# Carbon Sequestration and Emission Management: A Costa Rican Case Study

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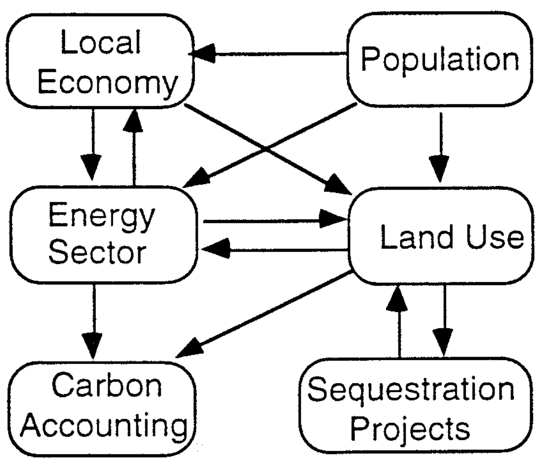
## Overview:

Global climate change has become a major concern for international and national policymakers. Costa Rica has taken a leadership role by announcing an integrated national environmental strategy, including some management of its carbon emissions and sequestration. The Costa Rica Carbon Management (CRCM) model is intended to assist national policymakers understand the long-term interactions between the economy, population and natural processes influencing the country's net carbon balance.

The model was originally developed as part of the Business Applications in System Dynamics course at the Sloan School of Management at MIT. An expanded MIT modeling team,[1] with the support of the Center for Sustainable Development of the Universidad de Costa Rica (CIEDES) and the Central American Climate Change Program, is now working to: (1) enhance the feedback relationships within the land use and energy sectors and between the economy and the remaining sectors, (2) obtain better estimates of parameters in the model, and (3) develop more realistic policy scenarios.

**Figure 1**
**Model Sector Diagram**




The Costa Rican population has land, energy and economic needs. Based on individual and national policy choices, these needs are translated into land use patterns, economic growth rates and energy consumption and production. Some of these human activities result in carbon emissions. By engaging in reforestation and forest protection, Costa Rica can offset carbon emissions through carbon sequestration.

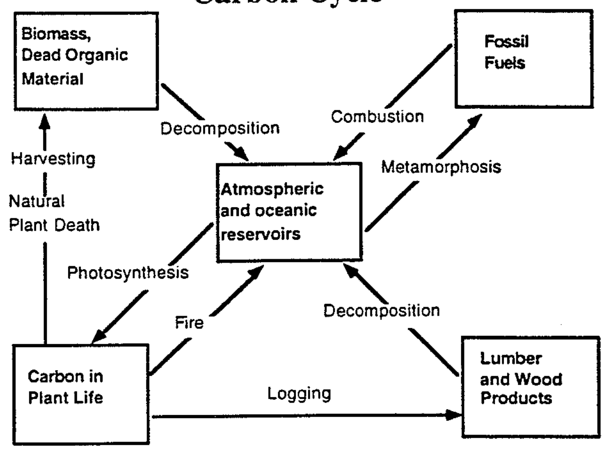
## Design Considerations and Model Structure:

A country-level model was selected for several reasons: Traditionally, climate change modeling has focused either on global issues or individual projects. Unlike global climate change models, a country model can incorporate the policy options available to the national policymaker. Project models (Faeth et al. 1994) are effective in depicting the direct effects of a single carbon sequestration project, but they are unable to capture important secondary effects, such as displacement, that are outside the project's boundary. Displacement occurs when protection of one standing forest simply moves logging or burning activities to another location. The modeling team decided to make a region the model boundary in order to account for displacement and concerns of policymakers. Figure 1 depicts and explains the main subsectors of the model and the key relationships.

[1] The full modeling team consists of: Luis Benoliel, Dr. Roland Franke, Fredrik Johnsson, Elizabeth Krahmer, Cesar Perez-Barnes, and Scott Rockart.

The modeling team's original formulations drew from the background of a biochemist team member (Dr. Roland Franke) and from understanding of the carbon cycle (see Figure 2). The World Resource Institute's system dynamics LUCS model (Faeth et al. 1994) served as the basis of portions of the population, land use and carbon sequestration subsectors. Interviews were conducted with scientists and other researchers familiar with Costa Rica to expand and adjust the model to depict country-wide dynamics. The model parameters were determined using data from Swisher (1994) and the World Resources Institute (1988, 1992) on historic land use patterns, economic information from the Economist Intelligence Unit, and energy demand and consumption statistics from the Costa Rican Dirección Sectorial de Energía (1993). The feedback structure and parameter values are presently being revised based on insights gained from presentations of the model and interviews conducted in Costa Rica in January as well as ongoing work with CIEDES.

