BIOFUELS AND LAND USE: GLOBAL REQUIREMENTS AND LOCAL IMPACTS

by

Kieran Mark Findlater

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ABSTRACT

Citing the need for energy security, climate change mitigation, and support for farmer incomes, more than two-dozen countries have announced biofuel production or blending targets for ethanol and biodiesel. The Indian government is no exception, having enthusiastically adopted an oilseed-bearing shrub, *Jatropha curcas*, as a biodiesel feedstock. There is increasing concern in the scientific community about the potentially expansive land area required to meet such targets. While the carbon dioxide and energy balances of biofuels have been thoroughly examined using lifecycle assessment (LCA), the land-use impacts have received considerably less scrutiny. Studies that have estimated land use requirements have typically examined individual national targets on an ad-hoc basis, with widely varying assumptions.

To better understand the impacts of biofuel production on land use, I approach the issue on two scales. At the macro scale, I use a model to estimate the future land area that will be required to meet national biofuel targets, using a uniform methodology to examine the effect of future crop yield growth and co-product allocation. At the micro scale, I examine the specific local impacts that are anticipated to result from *Jatropha* biodiesel plantation development in rural Rajasthan, India. Researchers and policy-makers across the developing world have expressed a strong interest in following India's example, and rural Rajasthan makes for an excellent case study from which we can draw lessons applicable to other developing countries.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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KIERAN M. FINDLATER

The University of British Columbia
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CO-AUTHORSHIP STATEMENT

Both manuscripts were co-authored with my supervisor, Dr. Milind Kandlikar, while the first was also co-authored by my other supervisory committee member, Dr. Simon Donner. I identified and designed the research programs with input from my co-authors. I performed the research, analyzed the data, and drafted the manuscripts. I revised the manuscripts on the basis of discussions with my co-authors.

1 INTRODUCTION

Although liquid biofuels for transportation (i.e., ethanol and biodiesel) have existed for more than a century, recent volatility in oil prices, instability in major oil-producing regions, concern for climate change, and support for farmer incomes have combined to generate a dramatic surge in biofuel development in the first decade of the 21st century. Twenty-nine countries have announced ethanol or biodiesel targets, including the United States (US), the European Union (EU), China, India, Brazil, South Africa, and Australia – major economies from every continent (REN21, 2009). The United States alone has mandated the consumption of 136 billion litres of ethanol in retail gasoline by 2022 (EPA, 2009), while the European Union has asked that 10% of the energy in gasoline and diesel come from ethanol and biodiesel, respectively, by 2020. Additionally, many countries have publicly funded biofuel research and development programs, or have enacted subsidies and repealed fuel taxes for ethanol and biodiesel (REN21, 2009). Using an economic model, Searchinger et al. (2008) predict that US demand for maize in ethanol production will sharply increase demand for agricultural land, increasing crop prices and decreasing agricultural exports. Despite the best efforts of the research community, the land-use impacts of this biofuels surge are not yet well known. The potential contribution that biofuels can make to climate change mitigation and energy security has been critically examined using lifecycle assessment (LCA), but the land-use implications of this rapid development are still very uncertain.

To better understand the impacts that future biofuel production may have on land use, I approach the issue on two scales: macro and micro. At the macro scale, I use a model to estimate the future land area that will be required to meet the national biofuel targets, using a uniform methodology to examine the effect of future crop yield increases and co-product allocation. At the micro scale, I examine the specific local impacts that are anticipated to result from biodiesel plantation development in rural Rajasthan, India – an excellent study site from which we can draw lessons applicable to other developing countries. In Section 1.1, I provide an overview of the current state of biofuel research and development, as well as the justification for policies that now exist. In Section 1.2, I detail the specific biofuels context in India and provide a rationale for the importance of the example that it sets. I then discuss my research questions in more detail and describe my two-pronged approach to the impact of biofuels on land use (Section 1.3).

1.1 THE BIOFUEL CONTEXT

Biofuels may provide a crucial short- to mid-term contribution to climate change mitigation, but the significance of this contribution hinges primarily on three important factors: their energy ratios (outputs to inputs), lifecycle carbon dioxide equivalent (CO_{2e}) balances, and land-use impacts. The biofuel CO_{2e} balance depends heavily on how biofuel crop production initiates local, regional, and international land use change. The conversion of non-agricultural land (e.g., forests, permanently fallow agricultural land) to biofuel crop production can dramatically alter a fuel's lifecycle CO_{2e} balance (Fargione et al., 2008). The release of stored carbon from the soil and from the decomposition of cleared biomass (e.g., trees, shrubs, grasses) emits large volumes of CO_{2e} into the atmosphere. Non-agricultural land is both directly converted to biofuel crop production and converted indirectly through a cascade of crop-switching that forces lower-value crops onto ever more marginal land (Searchinger et al., 2008). At the global scale, this may decrease the effectiveness of biofuels in climate change-mitigation strategies. At the local scale, land-use change may negatively affect food security and rural livelihoods.

Concurrently, new technologies that enable increased feedstock production and more efficient crop-to-biofuel conversion may reduce land requirements per unit of output. The co-products of biofuel production processes may also replace other crops in animal feed, offsetting a portion of the biofuel land requirements and reducing the net land-use impact of the national targets. An integrated assessment of the role of co-product allocation and increasing crop yields in determining land-use change will help to clarify the contribution that biofuels can make to climate change mitigation.

In setting national targets, policy-makers touted ethanol and biodiesel as being carbon-neutral – emitting no net CO_2 – since their complete combustion simply releases the CO_2 that was absorbed by the crop during growth (Daschle et al., 2007). In the light of violent instability and potentially unfriendly political climates in major oil-producing regions (e.g., the Middle East, Nigeria, Venezuela), policy-makers were also convinced that domestically produced biofuels would contribute to energy security (DOE, 2006; Koh & Ghazoul, 2008).

To examine these assumptions, researchers use the LCA methodology to account for the inputs required and outputs created during the entire life cycle of the fuels. LCA can quantify the environmental impacts of economic activities in a comprehensive manner to help identify tradeoffs, enabling decision-makers to weigh the costs and benefits of alternative policies. Most biofuel LCA studies have focussed on the lifecycle CO_{2e} and energy balances to determine whether biofuels can effectively contribute to climate change mitigation and whether they actually produce more energy than they require in inputs. Farrell et al. (2006) and Pimentel & Patzek (2005), among many others, demonstrate that the early assumptions were optimistic in their predictions for both climate change mitigation and energy security (although they do not examine the implications of land-use change). For example, Farrell et al. (2006) estimate that the replacement of fossil fuels with biofuels will reduce CO_{2e} emissions by about 13%, but they indicate that published values vary from a 32% decrease to a 20% increase.

First-generation ethanol made from starch and sugar crops and biodiesel made from vegetable oil have therefore received less-favourable attention over time. The focus of research and development programs has expanded to include second-generation ethanol from cellulosic feedstocks (e.g., grasses, agricultural waste, and discarded biomass from forestry operations). But the combination of existing biofuel targets, entrenched support programs, and costly and uncertain cellulosic ethanol technologies has created substantial momentum for first-generation biofuels. Except for New Zealand, no national government has disbanded ethanol or biodiesel targets (REN21, 2009).

An examination of the existing literature makes it clear that land-use analyses have been integrated into biofuel research in a sparse and haphazard manner. The assumptions and methodologies vary significantly between studies, and most studies consider and compare only one or two feedstocks. Although Johnson et al. (2009) include a wide range of possible feedstocks in their calculation of potential regional biofuel production, they do not address the issue of co-product allocation. Only by including co-product allocation can we understand the net effect that biofuel crop expansion will have on the existing agricultural land area. If biofuel crops are grown in substantial areas of land that were previously used for other agricultural activities, national biofuel targets will either force the expansion of agricultural land into areas previously used in other activities (e.g., forested land or permanently fallow land) or will lessen the production of other crops.

1.2 THE INDIAN CONTEXT

Citing the need for energy security and rural development, the Indian government recently launched a major research and development programme to rapidly increase biodiesel production, targeting the 20% blending of biodiesel in fossil diesel by 2017 (REN21, 2009). The government has strongly promoted the adoption of *Jatropha curcas* – a hardy, fast-growing, oilseed-bearing shrub – as the primary feedstock (Planning Commission, 2003; Subramanian et al., 2005). *Jatropha* requires few inputs (e.g., irrigation, fertilizers) and can grow on agriculturally marginal or waste land. However, there is very little information about the oilseed yields under such conditions and the true availability of such land in India.

Previous studies of India's *Jatropha* production capacity have used decades-old definitions of marginal and waste land, based primarily on limited environmental parameters (e.g., precipitation, slope, soil nutrient levels) and taxation categories, which may not represent the primary factors determining land-use. Such land may, nonetheless, be under cultivation for subsistence food production, forage production, or small-scale cash-cropping (Barnwal & Sharma, 2004). While there has been significant research into the impacts of intensified biofuel crop production in industrialised countries (e.g., increased use of chemical inputs and water (Hill et al., 2006)), there has not been sufficient research into similar impacts resulting from the widespread commercial-scale adoption of biofuel crops in rapidly industrialising countries. *Jatropha* has never been grown as a commercial crop anywhere in the world, and there are many uncertainties related to the variability of its yield and the plant's long-term response to conditions of drought and poor soil fertility (Achten et al., 2008).

Although India is a world leader in *Jatropha* plantation development, the plant's potential contribution to energy security and rural development has drawn very strong interest from many other developing countries in Southeast Asia, Africa, and South America (e.g., Lapola et al., 2009; Salé & Dewes, 2009; Ye et al., 2009). Thorough research must be conducted now to ensure that the projected growth of this nascent industry is sustainable in both socioeconomic and environmental terms.

1.3 APPROACH

The impacts of biofuels cultivation on land use will greatly affect their environmental sustainability, energy security implications, and socioeconomic benefits. We need a better understanding of the net land requirements of large-scale biofuel programs to better estimate the land-use change, the effect on crop prices, and the reduction of other crop production that may result. This requires that we allocate a portion of the biofuel land requirements to the co-products that are likely to offset land use by reducing the demand for animal feed crops. In parallel, we have a poor understanding of the local land-use change that may occur in developing countries where biofuel crops are promoted for rural poverty alleviation. The strong push towards biofuels, coupled with research suggesting that early outcomes (e.g., energy gain, CO_{2e} reductions) are not meeting expectations (Herrerra, 2006), requires that we thoroughly examine the implications of national targets to inform future policy-making. Land-use change is a critical component of biofuel sustainability, greatly influencing climate change mitigation potential, energy security, and benefits for the rural poor.

I approach the question of land-use change using two different methods. At the macro level, I examine the potential impact of biofuel targets by estimating their future land use requirements (see Chapter 2). I use a model to calculate the future biofuel land requirements, using regional energy demand projections, current demand data, GDP data, and crop yield data. I estimate crop yield growth using three scenarios and allocate land use to the biofuel co-products using four methods. I then calculate the future land use requirements using 24 possible feedstocks (biofuel crops), identifying the crops that are most likely to contribute to the biofuel targets on the basis of their impact on land use. In considering co-product allocation in detail and applying a consistent methodology across all feedstocks and all countries, I provide an assessment of the land-use implications of national targets.

While the macro analysis provides an important assessment at the national and global scales, it does not give us a detailed sense of the specific local impacts that will occur as biofuel crop production area is expanded in the next decade. At the micro level, I examine the impact of rapid biodiesel plantation development on rural livelihoods and land use in India (see Chapter 3). I interview local stakeholders in rural Rajasthan to identify the land use that has been displaced by *Jatropha* plantation development, and the potential present and future impacts of the planting activities.

Our study site in rural Rajasthan has a semi-arid climate and suffers from a high level of poverty. *Jatropha* grows naturally in this area; villagers have long used the plant to fence their fields and gathered the seeds to make soap. The relative abundance of dry wasteland and wild *Jatropha* plants has created a plantation boom in rural Rajasthan (Leduc et al., 2009). The level of *Jatropha* plantation activities has reportedly been greater in rural Rajasthan than in any other part of India, and India has pushed *Jatropha* development more strongly than any country in the world. These factors make Rajasthan an excellent case with which to gauge the plant's potential impact on rural livelihoods and land use. I expect that the lessons learned here will be broadly applicable to the study of biofuel-driven land use change in other developing-country contexts, and may provide insight for decision-makers when weighing the costs and benefits of *Jatropha* development. The results of the local study will therefore provide context for the national targets and global surge in biofuel production. The local context therefore enriches the global analysis, and vice versa.

