Land use issues in biomass energy planning

Gerald G. Marten

Land availability is a key consideration for evaluating the potential of biomass energy. This depends not only on how much land is physically suitable for growing the biomass crop, but also on the environmental implications of an energy farm and the extent to which land can be freed from competing uses. Energy planning should include inventories to realistically assess the amount of land potentially available for biomass production and the trade-offs involved in using such land for biomass farms.

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Many countries are seriously considering biomass energy as a significant part of their energy supply in the near future. Some have already committed themselves to heavy investments in this area, investments which have numerous implications, some of them environmental. In 1980 a small group of scientists and engineers from Australia, New Zealand, Indonesia, the Philippines and the USA assembled at the East-West Environment and Policy Institute for several months to explore ways that environmental issues can be clarified before heavy commitments are made. The group addressed the question 'How can environmental considerations be incorporated meaningfully into the biomass energy development process?'[1] It concluded that there is a need to put environmental information in a form which is comprehensible and meaningful to decision makers by graphically indicating how environmental impacts affect human lives.

Figure 1 presents a hypothetical dialogue on biomass energy that might take place in the course of policy and planning decisions.[2] In addition to questions concerning the amount of alternative energy that is really needed, much of the dialogue in Figure 1 bears on a fundamental question in deciding the role that biomass will have in the energy policy of a nation or region: 'How much biomass energy can potentially be produced?' The answer places an upper limit on the portion of the energy supply that biomass energy can be expected to provide.

The contribution that biomass can make depends in part on the per hectare yield to be expected when growing the biomass crop. It also depends on the efficiency of conversion of the biomass crop to useful forms of energy (eg electricity by combustion in a dendrothermal power plant, or ethanol by fermentation and distillation). However, the amount of land available to produce biomass crops is even more significant in its quantitative impact. This leads to another question, 'How much land is available for biomass production?' This paper discusses some of the essential considerations in answering this question, and includes simple diagrammatic forms of presentation that can be useful for decision makers in biomass energy development.

[1]G. G. Marten, D. Babor, L. Christanty, P. Kasturi, D. Lewis, C. Mulcock and I. Willington, 'Environmental considerations for biomass energy development: Hawaii case study', *East-West Environment and Policy Institute Report No 9*, HI, USA, 1981.
[2]D. Wojick, 'Issue analysis: an introduction to the use of issue trees and the nature of complex reasoning', 1975.

