degraded by 7.8% in total area during a period of 5 yr (1990–1995) as compared to an increase of 0.7% in west and central Asia and a degradation of 0.3% in the total area of the world’s forests (FAO, 1998). In fact, the extinction of certain tree species such as the Lebanese cedar, Abies Cilica and the Juniperus species is expected if the degradation of forestland continues (UNEP, 1996). Currently, the management of this important natural resource is undergoing numerous improvements particularly in terms of establishing protected forest areas and subsidizing forestation projects and wasteland conversion. Emissions of GHG from the LULUCF sector can be estimated from Equation (1) (IPCC, 1997) and the corresponding results are summarized in Table II.

$$Q_j = (B_i - B_i) \times q_j ,$$

where
TABLE II

<table>
<thead>
<tr>
<th>Activity</th>
<th>Changes in forest and other woody biomass stock (Gg)</th>
<th>Forest and grassland conversion (Gg)</th>
<th>Totals (Gg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>142.5</td>
<td>58.0</td>
<td>200.5</td>
</tr>
<tr>
<td>CH₄</td>
<td>–</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>CO₂ eq.</td>
<td>–</td>
<td>6.2</td>
<td>6.2</td>
</tr>
<tr>
<td>N₂O</td>
<td>–</td>
<td>0.0017</td>
<td>0.0017</td>
</tr>
<tr>
<td>CO₂ eq.</td>
<td>–</td>
<td>0.54</td>
<td>0.54</td>
</tr>
<tr>
<td>NOₓ</td>
<td>–</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>CO₂ eq.</td>
<td>–</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>CO</td>
<td>–</td>
<td>2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>CO₂ eq.</td>
<td>–</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Total</td>
<td>142.5</td>
<td>71.64</td>
<td>214.14</td>
</tr>
</tbody>
</table>

Qₗ = Total emissions of gas j, Gg C;

Bᵢ = Biomass loss from timber activities or fires, Gg C;

Bᵢ = Biomass increment from forest growth, Gg C;

qᵢ = Emission factor for gas j, Gg j/Gg C.

In 1994, the LULUCF sector was a source of CO₂ instead of a sink as is the case in most countries. This was attributed to extensive forest fires during that year (Lebanon, 1999). Note that only two categories are considered significant with respect to GHG emissions from the LULUCF sector in Lebanon, namely: changes in forest and other woody biomass stock (growth and cutting of woody biomass) and forest or grassland conversion (natural forest fires and induced ones to convert the area to cropland). CO₂ emissions and uptake from soils were negligible because of the calcareous, non-organic nature of soils in Lebanon. The change in forest and other woody biomass contributes 67% of the total emissions from the sector while forest and grassland conversion emit the remaining 33%.

Figure 2 illustrates the contribution of the various economic sectors in Lebanon expressed as mass of CO₂ with equivalent radiative forcing potential (CO₂ equivalent). The LULUCF sector contributed about 1% of the total GHG emissions. While it may appear that a 1% contribution is relatively insignificant, it is nev-
Nevertheless important in light of the fact that this sector normally acts as a sink of GHG and not a source. In comparison to other countries, per capita forestry related CO₂-equivalent emissions are evidently higher in Lebanon as depicted in Figure 3. Clearly, the LULUCF sector is a net carbon sink in most countries, offsetting emissions from fossil fuel by 1 to 2% in the Netherlands and Germany to 90% in Sweden (OECD, 1997).

3.1. LAND USE SCENARIOS FOR LEBANON

Present and future trends in land use patterns in Lebanon under baseline and mitigation conditions are summarized in Table III. The most likely trend or baseline condition (scenario 1), is the one that will take place in the absence of any mitigation policies and practices. Inefficient protection measures and poor silvicultural practices are assumed to persist under this scenario. The most relevant mitigation scenarios that were assessed include forest protection and management, and reforestation (scenario 2). Note that in accordance with government policies, neither the total forest land nor the total land use are expected to change significantly in area. However, the land use pattern in the subcategories will vary depending on the scenario.

The amount of incremental C sequestered and equivalent CO₂ reduced will depend on the area of natural forests protected and reforested as well as the rotation age of reforested areas. Evidently, the complete reforestation of forest land has the highest uptake potential (Table IV). The extent to which this potential can be achieved depends on the effect of economic and policy options and future forest management practices. In this context, the stabilization of GHG emissions and optimization of gas uptake by C sinks can be promoted by providing information

Figure 2. Contribution of various sectors to total equivalent CO₂ emissions in Lebanon (1994).
Austria (1997)  
Czech Republic (1998)  
Denmark (1997)  
France (1997)  
Germany (1997)  
Japan (1997)  
Jordan (1997)  
Lebanon (1999)  
Netherlands (1997)  
Poland (1998)  
Sweden (1997)  
UK (1997)  
USA (1999)  