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2 NATIONAL BIOFUEL TARGETS AND LAND USE [1]

2.1 INTRODUCTION

The rapid expansion of the biofuels industry (i.e., biodiesel and ethanol) has been driven by the volatile price of crude oil and the potential for climate change mitigation, as well as the subsequent government subsidies and mandates. Citing the need for energy security, climate change mitigation, and support for farmer incomes, more than two dozen countries have announced biofuel production or blending targets for the inclusion of ethanol and biodiesel in retail gasoline and diesel fuel, respectively (REN21, 2009). There is increasing concern in the scientific community about the potentially expansive land area required to meet such targets. For instance, recent studies have suggested that land conversion may have a large impact on the lifecycle carbon dioxide equivalent (CO_{2e}) balances for biofuels, by releasing stored carbon from the decay of aboveground biomass and soil organic carbon (Fargione et al., 2008; Searchinger et al., 2008). Although there has been some recent progress in the calculation of regionally specific per-hectare biofuel yields (Johnson et al., 2009), the issue of land use vis-à-vis biofuels has not received systematic attention. Studies have typically estimated land use requirements for biofuels using individual national targets on an ad-hoc basis, with widely varying assumptions (Kendall & Chang, 2009). In particular, the projected future fuel requirements for each country and the method by which a portion of the land area is allocated to the co-products of the production process have both created widely variable results between studies and among countries (Croezen & Brouwer, 2008).

In this study, we conduct a global assessment of the land area required to meet national biofuel targets. We develop a model to calculate the land area required to meet the biofuel targets of 28 countries, as well as the European Union (EU), using a uniform methodology. The model, described in Section 2.2, evaluates the land requirements by making assumptions about two key uncertainties: future crop yield growth and co-product allocation. The co-products of the biofuel production process may offset land used for other purposes; primarily, the production of animal feed. In each country, we compare the projected biofuel land requirements to the current crop

[1] A version of this chapter will be submitted for publication. Findlater K M, Kandlikar M and Donner S D National biofuel targets and land use.

production area for the biofuel crops and the total arable land area (Section 2.3). We conclude with an assessment of the relative capacity of each country to satisfy its own biofuel demand, the associated land-use estimates, and the impact that this may have on the use of the co-products (Section 2.4).

2.2 METHODS

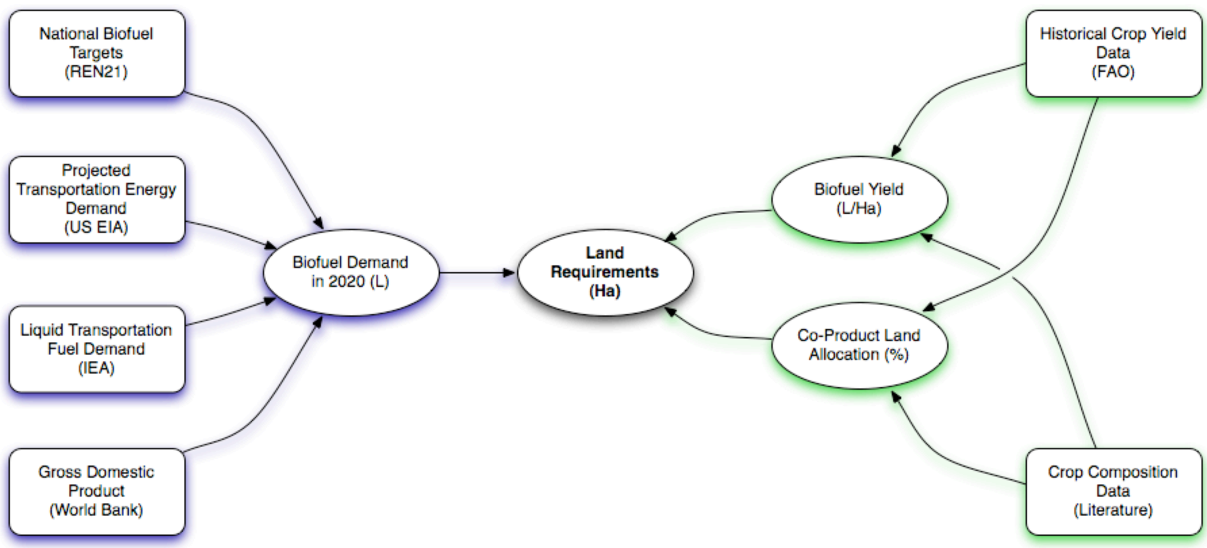

Figure 2.1: A simplified representation of the model used to calculate future biofuel land requirements (data sources indicated where applicable).

The model shown in Figure 2.1 has three key components, all at the national level: the estimate of biofuel demand; the estimation of future crop yields; and the evaluation of co-product land allocation.

Biofuel demand: Regional energy demand projections from the United States Energy Information Administration (US EIA) are used to calculate the future business-as-usual (BAU) fuel demand for each country, in conjunction with data on the current relative gasoline and diesel demand from the International Energy Administration (IEA) and current gross domestic product data from the World Bank (detailed in Section 2.2.2). The blending level targets (Section 2.2.1) are converted to absolute biofuel demand using the BAU gasoline and diesel demand in 2020 and the heating value of each fuel.

Crop yields: We use historical crop yield data from the Food and Agriculture Organization (FAO) to create future yield scenarios, based on past yield improvements (detailed in Section 2.2.3). We calculate the crop-to-biofuel conversion factors using crop composition data from the FAO and other literature (Section 2.2.4). We use the estimates of national biofuel demand, in litres, to evaluate the land required to meet each target, based on local projected crop yields.

Co-product allocation: Using four different methods, we allocate a portion of the land requirements to the land-intensive co-products of the biofuel production process (Section 2.2.5). Finally, the projected biofuel land requirements are compared with the land area currently under cultivation for each crop, as well as the country's total arable land.

We limit our land-use analysis to first-generation feedstocks (biofuel crops): starchy grains, starchy tubers, sugar crops, and oilseeds. Since they are common agricultural commodities, they directly compete with other food and non-food crops for prime agricultural land. We exclude cellulosic ethanol from this analysis because its medium-term viability is highly uncertain. Some countries have gone so far as to officially include cellulosic ethanol in their biofuel strategies (REN21, 2009), but at present, it does not seem that cellulosic ethanol will substantially contribute to ethanol production by 2020. Although pilot plants now exist, current economic and technical constraints make widespread adoption by 2020 unlikely (Carroll & Somerville, 2009; Pimentel, 2009).

For similar reasons, we do not consider *Jatropha curcas*, a feedstock that has garnered substantial interest from governments in Southeast Asia, South America, and Africa (e.g., Lapola et al., 2009; Salé & Dewes, 2009; Ye et al., 2009). Although it has considerable theoretical potential (Openshaw, 2000) and the conversion process is very similar to other oilseeds, current yields are low and it is only grown in very limited areas. Additionally, the high level of uncertainty in optimal crop management techniques and future technology improvements make it unlikely that this feedstock will substantially contribute to global biodiesel production by 2020 (Achten et al., 2008; King et al., 2009).

We do not presently account for international trade, since our purpose is to examine the capacity of individual countries to achieve their own biofuel, energy security, and rural development objectives. On the other hand, our model helps to understand the trade implications of these targets. Countries with low yields or ambitious targets requiring a substantial proportion of arable land are more likely to import biofuels, whereas countries that have a high production potential and low national targets may become biofuel exporters.

2.2.1 National targets

Twenty-eight national governments, as well as the EU, have announced target levels for the inclusion of biofuels in transportation fuel (REN21, 2009). Although many sub-national governments have also announced targets, these are excluded from the study. Most national targets are percentage-blending levels by volume (e.g., Canada), while a few are absolute production targets (e.g., Australia) or percentage-blending levels by energy content (e.g., the EU). All national targets are to be implemented by 2020, aside from that of the US (to be reached in 2022). Although several governments have publicly revisited their commitment to high biofuel targets (e.g., the EU), only New Zealand has withdrawn its commitment (REN21, 2009).

Although Germany, Italy, and the United Kingdom are included in the EU target, they also appear separately, since they have their own national targets. Not all countries have targets for both ethanol and biodiesel; a few are limited to one or the other. For instance, Australia and China have only ethanol targets, while South Korea and Malaysia have only biodiesel targets.

2.2.2 Fuel demand

We convert all of the biofuel targets to absolute production volumes, as a proportion of the projected BAU fossil fuel demand in 2020. Fuel demand data are derived from projections made at five-year intervals (2010-2030) by the US EIA, in quadrillion Btu of liquid transportation energy. While nine countries have individual projections (the US, Canada, Mexico, Japan, South Korea, Russia, China, India, and Brazil) (EIA, 2009), projections for others are made on a regional basis. For such countries we assume that the transportation energy demand (as a percentage of regional demand) matches the size of the country's GDP relative to the region's cumulative GDP, as reported by the World Bank (2006).[2] We therefore assume that the size of a country's GDP will not substantially change relative to the regional GDP, by 2020.

To calculate the future BAU[3] demand for gasoline and diesel (a portion of which will constitute the biofuel blending level) we calculate the current demand for these fuels as a proportion of current total liquid transportation fuel demand using country-level data from the IEA (2008). We assume that the proportional demand for different fuel types will not change significantly by 2020, since this would require a sizable shift in the vehicle fleet in each country. For countries with blending targets, the projected demand for ethanol and biodiesel is then simply a percentage of the BAU gasoline or diesel demand, either by volume or by energy.

2.2.3 Crop yield

We calculate the future growth in crop yields by examining historical yield trends for each crop in the each country. World average crop yields have grown significantly over the past 50 years, and we assume that yield growth will continue until 2020. To account for inter-annual yield variability, we use five-year averages to calculate present and historical yields, as well as rate of yield increase. We use crop yield trends for the past decade (for each crop and for each country) to estimate yields in 2020. Recent trends are very different from the longer-term historical trends. Low-yielding countries that have experienced high rates of increase over the past decade, because of improved crop management and agricultural extension, may show substantially lower annual rates of increase since 1961 (the first year for which the FAO has data). Additionally, there are differences in the rate of yield improvement between crops, and these differences have changed over time. Some crops have seen substantial improvement in recent years, while others have stagnated. A longer-term average would obscure these differences. With all of this variation in mind, no yield scenario is perfectly applicable across all feedstocks and all countries, and the appropriate scenario therefore depends on the country and crop.

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[2] A small number of countries were not included in the regional cumulative GDP calculations, as the World Bank does not provide GDP estimates for certain economies (e.g., Iraq and Cuba).

[3] In this study, the BAU case is simply the projected total gasoline and diesel demand in the absence of any ethanol and biodiesel blending (i.e., at a 0% blending level). The calculation of the current-day baseline includes ethanol in gasoline and biodiesel in diesel fuel.

We use three yield-growth scenarios to determine crop yield in 2020:

Scenario YI: An individual annual rate of yield increase is calculated for each crop and each country. Where the annual rate of increase was negative, the rate is set to zero, since we assume that, at worst, yields will not increase. This captures all of the variation between crops and among countries, but may extend unsustainable rates of increase, especially for countries that have recently seen sharp yield improvements. In this scenario, the yield hierarchy is not fixed. Countries and crops may overtake each other for reasons that are implicit in the historical data.

Scenario YII: An individual annual rate of yield increase is calculated for each crop across all countries (i.e., the world average). Where the annual rate of increase was negative, the rate is set to zero, as in Scenario YI. This captures the variation between crops, but not between countries.

Scenario YIII: An individual annual rate of yield increase is calculated for each crop. Additionally, countries with low starting yields are given a boost, by doubling their rate of increase. There is also a minimum rate of increase, matching the world average across all crops and all countries. As in Scenario YII, this captures the variation between crops, but also allows for low-yielding countries to catch up to high-yielding countries over time.

The crop yield data for the biofuel feedstocks are drawn from the FAO's ProdSTAT database (FAO, 2009), which includes country-level data on production (kg), cropping area (ha), and crop yield per hectare (kg/ha). Although Kim et al. (2004) found some discrepancies between FAO data and the data available on government websites for some countries, they concluded that ProdSTAT is the only comprehensive and global database available, using a common approach to estimate crop yields.