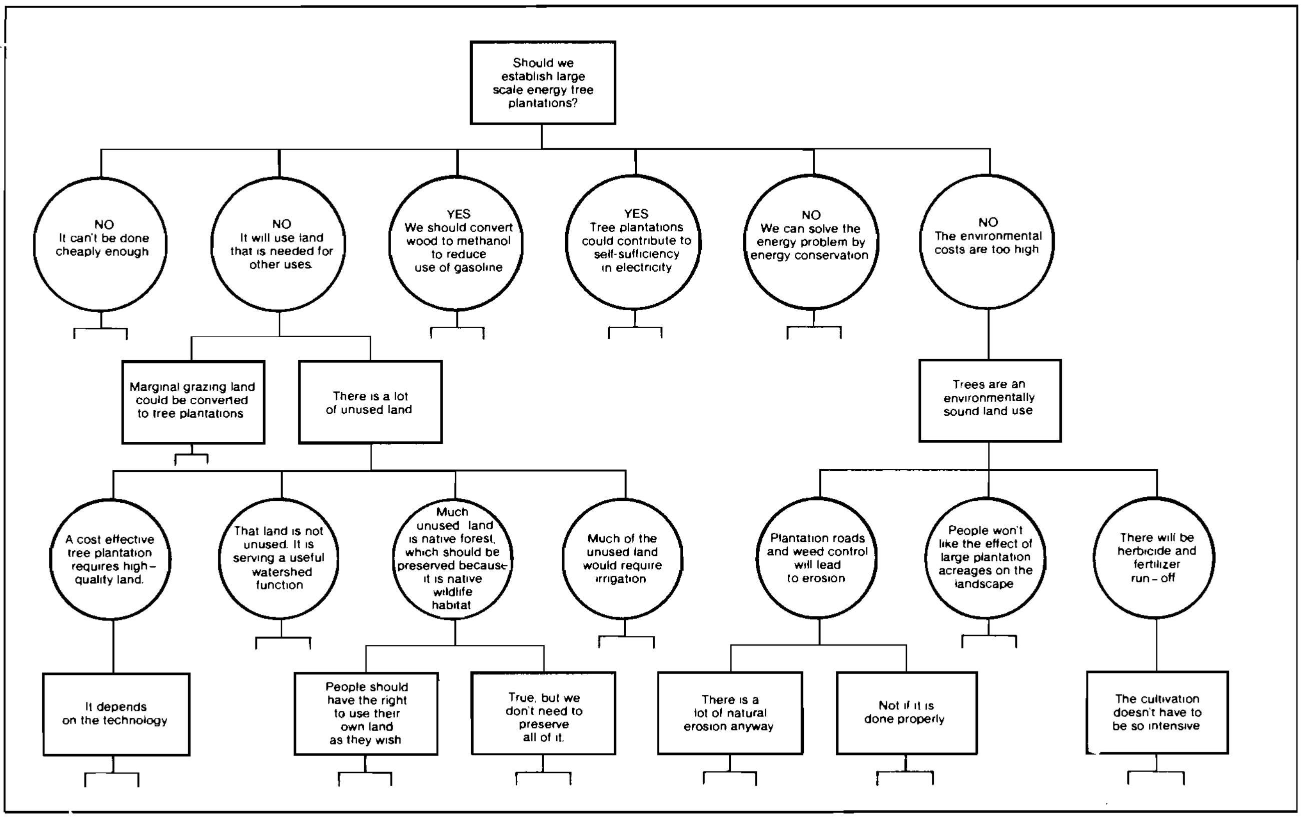

Figure 1. Issue tree for land use issues associated with energy tree plantations.[a]

[a]The tree proceeds from top to bottom as a dialogue between the squares and the circles. Policy questions occur at the top, and management questions develop as the tree proceeds downward.

Physical suitability

Systems of production. Whether or not land is suitable for a biomass energy farm depends very much on the system of production to be employed. Different crops and cultivation systems imply corresponding differences in yields, land requirements, intensity of inputs, and environmental impacts. For example, one can imagine several styles of energy farming:

- agricultural farms;
- silvicultural farms;
- farms for marginal land.

An agricultural farm is operated according to conventional agricultural practices. The land is plowed in preparation for planting; fertilizers, herbicides, and insecticides are applied; the crop is harvested in mass rather than plant by plant (as in logging); and the care of the crop is in general as intensive and mechanized as possible. This kind of farm is economically feasible only on high-quality agricultural land. The philosophy behind an agricultural energy farm is that the harvest should be as high as possible. However, as the establishment and operating costs for this kind of farm are high, it requires a rapid return on investment. Although an agricultural farm usually consists of crops such as maize, sorghum, sugarcane, sugarbeet, or cassava, an agricultural style of production can also be employed for tree farms.[3] Although the erosion and

[3]Mitre Corporation, 'Silvicultural biomass farms', *MITRE Technical Report, No 734,* 1976.

run-off from agricultural farms can be minimized by proper soil conservation practices, these environmental impacts will generally be greater for agricultural energy farms than for less intensive styles of farming.

A silvicultural energy farm (or tree plantation) represents a less intensive approach to energy farming, and per hectare yields and environmental impacts are generally correspondingly less. A silvicultural energy farm is not restricted to prime agricultural land, being feasible on any land of commercial forest quality, ie land that has sufficient rainfall and soil to support tree growth.[4]

A third kind of energy farm can be developed on marginal land. *Euphorbia*, for example, is a crop with low water requirements that produces hydrocarbons that could be used directly as petrol substitutes without conversion to alcohol.[5] The inputs for marginal-land energy farms would typically be less than for the other types, but the more marginal the land, the lower will be the yields.

Map overlays. The identification of suitable land can be facilitated by means of map overlays.[6] Figure 2 illustrates the identification of suitable areas for eucalyptus energy plantations on the island of Hawaii.[7] Several thousand hectares of these plantations are being planted to produce fuel-wood to supplement bagasse in providing electricity and processing heat for sugar processing plants on the island. Larger acreages may be employed to meet other energy needs of the state.