-2.50 -2.00 -1.50 -1.00 -0.50 0.00 0.50 1.00

**CO₂** equivalent emissions, tons per capita

*Figure 3. LULUCF related emissions in selected countries (A negative number indicates a sink. All numbers are based on country-specific national communication).*

**TABLE III**

Projected land use pattern under baseline and mitigation conditions (UNEP, 1996; Lebanon, 1999)

<table>
<thead>
<tr>
<th>Land use</th>
<th>Baseline scenario 2000 (1000 × ha)</th>
<th>Baseline scenario 2040 (1000 × ha)</th>
<th>Mitigation scenario 2040 (1000 × ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forest land</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. &gt;40% crown cover</td>
<td>32</td>
<td>93</td>
<td>282</td>
</tr>
<tr>
<td>B. 10–40% crown cover</td>
<td>43</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>C. &lt;10% crown cover-woodland</td>
<td>60</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>D. Range land</td>
<td>147</td>
<td>147</td>
<td>0</td>
</tr>
<tr>
<td><strong>Subtotal forest land</strong></td>
<td><strong>282</strong></td>
<td><strong>282</strong></td>
<td><strong>282</strong></td>
</tr>
<tr>
<td>Protected land (10–40% crown cover)</td>
<td>6</td>
<td>36</td>
<td>100</td>
</tr>
<tr>
<td>Grass land (pasture)</td>
<td>316</td>
<td>253</td>
<td>215</td>
</tr>
<tr>
<td>Crop land</td>
<td>297</td>
<td>360</td>
<td>380</td>
</tr>
<tr>
<td>Other</td>
<td>126</td>
<td>126</td>
<td>126</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1027</strong></td>
<td><strong>1057</strong></td>
<td><strong>1103</strong></td>
</tr>
</tbody>
</table>
TABLE IV
Effect of mitigation measures on C sequestration (Lebanon, 1999)

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Incremental C sequestered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mt C</td>
</tr>
<tr>
<td>Forest protection and management</td>
<td>5.59</td>
</tr>
<tr>
<td>Reforestation</td>
<td>49.30</td>
</tr>
</tbody>
</table>

Assumptions (based primarily on IPCC recommended default values)
- Equivalent CO$_2$ reduced = $3.66 \times$ C sequestered
- Biomass density = 5 and 146 ton ha$^{-1}$ for waste land and forest land, respectively
- Biomass density increase = 1 and 2% per year for baseline and mitigation conditions, respectively
- Carbon content of biomass = 0.5
- Annual biomass growth = 3 ton ha$^{-1}$ yr$^{-1}$
- Soil carbon density = 20 and 60 ton ha$^{-1}$ for waste land and forest land, respectively
- Soil carbon density increase = 1 and 2% per year for baseline and mitigation conditions, respectively
- Vegetation rotation period = 100 yr
- Storage period of carbon in soil = 75 yr
- Annual increment of soil carbon = 2 ton ha$^{-1}$ yr$^{-1}$
- Biomass decomposition period = 6 yr
- Amount of decomposing carbon left in soil = 5 ton ha$^{-1}$ yr$^{-1}$
- Average forest product lifetime = 40 yr
- Amount of carbon stored in products = 30 ton ha$^{-1}$.

...to policy makers about the costs and benefits of different options or scenarios in addition to their carbon implications. The costs, benefits and impacts of climate change mitigation and adaptation options must be weighed during the decision making process for any mitigation alternative. The policy goal normally seeks to maximize economic and social benefits from forestry while minimizing local and global environmental and social impacts.

3.2. LIMITATIONS

GHG inventories of the LULUCF sector are completed using a great number of estimates. These estimates are associated with uncertainties or errors because of the sources from which they are derived, namely: 1) forest survey data; 2) deriving carbon storage estimates for forest floor, understory vegetation and soil; 3) projections of the forest stocks for the year 2040; and 4) incomplete accounting of wood products (U.S.A., 1998). These inadequate data posed great difficulties to many
countries while compiling their GHG inventories. Omission of estimates was considered in lieu of using inaccurate default methodology and data. However, experts finally agreed that the error arising from omitting estimates is probably greater than the error of their inclusion (Lim et al., 1997). Similarly, the national GHG inventory of Lebanon suffers from the inherent uncertainty of the methodology itself in addition to country-specific uncertainties or errors induced by unreliable data collection, lack of records and unavailability of country-specific parameters that are needed to conduct the estimations. For the LULUCF sector, the major source of uncertainty – forest survey data – is a cause to special concern due to its importance. The surveys are based on a statistical sample designed to represent a wide variety of growth conditions present over large territories. Therefore, the actual timber volumes contained in forests are represented by average values that are subject to sampling and estimation errors.

