Chapter 21
Remote Sensing and GIS Techniques for the Assessment of Biofuel and Biomass Energy Resources

Lalit Kumar and Anirudh Singh

Abstract The Pacific Island Countries (PICs) are faced with energy challenges arising from the lack of availability of fossil fuel sources in the region. Renewable energy has been identified as a primary means by which these challenges could be met. The successful utilization of renewable energy resources of the region will, however, depend on several factors. Among these are the availability of the relevant resources, and the political and legal framework, human capacity, and institutional mechanisms required to develop and implement renewable energy projects. Biomass and biofuels are two important resources available to many of the PICs. However, before these forms of renewable energy can be used, a necessary first step is the assessment of the availability of these resources, and the land area required to produce them. Remote sensing and GIS are two important techniques that can be employed for this purpose. In the technique of remote sensing, satellite imagery is used to quantitatively assess the biomass cover and available land area over large areas of a country. The information thus collected is conveniently stored in GIS systems which can be used for decision-making. This paper begins by showing why there is a need for a quantitative assessment of the biomass and biofuel resource potentials of the region before decisions about the use of such resources can be made. The techniques of remote sensing and GIS are then introduced, and examples of their potential application in the assessment of biomass and biofuel resources provided. The need for a biofuel resource assessment for Fiji is then considered in detail. Finally, recommendations are made for a biomass and biofuel assessment strategy for the Pacific region.

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Short Introduction

The Pacific Island Countries (PICs), as many other countries nowadays, are trying to replace the fossil fuel produced energy with renewable sources. In the lack of fossil fuel sources in the region, biomass and biofuels showed to be two important potential renewable resources available to many of the PICs. In this paper, the techniques of remote sensing and GIS are used in order to test their potential application in the assessment of biomass and biofuel resources provided. Analyzing the results, the final recommendations are made for a biomass and biofuel assessment strategy for the Pacific region.

Need for Biomass/Biofuel Resource Assessment

Biomass and biofuels are important renewable energy options for the PICs in their endeavor to reduce their dependence on imported fossil fuels. While biomass is used traditionally as cooking fuel, it also provides the feedstock for biogasification plants and biomass-fired thermal power plants. Biofuels can be used either directly, or after conversion to biodiesel, for transportation and power generation.

An assessment of the biomass and biofuel resources of a PIC is therefore an important pre-requisite to the development of an effective national energy strategy for the country. These resources are, however, determined by the geography and geology of the country. While the rich alluvial soils which are often characteristic of volcanic islands are capable of supporting a variety of biomass and vegetation providing feedstocks for biofuels, the same cannot be said of the coral atoll states.

As the geography of the PICs vary widely, ranging from volcanic islands such as PNG, Solomon Islands, Vanuatu, Fiji and Samoa to coral atolls such as Kiribati. RMI and Tuvalu, the potential within these states for these resources will vary. It is therefore necessary to carry out quantitative measurements to ascertain the extent of these resources in these countries (Fig. 21.1).

Two important biofuels that can be produced from indigenously-derived feedstock in the PICs are coconut oil and ethanol. The former is derived on commercial scales from coconut plantations. The latter can be obtained either from sugar or molasses produced from sugarcane plantations, or from root crops such as cassava. It is therefore of interest to determine the extent of the existing crops of such feedstock, and to assess the potential for expanding these stocks further.