The three maps at the top of Figure 2 show the areas on the island which satisfy the physical requirements for eucalyptus plantations with a silvicultural style of production. They include:

[4] *Ibid.*
[5] P. E. Nielson, H. Nishimura, J. W. Otvos, and M. Calvin, 'Plant crops as sources of fuel and hydrocarbon-like materials', *Science*, Vol 198, 1977, pp 942–944.
[6] I. McHarg, *Design with Nature*, Doubleday, New York, NY, USA, 1971.
[7] W. E. Hillis and A. G. Brown, *Eucalyptus for Wood Production*, CSIRO, Canberra, Australia, 1978; E. O. Mariam, W. A. Wood, A. C. Kouchoukos, and M. B. Minton, 'The eucalyptus energy farm: feasibility study and demonstration. Phase I: site and species selection', Marelco Inc (for US Department of energy), 1978.

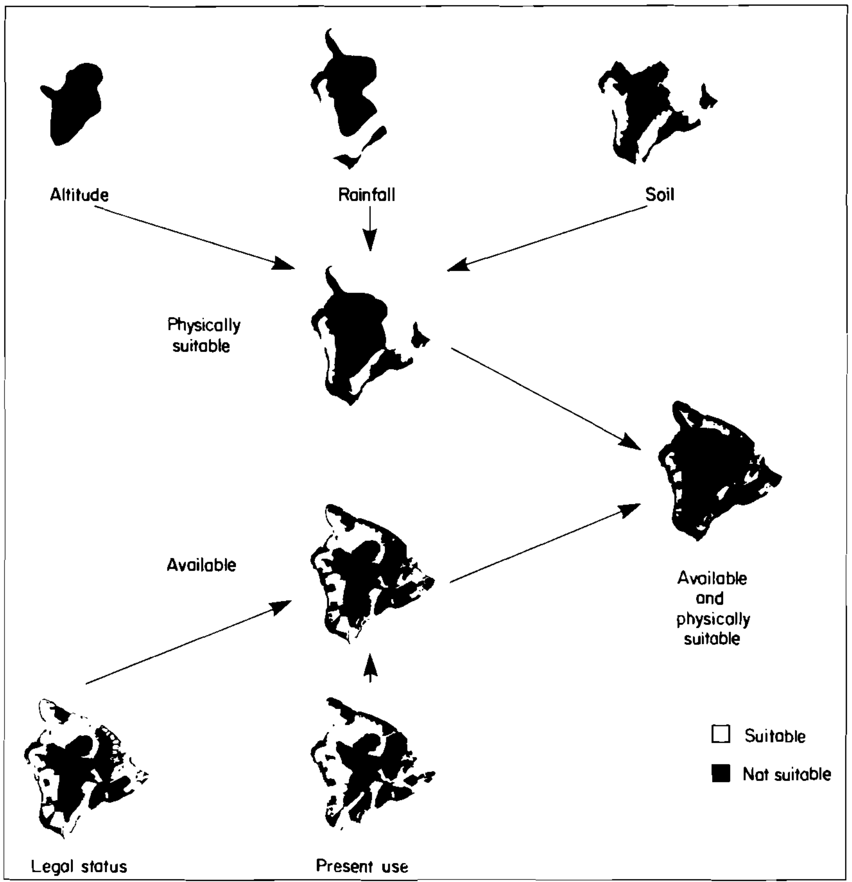

Figure 2. Map overlays for physical suitability of land for Eucalyptus plantations on the island of Hawaii.[a]

[a] Rainfall, altitude, and availability are based on the Hawaii Atlas (H. L. Baker, T. Sahara, T. M. Ryan, E. R. Murabayashi, E. T. Ching, A. Y. Fujimura, and F. N. Kuwahara, *Detailed Land Classification: Island of Hawaii*, Land Study Bureau, University of Hawaii, HI, USA, 1965). Only land zoned for agricultural use is mapped as legally available. Land in watershed (reserve) use and in agricultural crops is mapped as unavailable from a practical point of view. Soil suitability is based on the US Soil Conservation Service soil map for Hawaii, from which lava flow areas (whose soils are too thin for tree growth) are mapped as unsuitable.

