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# The Planning of Biomass Energy Systems in Latin America

The purpose of this paper is to speculate on potential contributions by geographers to the analysis and development of biomass energy systems in Latin America. Biomass energy from wood, bagasse, oils, animal dung, and the like is presently an important source of energy in Latin America, supplying roughly 30 percent of the energy consumed in Brazil and roughly 45 percent of the energy consumed in Guatemala (Goldemberg, 1978, 159; Fitzsimmons and Mcintosh, 1978, 15). The proportion of energy derived from biomass in Latin America is likely to decline because of increasing energy consumption and the development of additional energy resources such as hydroelectric power and geothermal heat. Nevertheless, because biomass energy can help to meet several important energy demands for which there are few alternate supplies, at least in the near and mid term, the future demand for energy from biomass is likely to be at least as large as it is today. Recent initiatives by governments in the region, most notably the alcohol and charcoal programs of the Brazilian government, are likely to increase the region's demand for biomass energy and to change existing biomass systems (Hammond, 1978).

Finding solutions to the problems of biomass energy production will require the knowledge and skills of a number of disciplines. Most of the research into biomass energy in the United States has been technically oriented, drawing upon engineers, chemists, and biologists. It is noteworthy that of approximately seventy papers presented at a recent conference on biomass energy systems sponsored by the Solar Energy Research Institute, all but one were devoted primarily to technical issues (SERI, 1979). Nevertheless, many of the questions pertaining to biomass energy are institutional, social, and economic, and many of these fall within traditional concerns of geography. The organization of this paper is twofold. The first part of the paper is a brief, general survey of geographical questions related to biomass energy. Following the general survey, the paper develops in detail a specific application of geography to biomass energy, drawn from the recent research theme of location-allocation modeling.

## Clarification

Several points require emphasis before proceeding. The first is that the term "biomass energy" is used in this paper for convenience, as a generalization of the great number of biomass resources that vary in availability, production and use. The speculations below are reasonably certain to apply to a wide range of biomass energy systems, but they may not apply to all, and they may require modification for some systems. Because of the regional differences in physical and cultural factors, geographers should be aware of this diversity and, indeed, expect it. However, much – though not all – of the United States' energy bureaucracy and policy-making establishment either ignores regional differences or displays serious ignorance of United States geography and its implications for energy development. It would not be surprising to encounter similar difficulties in Latin America, particularly if a disproportionate share of the civil service is from large urban centers rather than from rural areas.

A second point when considering biomass energy in Latin America is the need to clarify some perceptions that people in the United States have about biomass energy. From a general viewpoint, biomass energy is a form of solar energy, and both of these have begun to acquire a strong aura of decentralization and self-sufficiency in the United States (Reckard, 1979). Certainly it is possible to have biomass energy systems that match this perception. Indeed, most of the biomass energy used in the world is used in rural areas, where individual families gather or grow their own energy resources and consume the energy for cooking, heating, and other household needs. Most people would agree that these are truly decentralized systems. However, other systems are possible, and there may be less agreement about how decentralized these are. For example, a firm that harvests firewood in the countryside or in the mountains and sells it to families in the lowlands or in cities would be considered a decentralized activity by some observers but not by others. Some proposed systems, including Brazil's alcohol program and a proposal to produce charcoal from plantation-grown trees for mass commercial sale to rural populations, may be decentralized by comparison with United States experience but may be profoundly more centralized than past or existing energy systems in Latin America. This is an important point, because some United States advocates have ascribed to solar energy a potential for greater stability and freedom from disruption than that of more centralized energy systems. Stability is possible if appropriate systems are developed with it in mind, but it is by no means certain to accompany reliance on biomass energy. Indeed, unless they are handled appropriately, policies to change existing biomass systems in Latin America and develop new ones could be unsettling and socially disruptive. As in other ventures by United States scholars into overseas work, it is important not to assume that Anglo-American perceptions and values are appropriate for other cultures.

A third point is that sustainable biomass energy systems are agricultural systems, and that biomass research should be able to draw heavily upon agricultural research. Land suitability and productivity, yield estimation, and management practices for biomass may be very similar to those for food and fodder. The two types of crop will still have differences in emphasis and substance, however. For example, the energy required to harvest, collect, and process a crop may be of much greater importance for biomass than for food.