2.2.4 Conversion to biofuels and co-products

Starch and sugar crops are converted to ethanol using yeast fermentation, while biodiesel is made from vegetable oil by chemical reaction (transesterification) (see Table 2.1 and Table 2.2 for a list of the ethanol and biodiesel feedstocks, respectively). We calculate the theoretical biofuel and co-product yields from each crop based on its average composition and apply efficiency factors to adjust for imperfect, real-world conditions. We do not account for possible variations in crop quality between countries. This may be of consideration in future studies, but reasonable crop quality datasets do not currently exist.

Ethanol and its co-products

Aside from maize and sugarcane – and to a lesser extent, wheat and sugar beet – ethanol and co-product yields have not been well established on a commercial scale. For starchy feedstocks (grains and starchy tubers), we calculate the theoretical maximum ethanol yield based on the starch content of the crop. We then apply a conversion efficiency factor (90%) to account for wasted and incomplete conversion. The resulting ethanol yields are slightly higher than those reported by modern ethanol plants, since we assume that the conversion efficiency will improve slightly over time as production techniques are refined (e.g., Roehr, 2001; Shapouri et al., 2002; Thomas & Ingledew, 1995; Zhang et al., 2003).

The major co-product of starch ethanol production – Dried Distiller's Grains and Solubles (DDGS) – is the combined portion left over after the dry milling and fermentation of the feedstock, when the residues have been dried (Stock et al., 2000). The mass and composition of the DDGS co-product are primarily determined by the non-starch composition of the feedstock, with a smaller contribution from the yeast fermentation process. We therefore estimate the feedstock-to-DDGS conversion factors and the DDGS compositions from the feedstock compositions. We then apply an efficiency factor to account for waste (10% loss), resulting in co-product yields and compositions that closely match those reported in the literature (FAO, 2004; NRC, 1981; NRC, 2007; Zhang et al., 2003).

In contrast, the ethanol and co-product conversion factors for sugar beet and sugarcane are drawn from the literature (Goldemberg & Moreira, 1999; Shapouri & Salassi, 2006), since they are well known, and the production process differs from that of starch ethanol (see Table 2.1 for projected world average ethanol yields per hectare).

Biodiesel and its co-products

The feedstock-to-biodiesel conversion factors are calculated from the reported oil content of each feedstock. The crop-to-oil yield and the co-product mass were drawn from the FAO's Technical Conversion Factors for Agricultural Commodities (FAO, 2000), which reports world average extraction efficiencies (see Table 2.2 for projected world average biodiesel yields per hectare). An oil-to-biodiesel conversion factor, as reported by Demirbas (2005), is used to estimate the biodiesel yield from vegetable oil during the transesterification process. Since the biodiesel crops have long been grown for oil, the compositions of the oilcake co-products are well known and were drawn from the literature (e.g., NRC, 2007).

2.2.5 Co-product allocation

The co-products of biofuel production (e.g., agricultural waste, products of ethanol fermentation, glycerine from the transesterification of biodiesel) may have value in other applications, and must therefore be allocated a share of the inputs and outputs of the production process. Co-product allocation is a contentious issue, since it has more impact on the outcome of lifecycle assessment (LCA) than any other single parameter (CHEMINFO, 2008; Halleux et al., 2008; Hill et al., 2006; RFA, 2008). For instance, biomass waste from the production of sugarcane is burned to generate heat and power for the sugarcane ethanol production process, reducing the need for fossil fuels and improving sugarcane's lifecycle CO_{2e} and energy balances (Croezen & Brouwer, 2008).

Co-product allocation has been examined at length in lifecycle energy and CO_{2e} analyses for biofuels, but it has not been as thoroughly explored in land use estimates (e.g., Johnson et al., 2009). There are three standard methods for co-product allocation: by mass, by economic value, and by displacement of another, similar product. Allocation by mass simply assigns a share of the inputs and outputs to the co-product on the basis of the co-product's mass relative to the total mass of all products. If the oilcake from biodiesel production were the same mass as the biodiesel produced, each would be allocated half of the inputs. This method has an obvious and serious drawback, since it does not account for the utility of the co-product.

Allocation by economic value assumes that the value of the co-product will determine the area of land that it will offset. The animal feed crops that will be displaced by biofuel co-products are directly competing for the land on which the biofuel crops are grown, so the use of economic allocation requires an economic model for future co-product value, as influenced both by global markets and by the rise in biofuel production itself. Instead, the International Organization for Standardization (ISO) recommends the use of the displacement method, when viable, in their guidelines for LCA (ISO 14040) (ISO, 2006). Using this method, we allocate a share of land use to the co-products by displacing an existing, equivalent product that has known land-use requirements.

Ethanol can be produced from starch feedstocks by either wet-milling or dry-milling, creating different co-products. For maize, the major co-product of the dry-milling process is Dried Distiller's Grains with Solubles (DDGS), whereas wet-milling produces corn oil, corn gluten meal, and gluten feed (Shapouri et al., 2002). Dry-milling has played a central role in maize ethanol expansion in the US, and DDGS from maize has become a major animal feed additive (Mathews & McConnell, 2009). The feeding value of maize DDGS has been well established in the literature, while the feeding value of DDGS from wheat and sorghum has also been examined in a number of studies (Stock et al., 2000). We therefore assume that all of the starch feedstocks are dry-milled.

Sugar beet ethanol production generates pulps and slops, which can be dried and sold as animal feed, while sugarcane ethanol production does not generate animal feed co-products (Croezen & Brouwer, 2008). We therefore assume that the primary co-products of ethanol production from grains and tubers are palatable, and can be included, on average, in animal feed.

During biodiesel production, oilcake is the remaining portion after the oil has been extracted from the biodiesel feedstock (e.g., soymeal from soybeans). While toxic oilcakes are currently used as fertilizer rather than feed (e.g., castor oil seed cake), research is underway to develop methods to detoxify them (Singh & Pandey, 2009). To simplify the allocation process and allow for innovation, we assume that, by 2020, all oilcakes can be detoxified and are used as animal feed. If this assumption proves unrealistic, we can simply refer to the land-use requirements presented without co-product allocation.

Other co-products of biofuel production, such as agricultural wastes, are used primarily as fertilizer or to generate heat and power for the biofuel production process. This electricity would otherwise be generated from fossil fuels or renewable energy – drawn from the grid or generated locally – and does not directly and definitively affect agricultural land use. We therefore limit the scope of the analysis to exclude land allocation for such co-products. Sugarcane, therefore, benefits from no co-product allocation in any scenario, since none of its co-products are primarily used in animal feed (Croezen & Brouwer, 2008).

We assume that all animal feed co-products will be consumed, rather than wasted. This requires that the global animal feed market be large enough to absorb the co-products from new biofuel production. This is the best-case scenario for land use, since some co-product may be wasted as the price drops due to increasing supply (Croezen & Brouwer, 2008). Using this assumption, we can identify the ceiling for co-product allocation.

Co-product allocation scenarios

In addition to the calculation of land use without co-product allocation (Scenario A0), four allocation scenarios (A1 through A4) are used to explore the range of possible outcomes. All of these scenarios use the displacement of animal feed to allocate land use to the major co-products. In each case, the per-hectare yield of the displaced animal feed crop greatly influences the co-product allocation. Therefore, each allocation scenario requires that we make assumptions about the source of the displaced feed crops (Sub-scenarios a, b, and c):

> **(Sub-scenario a) US yields:** The biofuel co-products displace animal feed crops grown in the US. The US is the world's largest exporter of maize and

soybeans (FAO, 2009), and therefore has a disproportionate impact on the land area required for production of the world's animal feed.

(Sub-scenario b) Local yields: The biofuel co-products displace animal feed crops grown locally. If most animal feed within a given country is produced and consumed locally, then it is likely that biofuel co-products that displace animal feed will also be consumed locally. This implies that the country's animal feed market is not well connected to global feed markets.

(Sub-scenario c) World average yields: The biofuel co-products displace animal feed crops on the global market. The use of international yields gives a better representation of the global nature of modern animal feed markets.

Scenario A1: Displacement of maize in animal feed, by protein content

The biofuel co-products displace maize in animal feed, on the basis of their relative protein contents. We multiply the co-product's yield per hectare by its protein content to calculate the protein yield per hectare. We then divide this by the protein content of maize to determine the displaced mass of maize, and divide by the per-hectare yield for maize (either local, US, or world average yields) to calculate the crop land area that is offset by the co-product's use in animal feed.

Scenario A2: Displacement of soymeal in animal feed, by protein content

The biofuel co-products displace soymeal on the basis of their relative protein contents, in similar fashion to A1. Since both soymeal and soy oil are valuable soybean products (USDA, 2008a), we must first allocate a portion of soybean land to each, so that we can use soymeal as the basis for further co-product allocations. Following the ISO guidelines described above, we use economic value for this allocation, based on USDA soybean market forecasts to 2017 (USDA, 2008a).

Scenario A3: Displacement of a representative mixture of animal feed crops, by mass

We displace a representative sample of animal feed crops, by mass, with the biofuel co-products. The relative contribution of different feed crops to this sample is calculated from USDA data on US and international animal feed crop consumption (USDA, 2008b). This method does not account for the specific nutritional values of the co-products. Instead, it assumes an average one-to-one displacement, by mass.

This method sidesteps the contentious issue of feeding values, for which only maize DDGS and soymeal have been well studied. It is therefore more suitable for co-products for which the feeding values have not been well established. While soymeal and maize DDGS are already widely used in animal feed, most other co-products – especially those of ethanol (e.g., cassava or wheat DDGS) – do not have long histories as animal feed ingredients.

Scenario A4: Displacement of maize, using a ratio of DDGS to maize calculated by the USDA

The USDA has conducted extensive studies on the feeding value of DDGS to facilitate the integration of growing quantities of maize DDGS into US animal feed (USDA, 2006). According to their estimates, maize DDGS will displace an amount of maize equivalent to one fifth of that used in ethanol production. Therefore, if ethanol production creates 0.343 kg of DDGS per kg of maize input, 1 kg of DDGS will displace 0.583 kg of maize. Since this ratio was specifically designed for maize DDGS, we have only applied it to other feedstocks that produce DDGS as a co-product. This includes all ethanol feedstocks except for sugar beet and sugarcane.

2.3 ANALYSIS & RESULTS

2.3.1 Crop yield scenarios

In Scenario YI, some countries have 10-year average annual yield increases of as much as 25%. Low-yielding countries that have experienced substantial yield improvements in recent years are allowed to carry this momentum forward, and high-yielding countries with stagnant yields remain as such. For example, Vietnam and the Dominican Republic experience rapid crop yield growth by 2020, overtaking more established high-yielding countries (see Figure 2.2).

In Scenario YII, for some crops, average yields have been stagnant over the past ten years. Low-yielding countries remain stagnant, relative to high-yielding countries, and fall further and further behind, in terms of the absolute differences in yields.

In Scenario YIII, the annual rate of yield increase is calculated from the world average yields for each crop, with a higher rate of increase for low-yielding countries. This scenario results in higher average yields than Scenarios YI and YII, because the minimum annual increase is set at 1.15% across all crops and all countries.

2.3.2 Co-product allocation scenarios

Since the crop yields, co-product mass, and co-production composition vary, no allocation scenario is applicable across all feedstocks and countries. It is particularly difficult to apply the same scenario to both ethanol and biodiesel co-products, or to the co-products of different categories of ethanol feedstock (i.e., grain, starchy tuber, and sugar crops).

Except for Scenario A2, at least a few co-products in each scenario are allocated more than 100% of the land used to grow the biofuel crop. This is generally due to high feedstock crop yield relative to the crop yield of the displaced animal feed. For example, potato has a very high yield (in kg/ha) compared to maize, giving potato a very high co-product allocation in Scenario A1. As shown in Figure 2.2, the allocation sub-scenarios have a substantial impact on the outcome.

Sub-scenario (a): Displacement using US animal feed crop yields

The US has relatively high crop yields, which minimize the instances of co-product allocations in excess of 100%. This sub-scenario generates lower co-product allocations, on average, than the other sub-scenarios.

Sub-scenario (b): Displacement using local animal feed crop yields

Some countries do not have local maize and soybean yields to use in this calculation, while others have yield data, but have very low production areas for maize and soybeans, making their local displacement very unlikely. Both of these factors limit the utility of this sub-scenario, since scenarios A1, A2, and A4 depend on maize and soybeans, while this sub-scenario does not apply to A3. This sub-scenario generates substantially higher co-product allocations, on average, than when using US yields (a) and slightly higher allocations than when using world average yields (c).