- areas below 5000 ft elevation (higher elevations being too cold for rapid tree growth);
- areas where the rainfall is greater than 40 ins per year;
- areas where the soil is of commercial forest quality (ie sufficiently deep).

The three maps (for elevation, rainfall, and soil) are combined in Figure 2 to form a single composite map showing areas which are physically suitable for eucalyptus plantations from all three points of view.

The example presented here is a simple one, but real suitability map overlays sometimes become so complicated that they are not practical for manual use. Fortunately there are graphics computer programs that can sort through large numbers of maps, creating composite maps on the basis of the 'and/or' logic of boolean algebra.[8]

Environmental impacts

The composite map for physical suitability in Figure 2 identifies areas in which the trees will grow, but whether or not a given parcel of land is suitable also depends on whether it is environmentally acceptable for establishing a particular kind of energy farm (Table 1).[9] The environmental impacts of energy farms are similar to those of any kind of agriculture, the most important considerations being soil conservation[10] and run-off of agricultural chemicals.[11] Because the slope of the land has an overriding influence on erosion and run-off, and because slopes can sometimes change radically in the space of a few hundred metres, the spatial scale of land suitability from an environmental point of view can be much finer than in Figure 2. Marten and Sancholuz[12] have developed techniques for sampling aerial photographs to inventory the percentage of the land in a given area which is environmentally suitable for different crop systems from the point of view of climate, soil and topography.

There are several ways, however, in which energy farms may be somewhat different from other farms. Since all of the crop is useful for

Table 1. Energy, environmental and economic considerations of biomass energy alternatives.

	Biomass production	Conversion	End use
Alternative technologies	Bagasse Sugar Molasses Cassava Pineapple Wood	Combustion Fermentation Pyrolysis	Electricity Liquid fuels Gas Process heat
Energy	Net energy budget	Conversion efficiency	Petroleum substitution Energy efficiency
Environmental	Land use Water use Water run-off Water quality Erosion Soil fertility Pest problems Climatic effects Aesthetics	Emissions to air Emissions to water Emissions to land	Emissions to air Emissions to water Emissions to land
Economic	Yield Seasonal fluctuations Price for product Market structure Capital Employment Costs	Yield Availability of inputs Price for product Market structure Capital Employment Costs	Demand structure Flexibility Cost to consumer

[8]Western Energy and Land Use Team (Systems Application Group), 'PAN – a refuge planning general information system', US Fish and Wildlife Service, Fort Collins, CO, 1980.
[9]G. Morris, 'Integrated assessment issues raised by the environmental effects of biomass energy systems: a case study', Energy and Resources Group (ERG–WP–80–6), University of California, Berkeley, CA, 1980; Oak Ridge National Laboratory, 'Environmental assessment: biomass energy systems program', Oak Ridge, TN, USA, 1981.
[10]S. A. El Swaify, E. W. Dangler, and C. L. Armstrong, *Soil Erosion by Water in the Tropics: A State of the Art*, University of Hawaii Press, Honolulu, HI, USA, 1981; W. H. Wischmeier, and D. D. Smith, 'Predicting rainfall erosion losses – guide to conservation planning', *Agriculture Handbook*, No 537, US Department of Agriculture, Washington, DC, 1981.
[11]A. W. A. Brown, *Ecology of Pesticides*, Wiley, New York, NY, USA; B. A. Stewart, D. A. Woolhiser, W. H. Wischmeier, J. H. Caro and M. H. Frere, 'Control of water pollution from cropland', *A Manual for Guideline Development*, Vol 1, US Department of Agfriculture Report No ARS–H–5–1, Washington, DC, USA, 1975.
[12]G. G. Marten, and L. A. Sancholuz, 'Ecological land use planning and carrying capacity evaluation in the Jalapa region (Veracruz, Mexico)', *Agroecosystems* (in press).

Table 2. Environmental impacts of alcohol stillage on water quality and the aquatic ecosystem.

Depletion of dissolved oxygen*
Discolouration*
Odours*
Eutrophication
Salinization (in fresh water)
Acidification
Increase in water temperature (locally)
Changes in species composition of aquatic flora and fauna*
Fish kills (in extreme cases)

*Most significant impacts

energy purposes, the harvest may emphasize removing as much of the crop as possible, rather than leaving significant quantities of crop residues behind. This means less cover to protect the soil from erosion and less litter to decompose and maintain soil organic matter and return nutrients to the soil. Furthermore, energy farms may be established on land which has not been in intensive use because it is marginal for agricultural use. Such land may require higher chemical inputs than usual and is likely to be more susceptible to erosion, run-off and soil degradation than high-quality agricultural land.