The potential contributions of geographers to biomass energy development could be grouped in several ways. The scheme adopted here considers three general areas: 1) analysis of the biomass (physical) resource base; 2) examination of economic, social, and institutional factors that affect demand for biomass energy and development of the resource; and 3) studies of policies and infrastructure associated with developing and managing the resource. The classification is primarily for convenience of discussion, and many geographic research efforts will of necessity fall into more than one class. Although the emphasis is on applied research, there are also important basic research questions to be answered.

## The Resource Base

In analyzing the physical resource base, the major questions involve where the biomass can be grown, what types can be grown, what the expected yield will be, and what limits are imposed on the system by such factors as climate, soil fertility, topography, and the availability of water. Geographers can draw upon their backgrounds in physical geography, climatology, soil science, and quantitative methods, upon their familiarity with the region, and upon models developed by foresters and agricultural economists to help answer these questions. For example, forest researchers have models that estimate current volumes of sawtimber on a land parcel, based on various landscape and silvicultural variables, or that estimate future volumes.

Although some work may be done – perhaps with remote sensing – to identify existing stands of abundant natural vegetation for harvest, the emphasis in biomass energy systems will have to be on land and resource management if biomass is to be a long-term, reliable, significant source of energy. Maintenance of soil fertility, prevention of soil erosion, susceptibility of pure stands to disease, and estimation of the long-term carrying capacity of the land should be major concerns in these analyses. Maintaining the long-run viability of a system may reduce its net energy yield in the short run, and this may lead to conflict between parties who have different interests in the system's management.

**Spatial Aspects of Demand and Supply**

The institutional factors that influence both the demand for biomass energy and the development of the resource are more complex than the physical factors, at least to discuss in a brief survey. As noted earlier, biomass energy can help to meet energy demands for which there are few alternate supplies. One of these is energy for cooking and heating in rural areas. Biomass energy now meets much of this need, and most alternatives would raise the real costs of energy to poor rural families. Alternatives such as direct solar energy are often capital intensive, and alternatives such as hydro-electricity tend to be more capital intensive for low density, rural areas than for urban ones.

The demand for biomass energy in rural areas is thus related to spatial structure, and there should be research opportunities for geographers in estimating potential changes in this demand. Changes in the rural fuel system seem likely because the population and its material goals are increasing. In some parts of Asia and Africa, this increased demand is damaging the land that now supports the rural fuel system, and this may also be true in Latin America. One policy could be to encourage rural economic development in ways that reduce the cost paid by rural inhabitants for alternate fuels. Such reductions might involve tapping transportation systems set up for other purposes, or perhaps directly tapping energy from other activities in a co-generation scheme. Either approach, properly managed, would tend to lower the average capital cost barriers to alternate fuels now faced by rural inhabitants. Geographers should be able to assist in determining what the cost reduction would be for alternate systems in different locations and different scales; if the reductions would be large enough to reduce demand for biomass energy, research can identify locations that might reduce biomass demand or pressure on local resources by the greatest amount. An alternate policy would be to develop more centralized biomass systems at the local scale, relying on more intensive management of a smaller area of land to meet the energy needs of each village.

A second, crucial demand that biomass energy can meet, although it has not been a traditional use, is for liquid fuels that have the cleanliness, portability, and ease of handling needed for mechanized transportation. Petroleum is presently the source of most liquid fuels and the difficulty of obtaining adequate fuel for the transportation sector from other sources is a major obstacle to reducing or eliminating the expenses of imported petroleum (Craig et aI., 1978). Again, the amount of transportation demanded and liquid fuels required depend in part upon the spatial structure of the economy. Modifications of that spatial structure could reduce the amount of liquid biomass fuels needed, or could reduce future increases in demand.

The physical limitations to biomass energy supplies discussed earlier may not be the only, or even the major, constraints on this source of energy. In some local areas, and perhaps over large regions, competition for land by other uses may limit biomass energy production. Other uses include the food crops, grazing, lumbering, and urban uses common to land use competition models, but they may also include competing forms of biomass production, and reservation of land to protect ecosystems. The competition between biomass crops may be particularly important when more centralized biomass energy systems are proposed to supplement or replace existing decentralized systems. Poaching firewood from forest preserves or plantations is a problem in rural Asia and in parts of the United States, and a similar problem can be expected in Latin America unless appropriate incentives or enforcement measures are prepared (Eckholm, 1976). One approach to studying the competitive position of biomass energy would use a von Thünen type of model modified to reflect current decentralized consumption, energy cost, the energy required for other activities, and any government policies to subsidize or encourage change in particular land use patterns. Development of such a model has been discussed at Oak Ridge for application to biomass in the United States, but as yet the model remains unformulated (Dobson, 1979). The issue of land use competition in Latin America also needs to be addressed.