3.3. Economic Valuation

Land use change and C sequestration economics are dependent on a multitude of assumptions, methods, and data used with respect to land area and costs, treatment costs, discount rates, carbon capture rates and patterns, ecosystem components included in the analysis, and the market for forest products (IPCC, 1995). The benefits from forestry projects often extend far into the future and therefore, when high costs are incurred at the beginning, it translates into high risks of potential project failure, which should be taken into consideration to ensure an accurate economic appraisal (Neil and Sedjo, 1997).

3.3.1. Benefits

If it is accepted that the increase in atmospheric GHG is a contributing factor to potentially-damaging global climate change, then accurate damage characterization (when feasible) can be expressed in terms of real monetary units per unit of C released to or removed from the atmosphere. Under this assumption, the damage created by each additional ton of GHG emitted to the atmosphere can be used as a measure of the value of keeping that ton in terrestrial storage, or sequestering an additional ton from the atmosphere (Van Kooten et al., 1997).

3.3.2. Costs

Establishing the cost of reforestation projects involves the identification of agricultural lands suitable for conversion to forests and then estimating the compensation required by landowners for this purpose. Compensation is provided for forest establishment costs and foregone agricultural rents or the cost of the land (Moulton and Richards, 1990; Adams et al., 1993; Parks and Hardie, 1995). Landowners are assumed to accept the compensation for converting their land to forest. For nongovernmentally owned land, this assumption may not result in the true cost of C sequestration because compensation rates are often subjective and cannot account
for factors (such as option values, private non-market benefits, and asymmetric information) that may influence the decision of landowners (Plantiga, 1997). Also, government subsidies for agriculture tend to drive a wedge between market prices and the true cost of land particularly in countries that do not have well-established land markets, or have regulations that do not allow permanent transfer of land, or where the land is owned by the government.

3.3.3. Methods
With the above limitations in mind, several methods have been used to determine the costs associated with conversion of land to forest including the use of land rental rates derived from surveys (Moulton and Richards, 1990), the use of market prices adjusted for the elasticity of demand for agricultural land (Richards et al., 1993), the use of the estimated lost profits from removing the land from agricultural production (Parks and Hardie, 1995), and the use of consumer surplus loss from increases in food prices due to the constriction of agricultural land availability (Adams et al., 1993). Depending on the method of economic evaluation and the type of C sequestration, a wide range of costs for C sequestration in forests has been reported (Table V). These costs are derived from single point estimates of average costs associated with sequestration levels.

In the context of Lebanon, the costs associated with mitigation options include primarily the cost of two activities: 1) reducing deforestation through proper forest protection and management; and 2) expansion of C pools through reforestation. The first activity covers the direct cost of protection without the relatively larger opportunity cost of land, and varies between – 2 and 108 US$ per tonne of C sequestered (see Table V). The second activity involves setting the value of resources (land, labor and equipment) needed to establish, maintain, and monitor the project. This value varies between – 12 and 187 US$ per tonne of C sequestered (Table V). The upper ranges for both activities are clearly not affordable in a developing country such as Lebanon as they constitute up to 60% of its annual GDP (Table VI). Similarly, the lower ranges (negative values - see footnote IV of Table V) are also unlikely in Lebanon because the market for forest products is not well-developed. Note that where land and labor markets are not so well developed, the costs of administration and information gathering might rise significantly, even surpassing the direct costs of land acquisition and tree planting. In the context of developing countries where the pressure for changes in land use comes from agricultural activities or wood exports, transaction costs should encompass policies to ease this pressure (IPCC, 1995).

3.4. Policy Options
Policy options for managing GHG emissions are dependent on country-specific characteristics such as land use and forestry practices, economic, legal, political and cultural conditions (i.e., population trends, legal infrastructure such as land
TABLE V
Unit cost of carbon sequestration (IPCC, 1995)