Environmental effects can be displayed diagrammatically in terms of the different spatial components of a farm system, including the movement of materials within the system and the exchange of materials with the outside world. Figure 3 compares a cassava farm for ethanol production in an upland area of South-east Asia (the upper right panel of Figure 3) with the traditional slash-burn agricultural system (upper left panel of Figure 3) that might occupy the same land before the energy farm is established. The total area of each panel in Figure 3 reflects a unit of area (1 000 hectares) occupied by each agricultural system, and the sizes of the components (squares, octagons, etc) reflect the relative land areas occupied by each. The widths of the arrows reflect magnitudes of transfers. The squares, circles, octagons, arrows, etc, of Figure 3 might be removable plastic pieces of different sizes and colour in order to facilitate flexibility in setting up diagrams.

In the case of the slash-burn system, only a portion of the area is occupied at any one time by agricultural crops (represented by the octagon in Figure 3). The secondary forest around the garden represents fallow, as the garden rotates around the secondary forest area from year to year. In contrast, if an ethanol energy farm is placed on the same area, the entire area formerly occupied by secondary forest is in permanent agricultural use (the energy farm). The energy farm also supports a larger human population in the same area.

The people in the two systems experience different life-styles, each with its advantages and disadvantages. Figure 3 shows that the energy farm will have a higher overall rate of erosion because more land is in cultivation. This higher rate is reflected in the greater width of the arrow for sediment passing from farm to river. The energy farm will also have a higher rate of pollution than the slash-burn system, due to agricultural chemicals passing from farm to river and liquid waste passing from distillery to river (Table 2).[13] It may also lead to a lower level of nutrition for the human population, because foods are purchased rather than home-grown. The energy farm may have disease problems which are not present in the traditional system as it may provide habitats for disease vectors which were not present in the forest, and the higher human population density may result in sanitation problems and intestinal parasite infestations.

All of this not only affects the quality of life (nutrition, health, etc) of the human population in the area, it also affects the flow and water quality of the river, which transports the effects downstream to other communities in the same watershed.[14] The environmentally mediated impact of human activities in upland areas on the quality of human life in the lowlands can be greatly magnified because of the higher human populations which often occur in the lowlands.

The bottom panels in Figure 3 display a rice paddy system in the lowland area. Paddy food production depends on activities in the uplands

[13] I. P. Willington and G. G. Marten, 'Options for handling stillage waste from sugar-based fuel ethanol production', *Resources and Conservation* (in press).

[14] H. C. Pereira, *Land Use and Water Resources in Temperate and Tropical Climates*. Cambridge University Press, Cambridge, UK, 1973.