## Policy and Infrastructure

The final group of contributions by geographers involves work with policies and infrastructure related to biomass energy development. In the matter of policy, it seems logical to link biomass energy systems and rural development and to draw upon the background that many geographers have in studying development. Rural employment opportunities are now seen as important to the overall economic and social development of nations. Although it is possible to design biomass energy systems that require relatively little labor, most biomass systems have the potential to employ significant numbers of rural inhabitants and to supplement rural income. In addition, the development of more centralized biomass systems may raise the quality of life for some rural inhabitants by reducing the amount of uncompensated effort now spent in foraging for fuel. However, this presupposes an adequate level of income or some other arrangement to permit the purchase of fuel that may now be free for the taking. Finally, biomass energy systems must be related to other aspects of rural development planning, with attention to equitable distribution of development planning effort and the spatial linkages between biomass energy and other parts of the economy.

The role of geographical analysis of biomass infrastructure is perhaps best illustrated with an example involving a centralized system that grows and harvests biomass for processing into fuels, or perhaps feedstocks, for the regional or national economy. Unprocessed biomass is a high bulk, high weight material, and there is thus a limited distance over which the raw material can be shipped economically, even after some drying has occurred. For a wood-burning electric power plant in Vermont the limiting maximum transportation distance for the fuel is approximately 80 km (Leonard, 1979). For different regions of Latin America, using less mechanized transportation on poorer roads, the limiting distances probably will be much shorter. Production, however, may remain an extensive activity. To develop a regional or national energy system, therefore, it will probably be necessary to establish a system of stations where raw biomass can be collected, processed (perhaps by fermentation into alcohol or conversion into charcoal) and shipped more efficiently into the rest of the economy. This is a problem for which location-allocation modeling is particularly well-suited, and the following section considers the problem in greater detail.

## A Location-Allocation Model for Biomass Collection

The following model is one of many that might be useful in planning the locations of biomass collection stations. Church (1979) developed the model and used it to plan locations and collection areas of solid-waste processing centers for the Tennessee Valley Authority. At a conceptual level the waste problem and the biomass problem share many common features, and in fact much of the solid waste to be collected at the TVA stations is derived from biomass and could be burned for heat or converted to liquid or other fuels if market conditions permit.

The model has three objectives. One objective is to minimize the transportation of biomass from point of harvest to the collection station. This is intuitively a reasonable objective, given that much biomass conversion involves substantial weight reduction, and the desire to yield as much net energy from the system as possible. The second objective is to maximize the amount of biomass that is transportable to the collection stations. This is also intuitively reasonable. In general, it will not be possible to build and operate enough stations to collect and process all of the biomass resource, and for any given number of stations it is preferable to be able to tap more of the resource than less. The resource cannot be tapped if it is too far from the station to be transported. The third objective is to maximize what Church has termed the justifiability of the stations. That is, as many of the stations as possible should process at least some minimum amount of biomass in order to justify their construction. If each station were required to be justifiable this objective would be unnecessary. ln many public systems and in some private ones, however, it may be necessary to provide service to some areas that do not generate enough demand to completely justify a station. For example, a station may be established in an area that cannot fully justify it now, but that is expected to yield additional amounts of biomass in the future. Treating minimum operating size of the stations as an objective, rather than as a constraint, allows greater flexibility to examine this type of situation. At the same time, the model can require all stations to be justifiable.

Mathematically, the three objectives are stated as:

$$\text{minimize } z_1 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_i d_{ij} x_{ij} \quad \text{(transportation)}$$

$$\text{maximize } z_2 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_i c_{ij} x_{ij} \quad \text{(resource coverage)}$$

$$\text{minimize } z_3 = \sum_{j=1}^{n} y_j \quad \text{(justifiability)}$$

where i denotes a harvesting region, wi is the number of tons of biomass to be transported, and j denotes a candidate site for a collection or processing station. In this case, each harvesting region is a candidate site, but this can be modified easily. In addition,

$d_{ij}$ = distance from area i to candidate j

$c_{ij}$ = 1 if area i is close enough to candidate j to permit transporting the resource, 0 otherwise

$x_{ij}$ = 1 if area i is served by a center at j, 0 otherwise

In most cases it will not be possible to find a location pattern that simultaneously optimizes all three objectives; instead, it will be necessary to yield a bit on one objective to gain on another. For example, in order for a station to tap more of the biomass resource, it may have to be moved so that it is farther from the resource that it taps now. To handle the three objectives within a single model it is necessary to give a weight to each objective. The weights may be chosen arbitrarily and varied systematically during the analysis to yield a range of "best compromise" location patterns; in a "best compromise" pattern it is not possible to gain on one objective without losing on another. The "best compromise" patterns are good starting points for more in-depth study using detailed knowledge of the region in which the system is to be developed, and engineering or other professional judgement.