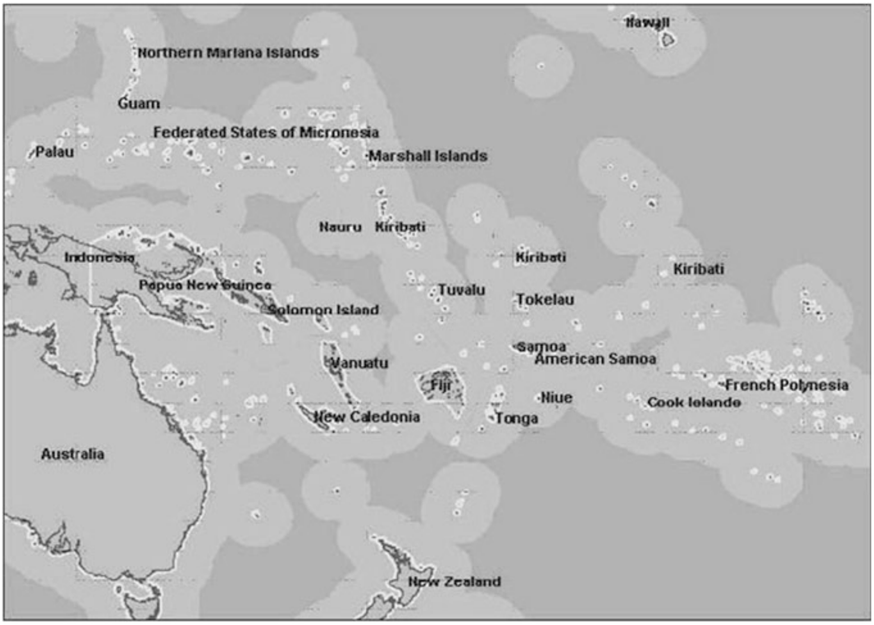

Fig. 21.1 Map of the Pacific, indicating the volcanic chain of islands to the West and the coral atoll nations to the North East

Some data for the quantities of these biofuel feedstock already exists (Key statistics 2011a, b; Krishna et al. 2009; Report on Fiji National Agricultural Census 2009) (Table 21.1).

However, additional information is needed for the further development of these resources. For instance, one requires an assessment of the land resources and their distribution. Further information needed to inform the process of the energy strategy development, includes

- How much land area is available for further biofuel feedstock development
- The suitability of such land for biofuel feedstock crops
- Other issues, including land availability and access.

Not all of such information is currently available. There is therefore a need to collect the additional data to better inform the biofuels development program for the region.

Table 21.1 Data on available or proposed biofuel feedstock crops in Fiji

Feedstock or crop	Land area (ha)	Volume harvested p.a.(t) (2010)
Sugarcane	45,000 (2010) [1]	132,000 [1]
Cassava	2,600 [2]	34,500 [2]
Coconut	15,000 (2009) [3]	4,977 (2009) [4]

Much of such data can be obtained through Remote Sensing (RS). This data can then be combined with the other forms of information mentioned above in the layers of Geographical Information System (GIS) models.

GIS and Remote Sensing Technologies

Introduction

Timely data at appropriate scales is critical for the management of natural resources. Remote Sensing provides the means to collect data at broad scales and at variable resolutions for input into GIS based models so that the satellite data can be integrated with other ancillary data for modelling purposes.

A thorough knowledge of the spatial distribution and quantity of resources is critical to any decision making process. In regions with limited resources, there is always competition between interested groups for the utilisation of such resources. In the Pacific Islands there is the added problem of the geographic spread of such resources and their accessibility.

Remote Sensing, which uses satellites or other airborne sensors is a technology that has made great strides in the last 20 years in terms of resolution and repeatability. There are many more satellites from which data can be obtained, and the spatial resolutions are much better than when the first environmental satellites were launched. The repeat cycles (i.e. number of days to repeat capture) have also improved greatly.

In areas with limited resources there is always competition between interested groups for food and resources. Timely data at appropriate scales is critical for conflict resolution and management of the resources. Remote Sensing (RS) provides the means to collect data at broad scales and at variable resolutions for input into GIS-based models so that the satellite data can be integrated with other ancillary data for modelling purposes.

Biomass Estimation

Methods of Biomass Estimation

In general, biomass includes both the aboveground and below-ground living mass, but due to the difficulty in field data collection of below-ground biomass, RS researchers mainly focus on aboveground biomass (Burton et al. 1991; Brown 1997; Drake et al. 2002).

Biomass can be measured using 3 different methods: (a) direct methods (destructive sampling), (b) indirect methods (tree measurements and models), and

(c) remote sensing approaches. To reduce the need of destructive sampling and develop a rapid and relatively accurate method, non-destructive approaches are usually used. Houghton et al. (2001) compared different estimation biomass methods in the Brazilian Amazon. The methods included three field measurements, two environmental gradients methods, and two remote sensing techniques. The results indicated that, among the 3 methods, the Olsen method (Olson et al. 1983) estimated the lowest and the Fearnside method (Fearnside 1997) the highest rank of total biomass, but they concluded that a combination of satellite data together with field measurement could have better results for above ground biomass.