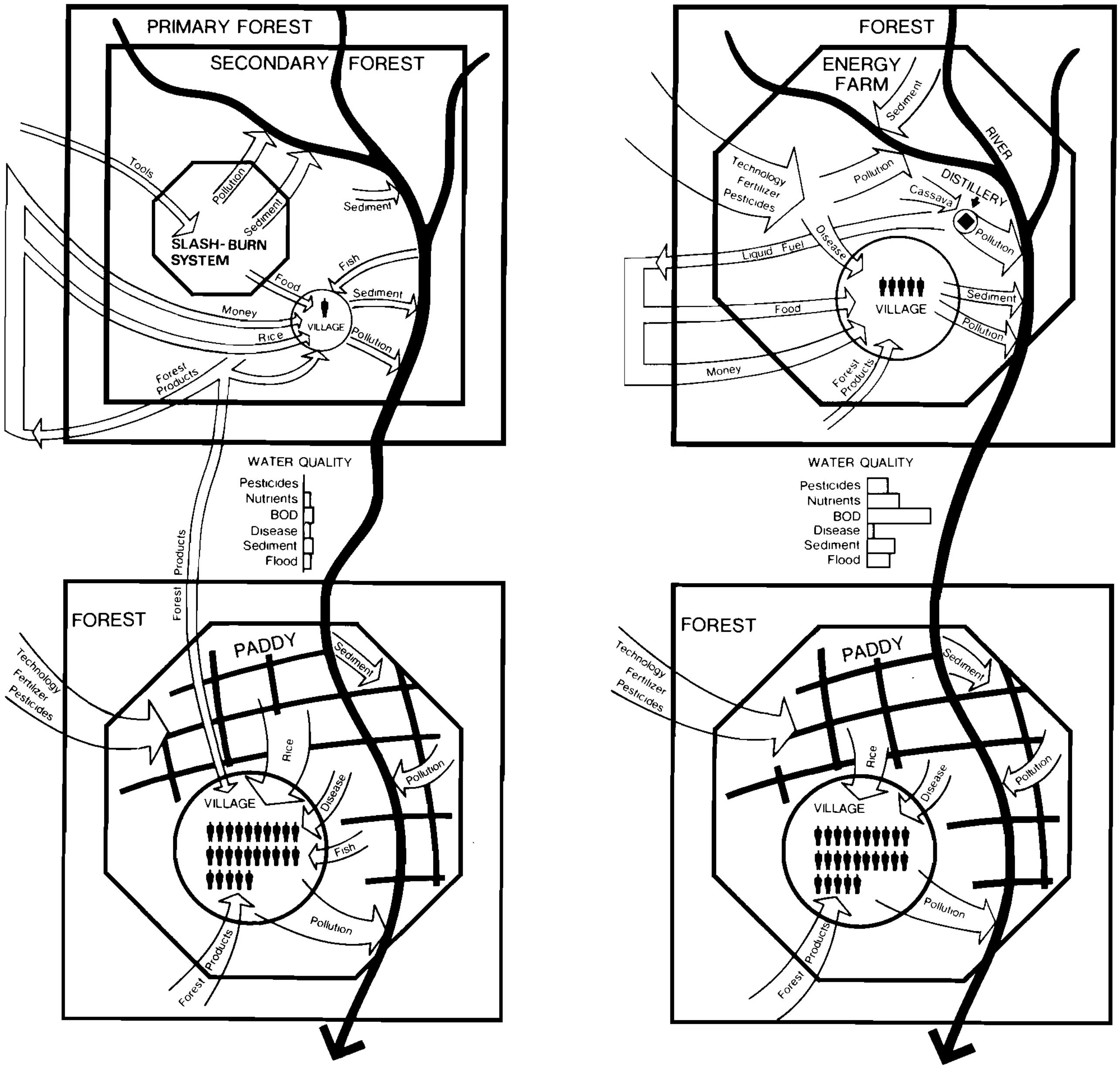

Figure 3. A comparison of the environmental effects of a cassava-ethanol energy farm with a slash-burn agricultural system.[a]

[a]The total area of each square is one thousand hectares. Each human figure represents one hundred inhabitants. The widths of the arrows reflect magnitudes of transfers.

because it can be damaged by drought, floods, or excess silt. Furthermore, water polluted with pesticides or organic wastes may not be suitable for fish which are cultured in paddies and which constitute an important source of protein for rice cultivators. The same effect can be transported further downstream, affecting the livelihoods of fishing villages along the coast. Damage to coastal fisheries in South-east Asia has in fact occurred as a consequence of urban, industrial, or mining pollution of rivers.

This is not to suggest that energy farms are necessarily worse than traditional agricultural systems. The purpose of the diagram is simply to point out that the magnitude of the costs and benefits which are associated with different systems of production. The slash-burn system in Figure 3 portrays a low human population density, but a slash-burn system could lead to numerous environmental and human problems if the population density were high (this would imply different magnitudes for the arrows in the diagram).

The environmental and human effects which are portrayed for the energy farm in Figure 3 are ones that have in fact been observed in other intensive agricultural systems (such as oil palm plantations) in upland areas of South-east Asia. The magnitudes of these effects depend on the kind of land on which the energy farm is established. Undesirable effects can be minimized by matching the right kind of energy farm to the right kind of land. Different diagrams can be made not only for different production systems but also for the same system on different kinds of land. The diagrams can then be used to explore with a policy maker the consequences of placing different kinds of energy farms on different kinds of land in a watershed context.