For any given set of weights u, then, the problem is to

$$\text{minimize } a = u_1 z_1 - u_2 z_2 + u_3 z_3$$

subject to several constraints that are needed to make the mathematics of the model consistent with the substantive problem of locating stations:

1 $$\sum_{j=1}^{n} x_{ij} = 1 \quad \text{for each area } i$$

2 $$x_{jj} - x_{ij} \geq 0 \quad \text{for all } i \text{ and } j,\ i \neq j$$

3 $$\sum_{i=1}^{n} w_i x_{ij} - \Omega x_{jj} + \Omega y_j \geq 0 \quad \text{for each candidate } j$$

4 $$1 \leq \sum_{j=1}^{n} x_{jj} \leq k$$

In these constraints, $\Omega$ is the minimum justifiable size for a collection station, stated in tons of biomass, and k is the largest number of stations permitted by, the funds for the system. Constraint 1 requires that every harvesting region i be considered by the model, although it does not require each region to be tapped. Constraint 2 prevents biomass from being transported from a harvesting region unless there is a station at candidate j to receive it. Constraint 3 defines the justifiable size of the stations for the third objective, and the fourth constraint limits the number of stations. The model assumes that a harvesting region that moves any biomass to a particular station moves all of its harvest to that station.

It is beyond the scope of this paper to discuss methods of solving the model in any detail. It is sufficient to note that the model is an integer linear program but that it can be solved using a robust heuristic that is much simpler to work with.

The model is an extension of the p-median model. Recent research has. shown that the p-median encompasses a very large number of models used to study locations for emergency medical services, schools, retail outlets, competitive firms, market centers, warehouses, and many other activities (Hillsman, 1979). Thus, although there may be situations for which the model above is inappropriate, it may be possible to make substantive changes to the model without changing its mathematical structure. For example, it may be appropriate to use tons of biomass in the first objective but to use energy output of a collecting station, rather than weight of biomass to determine a justifiable size. Alternately, if construction and processing costs vary from one part of the region to another, then it may be necessary to include an estimate of these costs as one of the model objectives. As a final example, the model could include a fourth objective to maximize the number of jobs supported by the system in rural areas, given differences in crops and agricultural practices among local areas. This could be written as

$$\text{maximize } z_4 = \sum_{i=1}^{n} \sum_{j=1}^{n} e_i c_{ij} x_{ij} \quad \text{(employment)}$$

where ei is the number of people who would be employed in raising and harvesting biomass in region i. These are only a few of the changes that can be made to this model without changing its mathematical structure. The underlying model is thus quite flexible, and it is a particularly suitable tool for a problem whose features vary widely with climate, culture, and public policy.

## Conclusions

The survey of research opportunities presented here reflects the background and interests of one geographer. Geographers with different backgrounds – including first-hand knowledge of Latin America – would probably identify additional questions to be answered. Nevertheless, the survey indicates that development of biomass energy systems will require answers to a wide range of geographical questions. If geographers do not become involved in the area, researchers from other disciplines will, of necessity, undertake the work.

Geographers might not be willing to claim all of the research areas suggested here. For example, the relationship between spatial structure and demand for biomass energy may seem more of a problem for engineers or economists. As noted earlier, funded research on biomass energy systems in the United States has emphasized technical questions that most geographers have not been trained to answer. However, many geographers can contribute to the studies of these questions as part of an interdisciplinary research team. In addition, by working with such teams, they can draw attention to the spatial and institutional aspects of biomass energy systems, and to the need to examine them. At some of the United States national laboratories, geographers are now filling these roles. To the extent that this research can involve work overseas and work with researchers from other nations, it may be possible for the United States and other nations to learn from each other's experiences and prevent some of the mistakes that might otherwise occur in the development of biomass energy systems.

## Note

1. Operated by the Union Carbide Corporation for the Department of Energy under contract W-7405-eng-26.

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