Sub-scenario (c): Displacement using world average animal feed crop yields

World average yields are lower than US yields, and this sub-scenario therefore generates more instances of co-product allocations exceeding 100%. This sub-scenario creates significantly higher co-product allocations than when using US yields (a) and slightly lower allocations than when using local yields (b).

Scenario A1: Displacement of maize in animal feed, by protein content

Maize is relatively low in protein, and highly variable in crop yield between countries (1100–11000 kg/ha in the countries under consideration). Since DDGS and oilcake are relatively high in protein, maize's low protein content creates high co-product allocations. In contrast, the relatively high maize yield in some countries (e.g., the US) lowers the co-product allocation. Overall, this method creates a much higher co-product allocation than any other allocation scenario (twice as high, on average).

Scenario A2: Displacement of soymeal in animal feed, by protein content

Soymeal is relatively high in protein, but low in per-hectare yield. Therefore, this scenario generates lower co-product allocations than A1 or A3. The initial land allocation for soymeal reduces biofuel co-product allocations even further, since the yield of soymeal per allocated hectare is greater than its actual yield per hectare.

Figure 2.2: Average biofuel yield across all potential feedstocks, by yield scenario, for selected countries

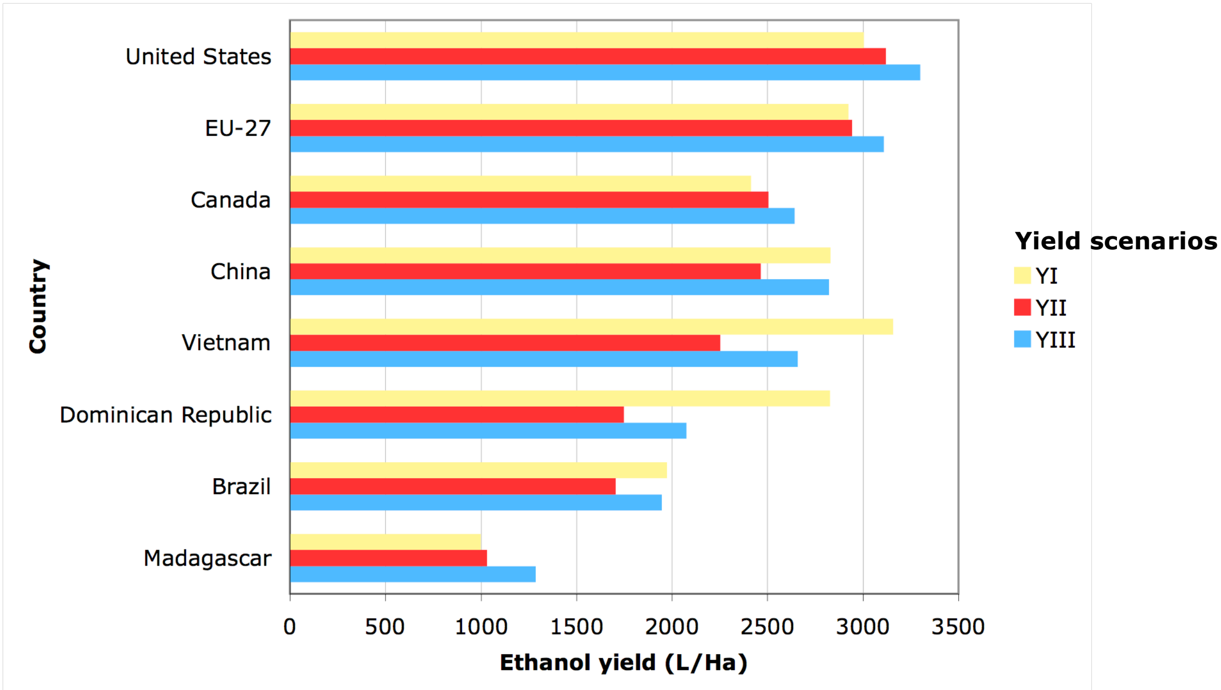

Figure 2.3: Proportion of biofuel crop area allocated to the co-products in each allocation scenario, averaged across all feedstocks, all countries and all yield scenarios

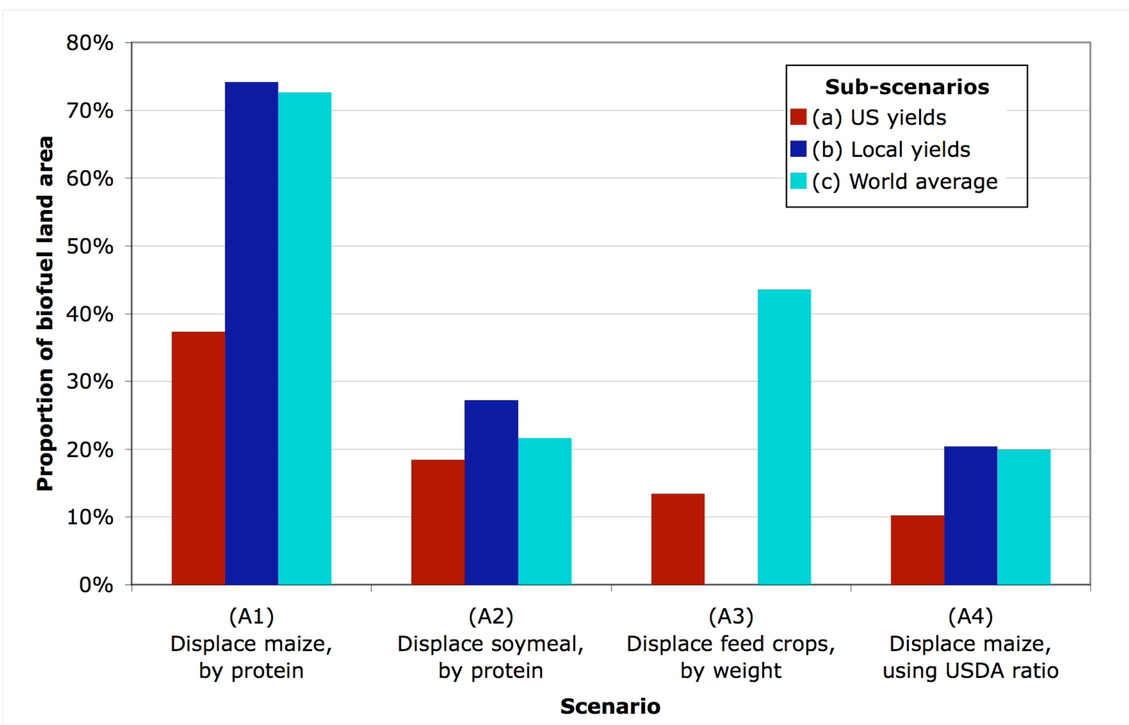

Table 2.1: World average ethanol yields per hectare in 2006 and 2020, using world average annual yield increases (Scenario YII)

Feedstock	Ethanol yield in 2006 (L/ha)	Ethanol yield in 2020 (L/ha)
Barley	900	1030
Cassava	1820	2210
Maize	1920	2500
Oats	610	750
Potato	1790	1920
Rice	1320	1520
Rye	850	930
Sorghum	540	540
Sugar beet	4580	6650
Sugarcane	5380	5930
Sweet potato	1470	1470
Triticale	1330	1330
Wheat	1090	1250

Table 2.2: World average biodiesel yields per hectare in 2006 and 2020, using world average annual yield increases (Scenario YII)

Feedstock	Biodiesel yield in 2006 (L/ha)	Biodiesel yield in 2020 (L/ha)
Castor oil seed	390	400
Coconut	730	910
Cottonseed	210	290
Groundnut	510	660
Linseed	330	430
Mustard seed	290	320
Oil palm fruit	3190	4330
Rapeseed	700	940
Sesame seed	210	280
Soybeans	450	520
Sunflower seed	560	610

Based on the predicted prices in 2017, soymeal is allocated 58% of the land on which soybeans are grown, while soy oil is allocated the remainder. Using the present-day relative prices for soymeal and soy oil only reduces this allocation by 1%. In comparison, if we calculate the allocation on the basis of relative mass alone – the least-recommended method in the ISO guidelines – soymeal is allocated 81% of soybean land (increasing subsequent co-product allocations).

Since Scenarios A1 and A2 are both done on the basis of the co-product's protein content, we can compare their relative impacts by examining the protein yield (kg/ha) of maize and soymeal. In the US, maize has a slightly lower protein yield per hectare than soymeal – 720 kg/ha compared with 950 kg/ha (76% of soymeal protein yield). This simply means that the fraction of land allocated to the co-product will be slightly higher in the case of maize displacement, since it takes a greater area of land to grow the maize protein displaced by the co-product than it does to grow the soymeal protein.

Using world average crop yields, the per-hectare yield of maize protein is even lower relative to soymeal protein – 370 kg/ha compared with 810 kg/ha (46% of soymeal protein yield). In both cases, soymeal has an even higher protein yield per allocated hectare after taking into account the initial co-product allocation detailed above.

Scenario A3: Displacement of a representative mixture of animal feed crops, by mass

This method may either underestimate or overestimate the co-product allocation, depending on the relative nutritional values of the co-products with respect to the representative feed crops. It does not work well for feedstocks that produce a large amount of co-product with low nutritional value. For example, sugar beet's co-product allocation becomes 140% of land area, averaged across all yield scenarios, and exceeds 200% in some cases. Cassava and sweet potato show similarly inflated allocations relative to other feedstocks and to Scenarios A2 and A4.

Since the relative consumption of animal feed crops is not readily available at the country level, except for the US, we do not include a sub-scenario that uses local crop yields to calculate the co-product allocation. Instead, we have only two sub-scenarios: US animal feed data with US crop yields; and international animal feed data with world average crop yields. The composition of animal feed consumption is markedly different in the two cases. US animal feed is dominated by maize (95.0%), with the remainder split between sorghum (3.0%), oats (1.3%), and barley (1.0%). The international feed mixture is more diverse, containing primarily coarse grains (52.0%; containing millet, oats, rye, and mixed grain), maize (35.0%), barley (11.0%), and sorghum (2.4%).

Scenario A4: Displacement of maize, using a ratio of DDGS to maize calculated by the USDA

This method does not capture the variability in the nutritional composition of DDGS from different feedstocks. Maize DDGS, for instance, has a much higher protein content, per dry kg, than cassava DDGS (26% and 9%, respectively) and a lower protein content than wheat DDGS (37%). On average, this scenario generates co-product allocations that are much lower than those of any of the other allocation methods.

2.3.3 Results by country

As shown in Table 2.5 and Table 2.6, the relative land use requirements vary greatly by country. In the case of Australia, four potential ethanol feedstocks exist (maize, wheat, sugarcane, and sorghum), and only a small area will be required to meet the country's modest ethanol target. In contrast, an equivalent biodiesel target would require a much greater land area. The current production areas of Australia's biodiesel feedstocks are well below average, in proportion to the country's total arable land. Rapeseed is the only biodiesel feedstock comprising greater than 0.6% of arable land (at 2.4%), and Australia's rapeseed crop yield is well below the world average.

South Korea has only a biodiesel target, yet the current production areas of its two most likely biodiesel feedstocks, sesame seed and soybeans, are small. The national target would require greater than 7400% and 2300% of their current production areas, respectively, and require more than 100% of arable land, without co-product allocation.

Below, we examine five countries in detail. Soymeal-based co-product allocation (Scenario A2) generates results that are most consistent across the yield scenarios and allocation sub-scenarios. We therefore use Scenario A2 to illustrate the effect of co-product allocation on biofuel land requirements. The results are presented as ranges across the three yield scenarios.

Since all of the potential feedstocks are well-established crops with lengthy cultivation histories, we have used their current areas of production within each target country as a rough proxy for climatic suitability. We therefore assume that the climatic suitability of the crop is the main factor determining its level of production relative to other crops. This suitability is determined by calculating the relative fraction of the crop's current production area that will need to be diverted to meet the biofuel target. For annual crops (e.g., maize, sugarcane, soybeans), we compare the required production area to the country's total arable land area. For permanent crops (i.e., coconut and oil palm), we compare the required production area to total arable land and permanent crops (e.g., non-timber plantations).