Availability

Whether land can be used for an energy farm depends not only on its physical and environmental suitability, but also on its legal and practical availability for the kind of farm in question. Competition between energy farms and the food or fibre production that might take place on the same land can be a serious consideration.[15] For example, in the mid-western USA, corn that could be fermented to alcohol could also be fed to livestock or exported to nations that have food shortages. Sugar cane or cassava for a fuel alcohol crash programme in a developing country may be produced on land that would otherwise be used for subsistence agriculture.

Continuing with the example of eucalyptus plantations on the island of Hawaii, only land zoned 'agricultural' (the map for legal availability at the bottom of Figure 2) is readily available for tree plantations from a zoning point of view. Land zoned for urban or conservation use is not readily available, although some of that land is potentially available upon petition to the Hawaii Land Commission.

The feasibility of establishing a tree plantation also depends on the use the land already has. It is not likely that land which is already in use for agricultural crops (eg sugar cane or macadamia nuts) would be converted to energy tree plantations, since it would be difficult for a tree plantation to give an economic return that competes with such crops. The same applies to land which is in urban use. Moreover, conservation groups would oppose establishing tree plantations on land which is still covered with native forest, and municipal authorities would question intensive use of land that is being used for watershed purposes. This is summarized in the map for practical availability in Figure 2.

The maps for legal availability and practical availability are somewhat similar because the present land use on the island of Hawaii is shaped by the zoning on the island. One of the major differences between the two maps is that agriculturally zoned land which is already in crops (as opposed to other uses such as grazing) is legally but not practically available for energy tree plantations.

Legal and practical availability are combined in Figure 2 to give a composite map showing availability from these two points of view. As

[15]L. R. Brown, 'Food or fuel: new competition for the world's cropland', *Worldwatch Paper No 35*, 1980.

[16]H.L. Baker, T. Sahara, T.M. Ryan, E.R. Murabayashi, E.T. Ching, A.Y. Fujimura and F.N. Kuwahara, *Detailed Land Classification: Island of Hawaii*, Land Study Bureau, University of Hawaii, HI, USA, 1965.

with physical suitability, there are availability considerations that are finer grained than the map in Figure 2. For example, an energy plantation may require a certain size before it is commercially viable, and many private landholdings may be below that viable size.

The composite map for availability is combined with the composite map of physical suitability in Figure 2 to indicate the areas which are both physically suitable and readily available for eucalyptus energy plantations. Even though extensive areas of Hawaii are available or physically suitable, Figure 2 shows that only a few areas meet both criteria. These areas can be compared with the location of sugar processing plants at which the wood would be burned in order to determine which areas are economically feasible when the transport costs of the wood are taken into account. The end result gives an idea of how much suitable land is potentially available and where it is located.

A diagrammatic approach

Although maps are particularly useful for deciding where energy farms should be located, they may not be effective summaries for policy makers who want to see possibilities and trade-offs without being distracted by the detail that a map provides. The question 'How much land is available?' may best be answered without regard to where the land is located.

One approach is to use diagrams which summarize the amounts of available land in different suitability and present-use categories. Figure 4 is a way of summarizing a two-way table for land suitability and present land use, which in this example is based on a detailed classification of the land in Hawaii and its suitability for different uses.[16] Figure 4 is a response to the fact that the answer to the question 'How much land is available?' is not simply 'X hectares are available', because such an answer would require the question to be specific in many ways that are not practical at the broad level of policy and planning. Figure 4 deals with the fact that the amount of available land depends on (1) the kind of energy farms that would be employed and (2) the extent to which one is willing to allow energy farms to displace other useful activities from the same land.

The outer circle in Figure 4 represents the total amount of land on the island of Hawaii, and the inner circles represent the amounts of land which are suitable for different uses. The innermost circle (labelled 'agriculture') indicates the acreage of high-quality agricultural land. The dashed circle, which is labelled 'grazing', indicates the quantity of high-quality grazing land, and the circle labelled 'commercial forest' represents the quantity of land which will sustain commercial levels of tree growth. The outer ring of the diagram represents land which is not particularly suitable for any of the uses presented in the diagram.

Note that the agricultural circle is inside the other circles, indicating that all agricultural land is also suitable for grazing or commercial forest. Most of the land which is highly suitable for grazing is also suitable for commercial forest (the overlap of the grazing and forest circles), but there is considerable land that is suitable for commercial forest but not for grazing.