**Figure 2**
**Carbon Cycle**




A base case was developed assuming the current trends of strong economic growth, continued protection of existing forest but no reforestation projects. Key assumptions included current trends in population birth rate (3.45%), average life expectancy (72 years), economic growth (2.5%) and energy efficiency gains of 1.35% per person/year. A target of 50% reliance on hydro-electric power and forest growth rates of 1.2-1.8% per year were also assumed. The remaining sections describe insights from modeling and policy runs focusing on land use, energy management, and public transportation.

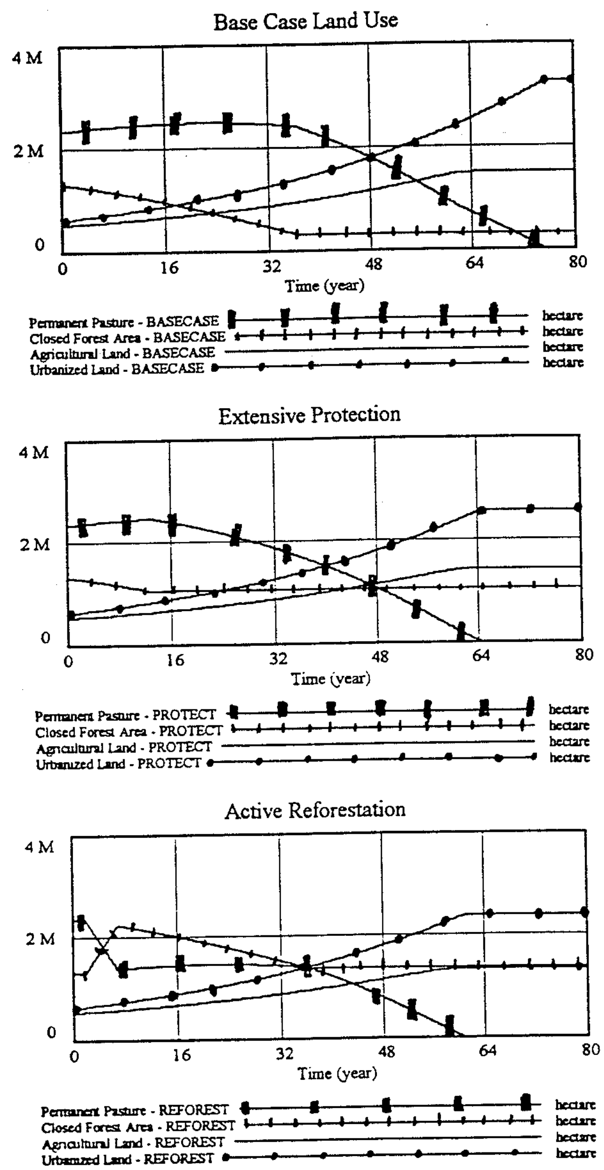
**Land Use Policies:**

One issue of paramount importance for carbon management is Costa Rica's choice of land use. The country has experienced rapid population expansion that resulted in a population of about 3.32 million as of mid-1994 with current growth rate of 2.3%. According to World Resources Institute (1992), closed forest cover has fallen from about 25,000 hectares in the mid 1960s to 13,000 hectares in 1988, while pasture land has expanded from 11,000 hectares to 23,000 hectares in the same time period.

The model distinguishes between seven types of land: closed forest, open woodland, pasture land, agricultural land, residential/ commercial land, tree plantations and other. The model is being revised to depict subcategories within each sector and better formulate the economic and political processes, which determine land use.

The model assumes that land can hold only a finite quantity of forest and carbon per hectare. Selective logging practices -- that include forest regrowth and use of the logs for housing or furniture -- can increase the total carbon sequestered per hectare of closed forest, but total capacity is limited. If carbon emissions from fossil fuels are continued, the forests' ability to absorb carbon from the atmosphere will eventually be saturated. A long-term carbon management plan will, therefore, need to address not only increasing carbon sequestration but also reducing carbon emissions.