A stand growth model, called the 3-PG (use of Physiological Principles in Predicting Growth), have been used in a number of studies. This model can calculate the total carbon from different factors such as solar radiation, temperature and rainfall and converts the carbon to total biomass (Landsberg and Waring 1997). Biomass can also be calculated by generalized biomass expansion factors (expanding the total stem volume to total biomass). The expansion factors vary depending on tree species, wood density, site fertility, and climate conditions (Lehtonen et al. 2004). Under fieldwork conditions, the diameter at breast height (DBH) and total height, are the most common variables for measuring biomass because of their estimation reliability (Popescu 2007). Some studies have shown correlation between tree height and stem diameter variables (Nilsson 1996).

Biomass Prediction with Remote Sensing Approaches

A number of studies have used the remote sensing techniques for estimating the aboveground biomass (De Jong et al. 2003a, b; Drake et al. 2003; Lefsky et al. 2001; Lefsky et al. 2005; Nelson et al. 1988; Roy and Ravan 1996; Strahler et al. 1986). Different approaches such as multiple regression analysis, neural network, and K nearest-neighbour have been used for estimating above ground biomass by remote sensing data (Nelson et al. 2000; Zheng et al. 2004).

The aboveground biomass mapping of the Mediterranean oak forest was done by De Jong et al. (2003a, b) by using digital airborne imaging spectrometer (DAIS7915), for collecting and analysing data; and spectral indices and multiple regression, for biomass prediction. The biomass map of the Wisconsin national forest was created by Zheng et al. (2004) by using various vegetation indices from Landsat 7 ETM+ and regression analyses. They concluded that forests stand age map, together with above ground biomass map, could help forest classification and further help to quantify carbon budget, to construct fire modelling and to determine fuel accumulation.

Jatropha: Yield Prediction with Remote Sensing and GIS

Many countries have established or are in the process of establishing Jatropha (*Jatropha curcus Linnaeus*) plantations as an alternative source of energy. The Fiji Department of Energy (FDoE) has a biofuel development program that will access the productivity of this crop as feedstock for Fiji's biofuel industry.

Jatropha has several advantages as an alternative energy crop:

1. it has a high yield content (Achten et al. 2008; Azam et al. 2005; Tiwari et al. 2007),
2. it is drought tolerant,
3. it requires only low levels of nutrients (Francis et al. 2005),
4. is highly adaptable to marginal lands (Francis et al. 2005) and
5. emits very low levels of greenhouse gases (Prueksakorn and Gheewala 2008).

The techniques of Remote Sensing and GIS can be used to obtain, store and analyse critical information on the viability of such crops over regions of the globe. Li et al. (2010) have used GIS to estimate the biological productivity and potential dry seed yield of Jatropha. They used a number of GIS layers to further classify yield according to levels of water and nutrient supply. To identify the spatial locations of future plantations, the yield levels were overlaid with global land cover types (data routinely generated from remote sensing). They then summed the potential area and production in each zone at the national, regional and global scales. The results are presented in Fig. 21.2.

Figure 21.3 shows the dry seed yield of Jatropha based on latitude, annual mean temperature and annual mean precipitation, found by the above workers. An

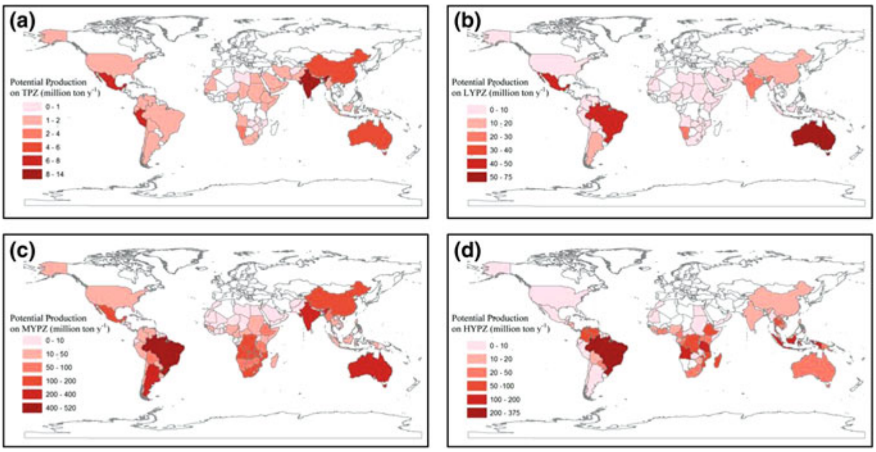

Fig. 21.2 Jatropha dry seed production potential at different zones at a national level. **a** Potential production on a tentative plantation zone. **b** Potential production on a low-yield plantation zone. **c** Potential production of a medium-yield plantation zone. **d** Potential production of a high-yield plantation zone (*Source* Li et al. 2010)