The patterned areas in Figure 4 represent present uses on lands of different suitability categories. It is seen that most of the land suitable for agriculture is already in use for agricultural crops (almost entirely sugar cane). Grazing dominates the scene outside agricultural lands. The land

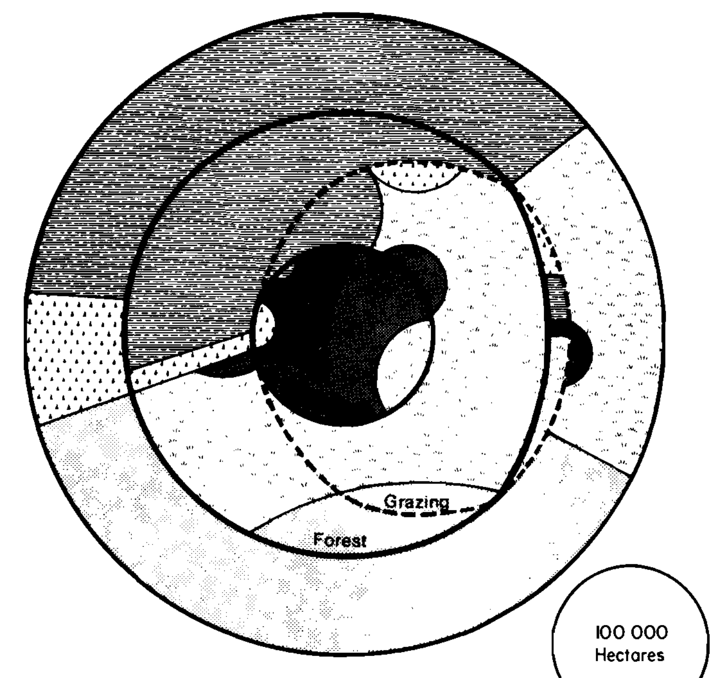

Figure 4. Diagrammatic presentation of the quantities of land of different suitability categories in different present uses.[a]

[a]The total area of the circle represents the total land area of the island of Hawaii.

suitable only for grazing is almost entirely in grazing use, and the land suitable for both commercial and grazing is also used primarily for grazing. Land suitable only for commercial forests is also used largely for grazing, even though it is marginal for grazing. As a consequence, most of the legally exploitable (ie non-reserve) forests are found on land which is not of commercial forest quality (the outer ring of the diagram).

The circle beside the diagram is for scale and represents 100000 hectares. If the energy farms were agricultural in style and therefore required land highly suitable for agriculture, 100000 hectares would occupy nearly all of the suitable land and displace nearly all of the existing agriculture. If the energy farms cannot displace existing agriculture, there is very little land available (the area in the inner circle which is not in agricultural use).

If silvicultural energy plantations are contemplated, the possibilities are much greater, lying anywhere within the circle labelled suitable for commercial forests. The 'reserve' land in that circle is not legally available for plantation use, but there are about 100000 hectares of land suitable only for commercial forest but now used for grazing. This land, which is marginal for grazing, might be best for establishing new silvicultural energy plantations with a minimum disruption to existing land uses.

For marginal land plantations, it is seen that there is considerable land available in the outer ring. As some of the land in the outer ring is too barren even for a marginal plantation, it would be necessary to draw a new suitability circle tailored to the needs of the marginal land crop under consideration.

With a diagram like Figure 4, one can visualize the scale of energy farms which can be established without serious displacement of other important land uses. Different diagrams can be prepared for different styles of energy farms, thereby allowing an evaluation of the land use implications of the different styles.

A biomass energy atlas

There is a need for inventories and summaries of the potential of biomass energy resources for both national and international energy planning. As we have seen, the biomass energy potential of an area cannot be represented by a single number. It depends on the kind of energy farm to be employed, the types of land in the area, the environmental consequences which can be tolerated, and the extent to which energy farms will be permitted to replace other forms of production from the land.

A compilation of the kind of information in Figures 1 to 4 into an energy atlas would be useful for energy planners and policy makers. It would not only assist in regional and national planning, but would also help to give an international picture of the potential of biomass energy and its implications for energy development policy.