## Figure 3
## Land Use Policy Scenarios

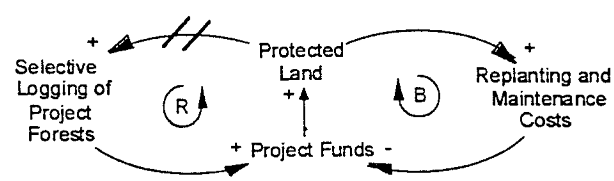



The policy runs in Figure 3 highlight the land use trade-off between rapid economic development and population growth -- which demand land for residential, commercial and agricultural use -- ranching, and closed forest protection or regrowth. In the base case, closed forest (except existing protected land) and pasture land are both converted into agricultural and urbanized land within 75 years.

Two alternative policies were tested: (1) active reforestation entailing 20 carbon sequestration projects, each of 52,000 hectares and (2) protection of 400,000 hectares initially with 50,000 hectares added annually if closed forest was available. The protection and reforestation scenarios result in higher levels of forest cover, but the residential and commercial sector are constrained to a much smaller land area. These runs helped reveal an insight not shown in the figure; if logging and burning pressures are not addressed, the forest will ultimately be decimated or else high on-going forest preservation costs will be incurred.

Uncertainties, such as funding shortfalls, incomplete implementation, adverse weather or natural conditions, and poor project design, can result in the failure of a carbon sequestration project. Some projects in Costa Rica address these uncertainties by utilizing "self-funding" practices that generate income, such as tree sales, park fees, nut/fruit harvests are more likely to succeed. Figure 4 depicts these "living endowment" practices loops.

## Figure 4
## "Self-Funding Practices" Diagram




## Energy Management and Public Transit:

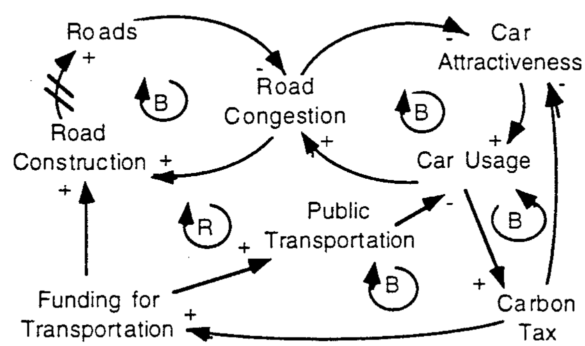
Energy production and public transportation are the two primary sources of carbon emissions in Costa Rica. The model is currently being improved to better reflect Costa Rican policy options revealed and data gathered from meetings with ICE, the Costa Rican power company, and others. The revisions are addressing the following points: ICE is implementing measures to limit carbon emissions, such as demand-side management and heavier use of non-fossil energy sources. Costa Rica has significant untapped hydro-electric potential as well as wind and geothermal sites. As access to investment funds for construction projects is relatively limited, Costa Rica has been encouraging private development of hydro-based electricity and other forms of power generation. Presently, promoting the burning of wood and agricultural residues (biomass) is a lesser priority of ICE. Rainfall can cause a wide variation in hydro-electric and wind power output, causing a reliance on backup power generators, many of which are oil or gas-fired.

The modeling of carbon emissions has revealed two interesting dynamics:

1. Carbon is released when either fossil fuel or biomass is burned. The long term effects of combusting these two carbon sources on the carbon balance are not, however, the same. Under natural conditions, the carbon in fossil fuel reserves are sequestered for thousands of years, while biomass is rapidly decomposing (see Figure 2). Increased combustion of wood and agricultural residues will initially provide a rise in annual carbon releases but will rapidly stabilize biomass-related carbon emissions to the natural decomposition rate of the biomass. Biomass energy has a second effect of eliminating a portion of the fossil fuel carbon emissions. As a result, biomass burning results in lower total carbon emissions than fossil fuel combustion.

2. Costa Rica has instituted a carbon tax on gasoline to discourage car usage. The revenues are used in part to finance road improvements. The Costa Rican carbon tax on gasoline has two effects as depicted in Figure 5: (1) The tax discourages car usage, thereby lowering carbon emissions, and (2) The tax encourages car usage and carbon emissions by financing new roads. As a result, the tax is encouraging more car usage with a time delay. If the taxes were invested in public transportation (buses) rather than roads, car usage would be further discouraged. Additional modeling is needed to determine whether the reduced carbon emissions from lower car usage will exceed the greater emissions from the enlarged bus system.

**Figure 5**
**Carbon Tax Diagrams**

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