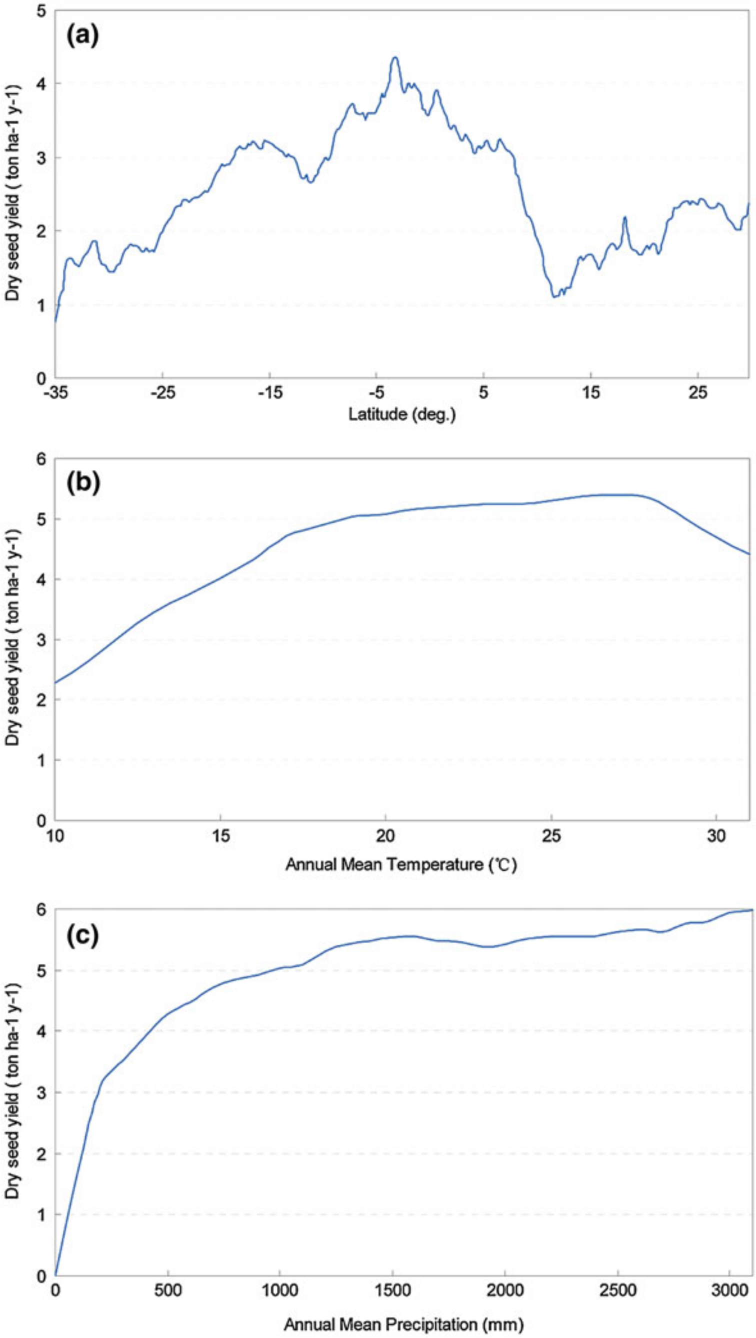

Fig. 21.3 Estimated *Jatropha* dry seed yield depending on the latitude (**a**), annual mean air temperature (**b**), and annual mean precipitation (**c**) (*Source* Li et al. 2010)

analysis of the location, temperature range and rainfall zones of the Pacific Island Countries shows that most of them would be ideal for Jatropha production. This however has to be linked to current land use and opportunities for conversion of this land for biomass plantations.

Assessing Fiji's Biofuel Resources

Introduction

Interest in biofuels as renewable energy alternatives to fossil fuels in the Pacific is currently confined to the r first generation biofuel feedstocks. These include sugarcane derived sugar and molasses, and cassava for the production of ethanol, and a range of existing or potential vegetable oils including coconut oil (CNO), jatropha, pongamia and castor oil for the production of biodiesel.