United States

The US has targeted the annual production of 136 billion litres of renewable fuel by 2022, equivalent to a 23% blending level, by volume, or 17%, by energy content, based on the projected fuel demand in 2020. This is the highest absolute target of any country. Although the legislation allows for a portion of this target to be met with equivalent amounts of energy from other renewable sources, such as biodiesel (EPA, 2009), the government has focussed primarily on ethanol development, and we assume that the entire volume is met with ethanol. Because of the relative ethanol and biodiesel yields, meeting a portion of the target with biodiesel would require a greater area of land than meeting the entire target with ethanol alone.

Based on the land-use analysis, maize is overwhelmingly the most suitable feedstock for ethanol production. Without co-product allocation, the target would require a crop area equivalent to 96–97% of the current maize production area, depending on the yield scenario, with a projected biofuel yield of 4800–4900 L/ha. Since the US produces relatively large quantities of soybeans, we use US yields to calculate the soymeal-based co-product allocation (Scenario A2(a)). For maize DDGS, co-product allocation may offset 49–50% of the land requirements, when maize

DDGS displaces US soymeal, meaning that maize ethanol production would only effectively require 49% of the current production area to meet the full target. This represents 8% of arable land in the US, as opposed to 16% without co-product allocation.

Wheat may also contribute to the target, although the land-use impact would be even higher, considering that it would require a production area equivalent to 450–540% of the current area to meet the full target, with a projected biofuel yield of 1200–1500 L/ha. Displacing US soymeal, wheat DDGS may offset 20–24% of the wheat ethanol land area. Wheat ethanol would then effectively require 340–430% of the current production area to meet the full target. This represents 40–50% of arable land in the US, as opposed to 52–63% without co-product allocation.

Although sugar beet and sugarcane have the highest projected biofuel yield (6000–6800 L/ha and 6000–7000 L/ha, respectively), they are unlikely to contribute substantially, considering that it would require more than 4000% of their current production areas to meet the full target without co-product allocation.

Although we have not explicitly examined a US target for biodiesel, it may contribute to the renewable fuel target. Based on their current production area, soybeans are overwhelmingly the most suitable feedstock for US biodiesel production. The US production area for soybeans, relative to arable land area, is very large (17% of arable land) and is above the world average (14%). Soybean biofuel yield (600 L/ha) is also comparable to most other potential biodiesel feedstocks. Although groundnuts and rapeseed are projected to have the highest biofuel yields (1300–1400 L/ha and 700–1200 L/ha, respectively), their production areas are very small (0.3% of arable land). Therefore, using the most suitable feedstock (soybeans), US biodiesel production will require six times more land than ethanol, per litre of fuel, making it unlikely that biodiesel will substantially contribute to the biofuel target.

European Union

The EU has targeted a 10% blending level (by energy content) by 2020, for both ethanol and biodiesel, making it the second highest target in terms of absolute production (24.6 billion litres

Table 2.3: Proportion of ethanol crop area allocated to the co-products, by allocation scenario, averaged across all yield increase scenarios and all countries

Scenario	Barley	Cassava	Maize	Oats	Potato	Rice	Rye	Sorghum	Sugar beet	Sugarcane	Sweet potato	Triticale	Wheat
A1	67%	52%	86%	64%	119%	52%	49%	58%	115%	0%	34%	71%	81%
A2	25%	17%	34%	23%	40%	18%	19%	19%	45%	0%	12%	30%	29%
A3	30%	50%	40%	34%	56%	24%	22%	20%	143%	0%	30%	27%	26%
A4	12%	28%	17%	14%	26%	11%	9%	9%	57%	0%	15%	10%	11%
Average	34%	37%	44%	34%	60%	26%	25%	27%	90%	0%	23%	35%	37%

Table 2.4: Proportion of biodiesel crop area allocated to the co-products, by allocation scenario, averaged across all yield increase scenarios and all countries

Scenario	Castor oil seed	Coconut	Cottonseed	Groundnut	Linseed	Mustard seed	Oil palm fruit	Rapeseed	Sesame seed	Soybeans	Sunflower seed
A1	36%	31%	46%	73%	47%	21%	22%	90%	75%	139%	48%
A2	12%	11%	15%	29%	18%	9%	8%	34%	26%	48%	18%
A3	9%	14%	10%	16%	16%	11%	11%	29%	21%	32%	15%
Average	19%	19%	24%	40%	27%	14%	14%	51%	41%	73%	27%

Table 2.5: Land requirements to meet ethanol targets in full, for selected countries

Country	Ethanol target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Australia	350 million litres	0.35	Wheat	660	4.3%	1.1%	11–15%	0.9–1.0%
			Sugarcane	7510	11%	0.1%	0%	0.1%
			Barley	650	12%	1.1%	10–14%	1.0%
			Sorghum	1020	51%	0.7%	13–18%	0.6%
Brazil	25% (volume)	9.84	Sugarcane	6570	27%	2.5%	0%	2.5%
Canada	5% (volume)	2.27	Wheat	1070	21%	4.7%	18–21%	3.7–3.8%
			Maize	4300	46%	1.2%	43–51%	0.6–0.7%
			Barley	1180	50%	4.2%	19–22%	3.3–3.4%
China	10% (volume)	16.6	Maize	2730	24%	4.6%	27–42%	2.6–3.3%
			Rice	2360	25%	5.2%	18–27%	10–11%
			Wheat	1850	40%	6.7%	30–46%	3.6–4.7%
			Sweet potato	2230	150%	5.6%	14–21%	4.4–4.8%
			Sugarcane	6120	200%	2.0%	0%	2.0%
			Potato	1720	160%	7.2%	20–31%	5.0–5.8%
European Union	10% (energy)	24.7	Wheat	2260	42%	9.9%	37–44%	5.6–6.2%
			Maize	3480	76%	6.4%	35–41%	3.8–4.2%
			Barley	1700	100%	13%	27–32%	9.0–9.7%
			Sugar beet	8790	130%	2.6%	39–46%	1.4–1.6%
			Potato	3040	330%	7.4%	35–42%	4.3–4.8%
South Korea	-	-	Rice	2450	-	-	18–32%	-
United States	136 billion litres	136	Maize	4890	96%	16%	49–58%	6.7–8.1%
			Wheat	1250	540%	63%	20–24%	48–50%

Table 2.6: Land requirements to meet biodiesel targets in full, for selected countries

Country	Biodiesel target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Australia	-	-	Rapeseed	570	-	-	16–22%	-
Brazil	5% (volume)	2.47	Soybeans	560	22%	7.4%	53–62%	2.8–3.5%
Canada	2% (volume)	0.326	Rapeseed	870	7.9%	0.8%	24–28%	0.6%
			Soybeans	580	50%	1.2%	54–64%	0.4–0.6%
China	-	-	Rapeseed	950	-	-	26–40%	-
			Groundnuts	1280	-	-	32–48%	-
			Soybeans	400	-	-	38–58%	-
			Cottonseed	340	-	-	22–34%	-
European Union	10% (energy)	25.9	Rapeseed	1660	340%	14%	45–54%	6.6–7.8%
			Sunflower seed	800	850%	29%	17–20%	24%
South Korea	3% (volume)	0.886	Soybeans	360	2800%	150%	34–58%	63–100%
			Sesame seed	340	7400%	160%	7.5–13%	140–150%
United States	-	-	Soybeans	620	-	-	58–69%	-
			Rapeseed	880	-	-	24–28%	-

of ethanol and 25.6 billion litres of biodiesel in 2020). This is equivalent to a 14% blending level (by volume) for ethanol in gasoline, and 11% (by volume) for biodiesel in diesel fuel.

Although the EU's renewable energy strategy relies in part on imports of renewable fuel from outside of the EU, we examine the regions capacity to contribute to the biofuel targets. On the basis of current production areas and biofuel yields, wheat, maize, barley, sugar beet, and potatoes are most likely to contribute to the ethanol target, while rapeseed and sunflower seed are most likely to contribute to the biodiesel target.

Although sugar beet again shows the highest biofuel yield per hectare (8200–8800 L/ha), it would require 130–140% of its current production area to meet the full target, without co-product allocation. Since the EU produces relatively small quantities of soybeans, and imports large quantities from the US, we use US soybean yields to calculate the soymeal-based co-product allocations (Scenario A2(a)). Displacing US soymeal, sugar beet pulps and slops may offset 37-39% of the land requirements. Sugar beet ethanol would then effectively require 77–85% of the current production area. This represents 1.6–1.7% of the EU's arable land, as opposed to 2.6–2.7% without co-product allocation.

Conversely, wheat has a relatively low projected biofuel yield (2200–2300 L/ha), but it would only require 41–43% of its current production area to meet the full target, without co-product allocation. Displacing US soymeal, wheat DDGS may offset 37–38% of the land requirements. Wheat ethanol would then effectively require 26–27% of the current production area to meet the full target. This represents 6.1–6.3% of the EU's arable land, as opposed to 9.7–10.1% without co-product allocation.

Meeting the biodiesel target by growing the feedstock within the EU is even less likely. It would require 340–350% of the current production area to meet the target using rapeseed, the most likely feedstock, without co-product allocation. Displacing US soymeal, rapeseed meal may offset 44–45% of the land requirements. Rapeseed biodiesel would then effectively require 180–200% of the current production area to meet the full target. This represents 7.8–8.4% of the EU's arable land, as opposed to 14–15% without co-product allocation.

Meeting the full target using sunflower seed biodiesel would require 710–850% of its current production area, with a biofuel yield of 800–960 L/ha. Sunflower seed meal may offset 17–21% of the land requirements. Sunflower seed biodiesel would then effectively require 560–710% of the current production area to meet the full target. This represents 19–24% of the EU's arable land, as opposed to 24–29% without co-product allocation.

The crop with the highest projected biofuel yield is sesame seed, at 2600–3500 L/ha, but would require more than 30,000 times its current production area to meet the full target.

Brazil

Brazil has targeted an average blending level of 25% (by volume) for ethanol (current), and 5% (by volume) for biodiesel by 2013. Brazil has been a world leader in sugarcane ethanol production for decades, and its production area reflects this. Based on Brazil's projected transportation energy demand in 2020, meeting this ethanol blending target will require only 25–27% of current sugarcane production area. This represents 2.4–2.5% of the country's arable land. Sugarcane ethanol does not benefit from co-product allocation, since it does not generate any co-products that are primarily used as animal feed.

Meeting Brazil's biodiesel target will require 21–22% of the current soybean production area, without co-product allocation. Since Brazil produces relatively large quantities of soybeans, we use local yields to calculate the soymeal-based co-product allocation (Scenario A2(b)). Displacing Brazilian soymeal, the soymeal co-product may offset 58% of the land requirements (since the co-product soymeal's per-hectare yield is equal to the displaced soymeal's per-hectare yield, this is simply the economic allocation described in Section 2.2.5). Soybean biodiesel would then effectively require 9.0–9.1% of the current production area. This represents 3.0–3.1% of the country's arable land, as opposed to 7.1–7.4% without co-product allocation.

China

China has targeted a 10% blending level (by volume) for ethanol in 9 provinces. Since we do not have sub-national fuel demand projections, we assume that this blending level is applied at the national level. The most likely ethanol feedstocks in China, by proportion of current production area, are maize, rice, and wheat. Based on China's projected transportation energy demand, meeting the full target using maize would require 24–29% of the current production area, without co-product allocation. Displacing international soymeal may offset 27–32% of the land requirements. Maize ethanol would then effectively require 16–21% of the current production area. This represents 3.1–4.1% of the country's arable land, as opposed to 4.6–5.5% without co-product allocation.

Meeting the full target with rice would require 24–26% of the current production area, without co-product allocation. Displacing international soymeal with rice DDGS may offset 20–21% of the land requirements. Rice ethanol would then effectively require 19–21% of the current production area. This represents 4.0–4.5% of the country's arable land, as opposed to 5.2–5.6% without co-product allocation.

Meeting the full target with wheat would require 36–40% of the current production area, without co-product allocation. Displacing international soymeal with wheat DDGS may offset 36–39% of the land requirements. Wheat ethanol would then effectively require 22–25% of the current production area. This represents 3.7–4.3% of the country's arable land, as opposed to 6.1–6.7% without co-product allocation.