<table>
<thead>
<tr>
<th>Source</th>
<th>Region</th>
<th>Evaluation method</th>
<th>$ per tonne C sequestered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Forest plantation</td>
</tr>
<tr>
<td>Moulton and Richards, 1990</td>
<td>United States</td>
<td>Levelized(^a)</td>
<td>9–41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flow summation(^b)</td>
<td>2–9</td>
</tr>
<tr>
<td>Nordhaus, 1991</td>
<td>Global</td>
<td>Levelized</td>
<td>42–114</td>
</tr>
<tr>
<td>Dixon et al., 1991</td>
<td>Boreal</td>
<td>Average storage(^c)</td>
<td>5–8</td>
</tr>
<tr>
<td></td>
<td>Temperate</td>
<td>Average storage</td>
<td>2–6</td>
</tr>
<tr>
<td></td>
<td>Tropical</td>
<td>Average storage</td>
<td>7</td>
</tr>
<tr>
<td>Van Kooten et al., 1992</td>
<td>Canada</td>
<td>Flow summation</td>
<td>6–18</td>
</tr>
<tr>
<td>Adams et al., 1993</td>
<td>United States</td>
<td>Levelized</td>
<td>20–61</td>
</tr>
<tr>
<td>Richards et al., 1993</td>
<td>United States</td>
<td>Levelized</td>
<td>9–66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flow summation</td>
<td>2–9</td>
</tr>
<tr>
<td>Dixon et al., 1994</td>
<td>South Africa</td>
<td>Average storage</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Africa</td>
<td>Average storage</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>South Asia</td>
<td>Average storage</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>North America</td>
<td>Average storage</td>
<td>–</td>
</tr>
<tr>
<td>Masera et al., 1997</td>
<td>Mexico</td>
<td>Average storage</td>
<td>5–11</td>
</tr>
<tr>
<td>Ravindranath and Somashekar, 1997</td>
<td>India</td>
<td>Flow summation</td>
<td>0.13–1.06</td>
</tr>
<tr>
<td>Xu, 1996</td>
<td>China(^d)</td>
<td>Average storage</td>
<td>(–12)–2</td>
</tr>
<tr>
<td>Parks and Hardie, 1995</td>
<td>United States</td>
<td>Levelized</td>
<td>5–90</td>
</tr>
</tbody>
</table>

\(^a\) Differentiates costs and accomplishments according to when the carbon is captured.
\(^b\) Sums the total C captured regardless of when the capture takes place. Early and late capture (release) are treated equally.
\(^c\) Divides the present value of the sum of all implementation costs over a specified period by the mean standing carbon storage averaged over several rotation periods.
\(^d\) The negative cost due to including revenues from the sale of timber and the demand for timber in China is high.
TABLE VI
Cost of C sequestration and CO2 emission reduction for Lebanon

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Incremental C sequestered (Mt)</th>
<th>Unit cost (US$/tonne)</th>
<th>Total cost (m US$)</th>
<th>% of GDP (World Bank, 1999)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest protection and management</td>
<td>5.59</td>
<td>(–2) to 108</td>
<td>(–11) to 603.72</td>
<td>(–0.07) to 3.71</td>
</tr>
<tr>
<td>Reforestation</td>
<td>49.30</td>
<td>(–12) to 187</td>
<td>(–591) to 9219</td>
<td>(–3.63) to 56.65</td>
</tr>
<tr>
<td>Totals</td>
<td>54.89</td>
<td>(–14) to 295</td>
<td>(–602) to 9822.72</td>
<td>(–3.70) to 60.36</td>
</tr>
</tbody>
</table>

... (rest of text)
Policies that aim at maintaining carbon stocks and expanding carbon sinks in Lebanon (Lebanon, 1999)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Policy</th>
</tr>
</thead>
</table>
| Forest protection and conservation | - Undertake a new-forest inventory and mapping (the first one was conducted in 1966) including a descriptive structure and composition of forest stands.  
- Develop forest management systems that improve the long-term productivity and ecological integrity of forests.  
- Develop sound methods of fighting fire, insects, and diseases.  
- Establish a network of ecological forest reserves throughout the country.  
- Adopt forest ecosystem management to assure a sustainable development that takes into consideration the capacity of forests and the various human-uses and needs.  
- Introduce intensive silviculture practices to increase forest growth and increase wood content in trees.  
- Train forest service personnel in forest management techniques and practices.                                                                                                                                 |
| Reforestation                     | - Building capacity of well-trained personnel knowledgeable of ecological, ecophysiological, and genetic criteria of forest species and seeds because of the climatic and soil constraints that encounter foresters in Lebanon.  
- Long rotation periods to increase carbon stock and reduce the cost per reforested unit area and the cost of the carbon sequestered.  
- Aggressive reforestation policies including incentives for reforestation, to private owners of degraded lands, emphasizing expanding plantation forestry for industrial wood.                                                                                       |
| Other                             | - Amendment of forest laws to allow various parties to participate in implementing reforestation programs and forest management plans and to share benefits generated from timber products and other non-wood products.  
- A comprehensive land use planning and zoning through which appropriate land is spread for agriculture, forestry and pasture. The less productive land will be reserved to infrastructure, industry, housing etc. It is important to avoid conflicts among various uses of land; especially conversion of forest or forest lands to other uses. Thus the delimitation and mapping of lands reserved for reforestation is essential to plan and elaborate reforestation programs.  
- Urban policies that discourage extensive and wasteful conversion of natural forests and forest lands to other uses.  
- Grazing, in forests and reforested lands should be managed to avoid damages that goats and sheep could cause to the regeneration of old forest stands or to the growth and development of young forests and new reforested lands.  
- Agro-forestry practices (wind breaks, linear plantations, and community forest) should be encouraged in agricultural areas. |
to implement the mitigation scenario and influence activity levels in the LULUCF sector.

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References