Ample data is available on the potential for producing ethanol from sugarcane-derived feedstocks. Information on sugarcane plantations and the tonnage of cane, sugar and molasses produced has been carefully maintained by the Fiji Sugar Corporation since the beginning of the industry nearly a hundred years ago. Summaries of such data is available from the Fiji Bureau of Statistics (Key statistics 2011a).

The annual national production of cassava (an ethanol feedstock) is also available (Key statistics Key Statistics 2011c). However there is little documentation of the location of the plantations and other details affecting the productivity of these farms.

While the sizes (areas) of CNO plantations as well as their productivity are known, there is a need to determine regions of plantations and scattered trees and road access to these. Information is also required on suitable land for further development of such plantations. In the case of new crops such as jatropha, a complete resource assessment will have to be undertaken starting from land availability, soil type and climatic conditions, as well as ownership and access issues.

Applcation of RS and GIS to Biofuel Resource Assessment

The techniques of remote sensing and GIS are useful devices for the assessment, storage and analysis of data on biofuel crops and a range of parameters that determine their productive yields. Table 21.2 exemplifies the utility of these techniques in the case of indigenous biofuel feedstock of the Pacific Island Countries (PICs).

Table 21.2 Application of RS and GIS to the determination and analysis of biofuel feedstock data

Feedstock	Location, terrain and land area	Soil type	Rainfall, temperature	Land ownership, road access
Ethanol feedstock				
Sugar	Known	Known	Known	Known
Cassava	New areas (RS)	(GIS)	(GIS)	(GIS)
Biodiesel feedstock				
Coconut	Area, no. of trees (RS)	GIS	GIS	GIS
New vegetable oil crops	RS	GIS	GIS	GIS

Sugarcane, which produces molasses as a feedstock for ethanol production, is only cultivated in Fiji and information on its production details is well documented by the Fiji Sugar Corporation. In the case of cassava, while summary data on the total amount of production is available for the whole region [Krishna], little is known about the geographical distribution of the plantations. In addition, no information is available on possible new areas where this crop could be grown. Remote Sensing will be instrumental in providing data for the further investigation of such new sites, while GIS provides a suitable technology for the storage and analysis of information on the soil types, rainfall, temperature and land ownership and road access details. Both these techniques can complement each other in the acquisition and analysis of data required for the production of new vegetable oil crops such as jatropha, pongamia and castor throughout the region.

Jatropha Cursis: Fiji Government Development Programme

The Fiji government has an ambitious programme for the trialing and cultivation of Jatropha as a potential feedstock for biodiesel production (Singh 2011).

The program will include the

- establishment of germplasm
- collection of promising progenies as future seed source
- establishment of nurseries for growing jatropha seedlings
- identification of suitable locations for jatropha plantations
- documentation of agri-techniques for the jatropha cultivation
- establishment of demo plots
- production of bodiesel, and the
- evaluation of the economics of the whole program.

The following data can be provided and managed through RS-GIS for this proposed program:

- Identification of suitable location, including terrain and soil types

- Rainfall data
- Road access and land ownership

The simple examples presented above illustrate the significant utility of RS-GIS techniques in the assessment of biofuel resources in the PICs.

A Strategy for Regional Biomass/Biofuel Resource Assessment

It is clear from the above examples that RS-GIS techniques can play a pivotal role in the resource analysis of existing or proposed biofuel crops in Fiji. A similar need exists for the rest of the region, as exemplified by the Samoan interest in biogasification (Ministry of Natural Resources, and Environment 2011), and the proposed use of CNO by the Tongan government in their energy roadmap (TERM 2011). A region-wide assessment of biomass and biofuel resources is thus in order.

A regional resource assessment strategy can use either a broad spectrum approach or a focused approach. In the former, a systematic assessment is carried out of all potential resources in all PICs, whereas in the focused approach, a selective assessment is considered, based on the stated requirements of the individual PICs. These requirements can be obtained from the individual National Energy Roadmaps of the PICs. If budget considerations are kept in mind, the latter approach is clearly a more viable alternative.

A suitable methodology will involve

- Determining the assessment requirements of each PIC through actual consultation
- Collecting initial data from individual lands departments
- Planning detailed satellite imagery based on the above information
- Looking for funding from, e.g. from regional development partners
- Preparing funding proposal (with, if possible, the involvement of trainee students), and
- Project implementation

Whatever the method adopted, the value of such a resource assessment to the development of energy policies in the region cannot be under-estimated.

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