Although we did not consider an explicit biodiesel target for China, the most likely biodiesel feedstocks, by current production area and biofuel yield, are rapeseed, groundnuts, and soybeans. China's rapeseed production area is large (5.3% of arable land) and is above the world average (2.9%), and it has a biofuel yield comparable to other feedstocks (950–1000 L/ha). The groundnut production area (3.6% of arable land) is also above the world average (1.0%), and it has a favourable biofuel yield (1260–1280 L/ha). China's soybean production area (6.9% of arable land) is slightly below the world average (9.0%), and it has a low biofuel yield (380–480 L/ha).

Canada

Canada has targeted a 5% blending level (by volume) for ethanol by 2010, and 2% (by volume) for biodiesel by 2012. The most likely ethanol feedstocks in Canada, by proportion of current production area, are wheat, maize, and barley. Since the neighbouring US has a much larger production area for soybeans (about 20 times larger), we use US soybean yields to calculate the co-product allocations. Meeting the full target with wheat would require 18–21% of the current production area, without co-product allocation. Displacing US soymeal with wheat DDGS may offset 17–21% of the land requirements. Wheat ethanol would then effectively require 14–18% of the current production area. This represents 3.1–4.0% of Canada's arable land, as opposed to 3.9–4.9% without co-product allocation.

Meeting the full target with maize would require 46% of the current production area, without co-product allocation. Displacing US soymeal with maize DDGS may offset 43–44% of the land requirements. Maize ethanol would then effectively require 26% of the current production area. This represents 0.7% of Canada's arable land, as opposed to 1.2% without co-product allocation.

Meeting the full target with barley would require 49–58% of the current production area, without co-product allocation. Displacing US soymeal with barley DDGS may offset 17–19% of the land requirements. Barley ethanol would then effectively require 40–48% of the current production area. This represents 3.4–4.1% of Canada's arable land, as opposed to 4.1–4.9% without co-product allocation.

The most likely biodiesel feedstocks in Canada, by proportion of current production area, are rapeseed and soybeans. Meeting the full target with rapeseed would require 6.0–8.3% of the current production area, without co-product allocation. Displacing US soymeal with rapeseed meal may offset 23–31% of the land requirements. Rapeseed biodiesel would then effectively require 4.1–6.3% of the current production area. This represents 0.4–0.7% of Canada's arable land, as opposed to 0.6–0.9% without co-product allocation.

Meeting the full target with soybeans would require 50–58% of the current production area, without co-product allocation. Displacing US soymeal with Canadian soymeal may offset 48–54% of the land requirements. Soybean biodiesel would then effectively require 23–31% of the current production area. This represents 0.6–0.8% of Canada's arable land, as opposed to 1.2–1.5% without co-product allocation.

2.4 DISCUSSION

Our model of the projected land requirements shows that national biofuel targets are likely to put a significant strain on existing agricultural systems. We determined the most likely feedstocks in each country by the proportion of current production area that would be required to meet each of the national targets in full. The results show that eleven countries may require greater than 5% of their arable land area to meet the ethanol targets in 2020. Eleven countries may also require greater than 5% of their arable land area to meet their biodiesel targets (see Table 2.5 and Table 2.6 for selected countries, and Appendix A for full results). Except for biodiesel from palm oil, per-hectare biodiesel yields are much lower than for ethanol, because oilseed yields are much lower than crop yields for grains and tubers. Therefore, on average, biodiesel targets are substantially more land-intensive than ethanol targets (see Table 2.1 and Table 2.2).

When considering the land requirements of first-generation biofuels, co-product allocation may have a crucial impact on the outcome, introducing significant uncertainty. As shown in Table 2.3 and Table 2.4, excluding sugarcane, the average co-product allocations across all target countries ranged from 8% of land area for palm oil cake (using soymeal-based allocation) to 143% for sugar beet pulps and slops (using a representative sample of feed crops).

Although the use of biofuel co-products as animal feed will help to offset the increased land area used for biofuel crop production, the feeding value of many co-products remains uncertain, and current research on maize DDGS confirms that there is a limit to the amount of co-product that can be added to animal feed. This is due, in part, to the increased concentration of nutrients in DDGS relative to the original feedstock, some of which may have a detrimental effect on the livestock at high concentrations (Mathews & McConnell, 2009). The feeding value of non-maize DDGS needs a more thorough examination. Although there are research groups looking at wheat and sorghum (e.g., the University of Saskatchewan and the USDA, respectively), peer-reviewed literature is scarce, and other feedstocks, such as cassava and sugar beet, have received substantially less coverage.

Better knowledge of the feeding value of the co-products will allow for more accurate co-product allocations. Researchers in the US have developed complex displacement ratios for maize

DDGS, involving multiple feed crops or feed additives, but little exists for other co-products. Displacement by protein content may give a rough estimate of the displacement value of the co-products, but it does not account for the amino acid composition of the protein or the energy content of the co-product, both of which are important in assessing the feeding value. The amino acid composition varies significantly between co-products, and the literature is not detailed enough to properly assess this variability and its impact on displacement. Digestibility and accessible energy are also important considerations in animal feed additives, and are not captured by this allocation method (Klopfenstein et al., 2008).

Of the co-product allocation methods used, displacement of soymeal on the basis of protein content yields the most consistent results, rarely exceeding 100% of the production area. In terms of nutritional value in feeding, soymeal more closely resembles DDGS and oilcakes than does maize. Soymeal is used as a high-protein feed supplement, whereas maize primarily delivers energy in animal feed (Klopfenstein et al., 2008). Since most of the co-products are relatively high in protein, and high-protein feed additives are a valuable component in animal feed mixtures, the co-products are more likely to displace soymeal than maize (Mathews & McConnell, 2009).

On average, soymeal displacement offsets 24% of the feedstock land requirements for ethanol and 21% for biodiesel. Using soymeal displacement, sugarcane and oil palm fruit, the feedstocks with the highest biofuel yields, also have the lowest average co-product allocations (nil and 8%, respectively). In countries where the sugarcane yield is moderate, the absence of land-intensive co-products for sugarcane may reduce its appeal relative to other feedstocks. Feedstocks with lower biofuel yield, but higher animal feed production may have less impact on local land use.

In our analysis, we assume that the co-products will be fully utilized as animal feed – the best-case scenario for co-product allocation. The economic value of the co-products is likely to decrease with an increasing supply of high-protein feed additives as biofuel production increases. The decreasing value is only of concern if it results in wasted co-products or their diversion to other applications. As long as the co-products are used in animal feed, the economic value will not significantly affect land use.

Despite the national focus of the biofuel targets, countries with high biofuel land-use projections are likely going to import biofuels to satisfy a significant portion of their future demand. Although our analysis does not directly address international trade, those countries that are best able to meet their domestic targets are most likely to export excess biofuels. If the primary objective of the target-setting governments is to increase energy security, energy independence and support for farmer incomes, then they would do best to satisfy their demands with domestic supplies. Alternatively, if their primary objective is to mitigate climate change, then production should take place in countries where it will instigate the least land-use change and have the least impact on other agricultural activities (e.g., Reijnders & Huijbregts, 2008).

2.5 CONCLUSIONS

Land-use change is a critical outcome of biofuel development and has received considerably less attention than the LCA of energy and CO_2. Many of the national biofuel targets are very high and will require the diversion of large proportions of important food and non-food crops for ethanol and biodiesel production. In countries where the potential agricultural land base is fully exploited, biofuel mandates requiring a significant proportion of arable land may disrupt the existing agricultural system. Co-product allocation may offset a significant portion of the biofuel land requirements, but cannot be relied upon to ensure the sustainability of biofuel production targets as the required production area expands. Alongside the potential economic and environmental benefits of biofuel production, policy-makers must give considerable emphasis to land-use requirements in re-examining current and future biofuel policies.

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3 INDIA'S BIODIESEL GOLD RUSH: LAND-USE IMPACTS IN RURAL RAJASTHAN[4]

3.1 INTRODUCTION

Liquid biofuels for transportation (i.e., ethanol and biodiesel) have received strong support in national policy-making worldwide. Twenty-eight countries, as well as the European Union, have enacted biofuel consumption targets, while many have provided substantial subsidies to producers. The Indian government is no exception, having mandated a 20% blending level for ethanol in gasoline and biodiesel in diesel by 2017 (REN21, 2009).

For biodiesel production, India has focussed its attention on an oilseed-bearing shrub called *Jatropha curcas*, which grows wildly in semi-arid parts of India and has long been used as a living fence around agricultural fields. While *Jatropha*, native to South America, had never previously been cultivated as a commercial crop due to the toxic nature of its seeds and oil, historical evidence shows that it survives well in hot and dry conditions with poor soil fertility. The potential per-plant seed yield of wild *Jatropha* is also very promising (Achten et al., 2008). Researchers and policy-makers in other Southeast Asian countries, South America, and Africa have expressed a strong interest in following India's example and pursuing *Jatropha* development to increase energy security and contribute to rural poverty alleviation (e.g., Lapola et al., 2009; Salé & Dewes, 2009; Ye et al., 2009).

The Indian government, along with many plant researchers, agricultural and energy companies (e.g., D1 Oils; Reliance Biofuels; Mission Biofuels), and some local NGOs, have leapt at the opportunity to improve rural livelihoods and national energy security through *Jatropha* biodiesel production (e.g., NOVOD, 2007; PC, 2003). Unfortunately, the reality is that *Jatropha* is still very much a wild plant, with high variability in plant characteristics and poorly framed best-practices for crop management (Achten et al., 2008). This has resulted in a huge diversity of approaches to cultivation and a resulting variability in yields. As of yet, no proper best-practices have been developed and, as discussed below, the science of *Jatropha* production remains very

[4] A version of this chapter will be submitted for publication. Findlater K M and Kandlikar M India's biodiesel gold rush: Land-use impacts in rural Rajasthan.

uncertain, even while government and private industry continue to pursue *Jatropha* biodiesel production at a rapid pace.

In Jhadol Tehsil, near Udaipur, Rajasthan, villagers have long collected seed from wild *Jatropha* plants and those used as fencing. Following the creation of the first government biofuel initiative in 2003 (PC, 2003), the relative abundance of wild *Jatropha* and dry waste land compared to other parts of India prompted a *Jatropha* boom in this area (Leduc et al., 2009). As a result, *Jatropha* has been planted on a variety of land by a variety of players, using what information was then available to plan the development and consider the costs and benefits. This setting provides an excellent case with which to examine *Jatropha*'s local impacts and the feasibility of present-day plantations.

The development of common land resources in rural India has received strong criticism in the past (Jodha, 2008). Farmers and other villagers in rural Rajasthan depend heavily on livestock for food and income (Agoramoorthy et al., 2009). Therefore, any development program that threatens to reduce the available private and common grazing areas must be critically examined to ensure that the potential impacts are incorporated into policy-making. India's official policies do not currently account for the value of waste land, assuming instead that there will be no impact if *Jatropha* is planted` on such lands (e.g., PC, 2003). In planning future planting programs, decision-makers in other Indian states and in other developing countries may draw on the lessons learned in Jhadol. In this study, we therefore undertake to examine the local impacts of *Jatropha* plantation development by conducting in-depth interviews with local stakeholders. What unconsidered impacts may the *Jatropha* plantations have on farmers and villagers in Jhadol Tehsil?

3.2 POLICY CONTEXT

Along with India's future 20% biodiesel mandate – enacted in the National Biofuel Policy of September 2008 – the central government has created policies and subsidies to promote the development of the *Jatropha* biodiesel industry. While other proposed biofuel programs have attracted sharp criticism in India because of their potential impact on food prices, *Jatropha* is promoted as having no impact on food or animal feed resources since it is inedible, precluding the direct diversion of food crops for biofuel production (Becker & Makkar, 2008; Francis et al., 2005)).

The central and state governments' official promotion efforts have focussed on the development of *Jatropha* plantations on relatively infertile land (PC, 2003; Revenue Department, 2007). The central government has based its prediction of the country's biodiesel production potential on the availability of waste land; a category that encompasses land that is considered to be too low in soil fertility, soil moisture, and biomass production to produce revenue. The character of the waste lands may vary from grassland to forest and from desert to wetlands. These lands may be entirely unusable, may be used for low levels of grazing or resource-gathering, or may be misclassified as waste land (Agoramoorthy et al., 2009).

There are huge uncertainties in the amount of available waste land in India; a situation primarily caused the improper classifications of common land, waste land, and grazing lands. This problem has long been recognized, but the underlying issues have not been addressed (Agoramoorthy et al, 2009; Brara, 1992; Jodha, 1985). Therefore, estimates of biodiesel production potential that are based on waste land availability are likely to be inaccurate.

The government's current biodiesel policies assume that waste land has no inherent value; that nothing is grown there and that nothing will be lost should *Jatropha* be planted (Agoramoorthy et al., 2009; PC, 2003). Although the central government recently revisited its biofuel policy in the face of heavy criticism, rather than addressing the policy's potential local impacts, the criticism implied that the previous policy did not go far enough to promote *Jatropha* adoption (Ghildiyal & Sethi, 2008).

In response to the central government's policies, the state government of Rajasthan has developed rules for the leasing of land to *Jatropha* plantation efforts. The policy specifically targets local employment generation and encourages the development of plantations by below-poverty-line (BPL) self help groups. Other groups eligible for the allotment program include community forest committees, Gram Panchayats[5], agricultural cooperatives, government departments, and private companies (Revenue Department, 2007).

In Rajasthan, most of the waste land that will be leased for *Jatropha* development is publicly owned land accessible to all villagers. The development of such common land has long been a contentious issue in rural India. In explaining the historical lack of proper development planning for common property resources (CPRs), Jodha (2008) argues that their value is systematically ignored:

> Despite their valuable contribution to rural economy, CPRs are among the most neglected areas of development planning in the dry regions of India. This disregard of CPRs is due to formal invisibility or statistical non-recognition of their contribution. This disregard further perpetuates the depletion of CPRs in terms of area, products and productivity.

Since the poorest villagers typically have the smallest land holdings – if any – the disappearance of common grazing land affects them disproportionately. Livestock are vital to rural livelihoods, providing food and income. Villagers who own land often have cows and buffalo, whereas the landless rely on smaller animals such as goats and sheep (Agoramoorthy et al., 2009; Jodha, 2008). The loss of forage area is therefore of critical importance, given the rural reliance on animal husbandry.

Jatropha advocates argue that plantation development will bring substantial benefits to rural villagers while incurring only small losses (e.g., Aswathanarayana, 2008). Conversely, some researchers and NGOs who have long been concerned with the misuse of common land resources point to *Jatropha* as the latest threat to rural livelihoods (e.g., FES, 2008b), claiming that this, as well as similar policies in other countries, constitutes a land-grab and an illegitimate use of common land resources that have long sustained the rural poor (Agoramoorthy et al., 2009; Cotula et al., 2009).

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[5] The Gram Panchayat is an elected council responsible for some local affairs and common land management in one or more villages. The elected leader of the Panchayat is called the Sarpanch, and the Patwari addresses the Panchayat's land-use affairs. In the study area, each Panchayat encompasses 2 to 6 villages, and each Patwari is responsible for one or more Panchayats.

3.3 SCIENTIFIC CONTEXT

Jatropha curcas is an oilseed-bearing shrub native to South America, likely introduced to India by Portuguese sailors sometime before the 19th century (Heller, 1996). The seed, as well as the subsequent oil and seed cake, contains toxins that make it inedible to both humans and livestock. It flowers and bears fruit one or more times per year, depending on the availability of water and nutrients. When ripe, the fruit is harvested manually and dried to allow for easier extraction of the seeds – up to three from within a single fruit. The oil is then extracted from the seed using either a solvent or a mechanical press. As with almost any vegetable oil, the oil from the *Jatropha* seed can be converted to biodiesel using a chemical process called transesterification (Achten et al., 2008).

The peer-reviewed literature relating to *Jatropha* is sparse, and Achten et al. (2008) provide a thorough review of the current state of scientific knowledge about *Jatropha* based peer-reviewed articles, published reports, and conference proceedings. They conclude that the most glaring knowledge gaps include the plant's response to agricultural inputs under specific environmental conditions, and the development of plant varieties with relatively stable characteristics, such as seed yield and seed oil content. The plant's responses to fertilizer, water, and pruning have not been well established, resulting in planting and management practices that vary widely. Similarly, biomass and seed production are highly variable at present – even between adjacent plants in the same field – because the planting material has not been refined to select for attractive properties (an issue specifically reviewed by Divakara et al. (2009)).

Although research pertaining to these issues is being conducted at both private and public facilities, it is difficult to rapidly and decisively quantify attractive properties in a plant that only matures over the course of four to five years. Additionally, private companies and universities are hesitant to share information that may be of commercial value. The yield estimates that were used in early policy-making were much higher than those that are now being achieved under scientific scrutiny (Achten et al., 2008). Current research suggests that *Jatropha* will indeed survive on waste lands without fertilizer and water, but that the plant does not thrive under such conditions and seed production is sharply reduced (Achten et al., 2008; Kheira & Atta, 2009).

Achten et al. (2008) contend that some of the variation in estimated yield potential might result from the extrapolation of per-hectare yields from the yields of a single plant or a small cluster of plants. These plants were most likely wild-growing mature plants, singled out for their size and yield to predict potential future yields. Since there is no significant experience growing *Jatropha* in block plantations, and the block plantations that now exist are rarely more than 5 years old, scientists have yet to detail the relationship between per-hectare plant density and seed yield. Although it is clear that per-plant seed yield decreases with increasing plant density, the precise relationship and optimal density have yet to be determined.

Achten et al. conclude that most of the public discussion has been conducted on the basis of unreliable preliminary estimates. This tendency is mirrored in the early peer-reviewed literature (e.g., Openshaw, 2000) and even in recent studies (e.g., Leduc et al., 2009). Achten et al. recommend that future planting be approached cautiously, to allow for the proper development of the scientific basis for planning.

3.4 METHODS

The study was conducted over the course of three months in early 2009. Initial interviews were conducted with experts at universities, NGOs, and private companies, followed by in-depth interviews with local stakeholders. The in-depth interviews were conducted during a three-week period in April 2009 in the rural sub-district of Jhadol Tehsil, 50 km west of Udaipur in the state of Rajasthan. These interviews involved four overlapping groups: farmers and villagers; government workers from the Forest Department and community forest management committee leaders; Gram Panchayat officials; and staff from the BAIF Development Research Foundation (BAIF). Ten of the interviews involved a single participant each, while the other fifteen included contributions from more than one individual. The interviews were semi-structured and were about an hour in length, on average. The participants provided informed consent to answer questions regarding their use of private and common land, their agricultural practices, their knowledge of plantation programs, and their perception of *Jatropha*. We transcribed the interviews and coded the content thematically, to ensure that we accurately captured the range of perspectives within each theme.

Women participated in seven in-depth interviews, while two of these interviews were conducted with female participants only. All of these were of the farmer/villager category. Since the interviewer and the interpreter were both male, local cultural norms generally precluded the use of single-participant sessions when interviewing women. In consultation with local NGOs, the mixed-gender interview method was determined to be the most viable way to include women in the study.

3.4.1 Study site

Jhadol Tehsil is a hilly sub-district within Udaipur District in southern Rajasthan. Of a population of 194,000 (as of 2001), 70% are designated as Scheduled Tribe and 2% as Scheduled Caste – the two categories explicitly recognized by the Indian constitution as requiring special protection. Jhadol Tehsil is comprised primarily of rural villages, with the town of Jhadol acting as the local centre of administration and trade (population 4,700) (Government of India, 2007). The climate of Udaipur District is semi-arid, with a mean annual rainfall of 645 mm, summer temperatures of 28.8 to 38.3°C, and winter temperatures of 11.6 to 28.3°C (Forest Department, 2009). The government's official land use classifications for the sub-district are: 76,000 ha of forest land; 5,700 ha of irrigated farmland; 17,000 ha of non-irrigated farmland; 16,000 ha of culturable waste land; and 28,000 ha of land unavailable for cultivation (Government of India, 2007).

3.5 *JATROPHA* PROGRAMS IN JHADOL TEHSIL

Two main government-run funding programs exist for the development of *Jatropha* plantations in Jhadol Tehsil. The foremost is conducted under the auspices of the National Rural Employment Guarantee Scheme (NREGS), enacted by central government legislation in 2005 (Ministry of Law and Justice, 2005), while the state government's Tribal Development Program has also provided funding for research and plantation development. The NREGS guarantees the provision of 100 days per year of employment at a guaranteed wage (Rs. 100 per day) to willing and able workers in rural India. As well as generating employment, the NREGS provides a mechanism for the regular implementation of local development projects, including, but not limited to, water conservation and harvesting, afforestation, road building, de-silting, land levelling, and plantation development.

With respect to *Jatropha*, the NREGS has funded plantations on lands governed by the state Forest and Watershed Departments, as well as those governed by the local village Panchayats. The *Jatropha* plantations on Forest Department land were developed in accordance with existing water conservation and tree planting programs. Although one of the participants reported that *Jatropha* had also been planted on Watershed Department land, we were not able to visit these plantations due to logistical constraints. Whereas national biofuel programs are promoted as mitigating climate change, increasing energy security, and contributing to rural development, local authorities emphasized the employment generated by land preparation and planting activities.

For the most part, forest land in Jhadol Tehsil is hilly, with serious degradation in areas that have not been walled off to prevent browsing by livestock. *Jatropha* plantations on Forest Department land are of two types. In some areas, *Jatropha* is planted in mixed plantations, alongside such other plants as mer, babool, mahua and bamboo. In other areas, *Jatropha* is planted as a de facto monocrop along the edges of water conservation trenches and bunds dug in parallel on hillsides. In the latter plantations, other trees and shrubs are present only in small numbers. Even within forest land, vastly different planting practices and management techniques were reported between different plantations. Seeds were sown along trenches, while seedlings or cuttings were planted in pits. In some places, the plants were pruned regularly, while in others they were not.

Village Panchayats also applied to the NREGS to fund the development of *Jatropha* plantations on Panchayat land; common land which is normally open to use by all villagers. These schemes also financed the development of plantations on adjacent private land. The decision to develop these plantations was taken locally by a meeting of the Gram Sabha[6], although their decision-

[6] Every village resident above the age of 18 is a member of the Gram Sabha, which votes by majority on issues of local importance, including the implementation of NREGS projects. Each Panchayat is also comprised of smaller wards, and the Ward Sabhas meet more frequently to discuss smaller issues.

making process relied strongly on information passed down by the Panchayat Samiti[7]. The Panchayat Samiti sent a list of possible NREGS projects to the Gram Panchayat, who in turn presented these options to members of the Gram Sabha. Members of each Ward Sabha then presented arguments for the selection of particular projects, at which point the Gram Sabha voted to select specific projects for implementation.

In addition to the state and local government initiatives, the third major plantation program is run by BAIF, a technologically focussed NGO with a long history of agriculture and silviculture projects in Jhadol Tehsil. BAIF is involved in *Jatropha* planting programs funded both by NREGS and by the state government's Tribal Development Program. A BAIF staff member explains:

> We are just putting our proposal, and they accepted it. We are presenting there, this is the scenario and this is the futurology for this crop, and this is wildly available in this area. Why do we not introduce some technical support for development of tribal families?

Starting in 2004, BAIF created pilot plantations on private pasture land within Jhadol Tehsil. The initial plantations garnered positive attention from government officials and biofuel companies, and BAIF expanded the program in subsequent years to eventually include 2,500 farmers.

BAIF targeted families appearing on the government's below-poverty-line (BPL) list. BPL families have, on average, the smallest land holdings – if any – and the least fertile land. BAIF anticipated that the *Jatropha* plantations could make use of relatively infertile and degraded pasture land, while generating income for the area's poorest families. No consideration was given to the loss of forage grass, since the land was considered to be useless waste land. For each farmer, BAIF paid labourers to dig water conservation trenches and planting pits in one acre of land. Four hundred *Jatropha* seedlings were then planted in the pits, and the pits were filled with a mixture of soil and fertilizer. Additionally, the land was sown with grass seed to improve forage conditions and to balance the loss of forage from the future increase of *Jatropha* canopy area.

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[7] At the Tehsil level, the Panchayat Samiti oversees the Gram Panchayats. In addition to other responsibilities, the Panchayat Samiti determines the viability of NREGS projects.

3.6 PERCEIVED IMPACTS

3.6.1 Farmers and villagers

Farmers and villagers have mixed feelings about *Jatropha*. Because the plantations are between one and five years old, most have not reached their full seed yield potential. Villagers have collected the seeds sporadically, and none of the participants reported substantial income from the selling of the seeds. In present or future scenarios, all indicated that they would dry the fruit themselves and remove the seeds from the dried husk, selling the seeds to local shopkeepers or the government-run cooperative, LAMPS[8], depending on the relative prices offered. In the past, shopkeepers have reportedly offered a better price than LAMPS, who provide a guaranteed price based on the market price in nearby Udaipur.

On the one hand, all farmers and villagers use the pasture land directly and noted the reduction of grass levels on land planted with *Jatropha*. The consensus among villagers was that *Jatropha* has a greater impact on grass levels than do other trees and shrubs because of the density of its foliage and the pruning techniques employed[9].

> Farmer 3: [D]ue to the leaves. The shadow being brought in that area… makes it difficult for the grass to grow…. [T]his thing has brought a kind of loss to [us].

> Farmer 8: [W]hen the *Jatropha* plant's leaves fall, they create a kind of a shadow…. [T]he grass doesn't grow on that portion.

Additionally, the most severely impacted farmers and villagers are those with the smallest land holdings; typically the poorest. They tend to be more heavily dependent on public land for forage, and the loss of grass due to plantations concerns them.

On the other hand, when asked about their motivations for planting *Jatropha*, the farmers with private *Jatropha* plantations indicated that they had been convinced of the income that they

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[8] Large-sized Adivasi Multipurpose Societies (LAMPS) are government-run cooperatives that provide a guaranteed market for agriculture and minor forest produce in tribal areas. LAMPS cooperatives are overseen at the state level by the Rajasthan Tribal Area Development Cooperative Federation.

[9] Pruning is used to induce branching, increase fruit production, and facilitate manual harvesting, and increases the plant's horizontal coverage as a result.

would get from the seeds. Since BAIF provided the labour and materials, and sometimes paid the farmers themselves to help prepare the fields, they did not see a downside when creating the plantation. Only later, when the amount of grass began to decrease and the seed yields were lower than expected did they begin to think that it might not have been such a good idea to plant.

In years with low rainfall, if villagers are not able to find enough fodder on their own land or by purchasing from other villagers, they go to common land and forest land to collect grass or graze their cattle. Some farmers indicated that they had found *Jatropha* plantations on all of the land where they would normally collect grass or graze cattle in years with low rainfall, whether on Panchayat land or forest land.

> Farmer 10: [W]hen [the *Jatropha* plants] are going to grow, then people are going to go to the shops and buy the grass…. [Y]ou have to go to further areas to get the grass….. [Y]ou have to go to the area where [*Jatropha*] is not there…. [Y]ou have to go to far away areas to collect grass… [where] there is [also] plantation of *Jatropha* by the government.

All of the villagers that were interviewed indicated that they have to buy additional fodder in years of low rainfall, and many cited the drought of 1987-88 as an extreme example. In that year, villagers reported the cutting down of trees to harvest leaves and the feeding of livestock with whatever was at hand.

The villagers' involvement ends once the seeds leaves their hands. The seeds are sold onwards to research organizations and private companies for the biodiesel production and the development of plantations. Despite Achten et al.'s (2008) assertion that the seed cake should be used as fertilizer on the plantation following oil extraction, this is not possible in Jhadol Tehsil since the extraction is not done locally. For locals, it is a cash crop having no value to them beyond the income that it provides. Prior to the development of block plantations, some local soap production and medicinal use existed, but these activities have now been superseded by the creation of biodiesel programs. Some villagers expressed disappointment that *Jatropha* had been planted in place of other trees of more immediate local use.

3.6.2 Forest workers

The Forest Department employs both foresters and workers at the local level. Foresters direct local forest workers – cattle guards, guards, and labourers – in day-to-day activities. Additionally, community forest management committees work with the Forest Department to manage the forest's resources, represent villager interests, and participate in resource development projects. Within the committee's jurisdiction, every villager pays a nominal membership fee to become a member with access to forest resources. In general, forest workers are also villagers. As such, many forest workers directly use the forest land for resource extraction, while others (e.g., foresters) are non-users.

The main differences in opinion are between direct land users and non-users. Non-users tend to think of *Jatropha* as a valuable addition to local livelihoods and see the plantations as having a positive influence. Land users tend to have a more ambivalent perspective; some are very concerned about the loss of grass or would have preferred the planting of other trees. In general, land users are unsure of the value of *Jatropha*. While they have not yet seen much benefit, they have been told that the seed yield will improve with time. In the following quotes, land users discuss *Jatropha*'s impact on grass levels:

> Forest worker 4: [W]herever the leaves of the plant fall, at that place there will be no grass growing.

> Forest worker 6: [W]hen it grows, it has big leaves, and it's dark under the tree. Because of the darkness, grass cannot grow.

In contrast, one committee leader indicated that *Jatropha*'s grass-reducing effect can be useful:

> Committee leader 2: [The villagers] use these [*Jatropha*] leaves in the field so that unnecessary grass can be avoided from growing…. For growing ginger, they will spread [the leaves] across the field, so that unnecessary grass will not grow.

Non-users were less concerned with the reduction in grass, arguing that the productivity of grass is low on forest land, and that the *Jatropha* seeds will provide income to villagers. In the following quote, a forester explains that villagers will share grass with each other in years of low rainfall, so the reduction in forest grass in not of concern:

> Forester 1: There is no problem for grass, because if somebody has no animals, but he collects the grass… then he borrows to another person. And next year… [that person] gives in return again. So they can help each other in these conditions.

Although most of the forest workers are also villagers, they are more keenly aware of the value of other resources within the forest, and the impact that forest management practices have had on resource levels. Echoing concerns voiced by the villagers, some forest workers expressed concern over the choice of tree. Rather than planting a tree of more immediate use to villagers, the Forest Department chose to plant a tree that is of no immediate value beyond the selling price of the seeds. In the following three quotes, two of the Forest Department workers elaborate on the perceived non-utility of *Jatropha* plantations. Here they compare *Jatropha*'s characteristics to those of other forest trees:

> Forest Department worker 1: First thing is, it has got a lot of water content in it. Even if you dry it, when you burn it, it burns very quickly, so you cannot really cook food. Whereas these woods – they burn slowly, so you can cook food.

> Forest Department worker 2: This tree is of no use at all. Even if you are going to cut it, where are you going to keep it and wait for it to be dry. And also… about the dead bodies. If somebody dies in the village – this wood you can use to burn their bodies. That wood you cannot use…. It's of absolutely no use…. It's useful because you get money. You go and sell the seeds, so you get money. But to make houses, it's of no use. If you want to cook, it's of no use. If you want to burn a body, it's of no use.

Furthermore, the committee leaders said that they were not consulted by the Forest Department about whether *Jatropha* would be a welcome addition to the forest. A committee leader recalls the Forest Department's motivation for planting *Jatropha*:

> Committee leader 3: [T]he Forest Department told [us] that, all over India, this program is going on, and we are going to plant these trees, and eventually it's going to make us free from the dependence on oil.

Another committee leader describes the growing awareness of the benefits of *Jatropha* that led to the boom in plantation development:

> Committee leader 2: [I]n 2002, the government brought the awareness that the seeds from the *Jatropha* plantation will be used for the preparation of diesel. So the people got

> aware of it, and understood the importance of these plants, and that's why they opted to grow *Jatropha*…. [L]ately, the information has spread very fast, so all the different organizations have also started making the people to grow *Jatropha*.

3.6.3 Panchayat officials

The Panchayat officials said that the loss of grass has been increasing in importance over time, and an awareness of the issue has grown among farmers and villagers as the plants have grown in size and the loss has become more obvious. The Panchayat officials, some of whom are land users, indicated that the current level of opposition to *Jatropha* plantations is such that new plantation developments would incur protest from locals, and that the members of the Gram Sabha had formed a majority position in opposition to future planting activities.

> Panchayat official 4: [E]arlier… there was a government scheme, and so the people got ready…[to] do the plantation. But… the present scenario is such that people are not ready for plantation. They say that [they] don't get enough grass for [their] cattle…. [E]ven if we suggest to them that – in a small patch of land, which is not being used for anything, which is barren land, which is infertile – we can plant over there. But they are not ready for that, because… [they say], "We are having the grass grown in this field… and if we grow the *Jatropha* over there, we will not be getting even the grass which we used to get earlier."

The Panchayat officials indicated that the villagers did not complain about the potential impact on grass levels at first. When the Gram Sabhas were debating the value of the *Jatropha* plantations, they were mostly concerned with the amount of employment that the projects would generate.

While all of the users of common land will be negatively affected by the planting of *Jatropha* on any Panchayat land, the beneficiaries vary. In some Panchayats, women's cooperative groups have been organized to manage the plantations and harvest the seeds for their own benefit, while in others the seeds will be freely available to any villager willing to pluck them. In one Panchayat, officials indicated that villagers would not be allowed to pluck the seeds. Instead, the Panchayat will hire labourers to harvest the seeds, selling them to raise money for other Panchayat programs.

3.6.4 BAIF

Some BAIF field staff members are also land users, while other staff members are not. The BAIF staff members indicated that they had not heard of any complaints from farmers about the grass. They acknowledged that beneath the canopy of the plant, grass production is reduced, but they said that this decrease is more than offset by the increase in grass between the plants. The soil and water conservation efforts, as well as the sowing of grass seeds, have created better forage conditions between the plants:

> BAIF program coordinator: Before plantation, they were harvesting zero. Now they are harvesting something.

A BAIF field supervisor explains why BAIF only discussed the possible benefits with the farmers, and not the possible negative effects:

> BAIF field supervisor: [The farmers] were knowing the side effects of the low grass, earlier. So [we] didn't find it necessary to tell them.

Of the total number of farmers that BAIF initially contacted, about half eventually opted into the planting program. The field supervisor describes the opposition that BAIF faced from some of the farmers that they approached:

> BAIF field supervisor: [We] had to face the opposition from some of the farmers. The reason being is that they are already having less land holding, and if they are going to grow *Jatropha* on some portion, then they will already cut short of the available land…. [T]hey are having less land holding for cultivation, and they are knowing that this will affect the grass level – the quantity of grass…. [Therefore], they didn't opt for the *Jatropha* plantation in their field.

The same field supervisor describes the circumstances under which *Jatropha* plantations would be beneficial to farmers:

> BAIF field supervisor: [I]f you talk all-in-all, then it is a beneficial kind of thing, because it doesn't require any maintenance. None of the cattle are going to graze it, you don't need to water the plants, and you need not to go for the fertilizer of the plant and all…. But… it will not be so much fruitful for the people having a very less land holding. But people who are having a good land holding, they can go for this plantation.

Interpreter: Do you expect that [the BPL] person is going to give you land for growing the plantation, when already he's getting short of land for cultivation?

BAIF field supervisor: [W]e approach to those people who are not using their land. It is either slopey land or rocky land, which they haven't been using for any other purpose.

3.7 DISCUSSION

While the central and state governments have strongly promoted *Jatropha* as a means to improve rural livelihoods through income generation, the impact in Jhadol Tehsil has been mixed, at best. Generally, the future loss of grass was not taken into account during decision-making and was therefore not weighed against the benefits of the plantations. The low seed yields and the reduction in fodder have combined to reduce the benefits and increase the costs of the plantations. While the degradation of pasture land is a serious problem in rural Rajasthan, the use of *Jatropha* to re-vegetate degraded lands – especially common lands – may not have as positive an impact on livelihoods as other, more immediately useful, alternatives.

Since *Jatropha* is planted almost exclusively on public or private pasture land, the most pressing concern has been the plant's impact on access to fodder. The most significant difference in perception is between land users and non-users. Non-users are generally not aware that the grass reduction is of concern to villagers, and for the most part, they say that no villagers voiced this concern during the planning of plantation schemes. Despite our initial concern with the low number of female participants, we did not find a significant difference between the responses from male and female participants.

Participants were often hesitant to judge the net benefit of the plantations. They were not able to clearly separate the impact of the *Jatropha* plantations from the effect of the simultaneous pasture closures, grass seeding, and soil and water conservation efforts. It is therefore important that the positive impacts of the other land improvements are differentiated from the negative impacts of the *Jatropha* plantations in future decision-making and analysis. In Jhadol Tehsil, the wet-season biomass must be measured, so that the loss of grass can be precisely determined and compared with the increases resulting from other measures. Only then will we be able to properly weigh the available alternatives.

All of the study participants, as well as the local NGOs with which we worked, agreed that green cover restoration was a very important objective for Jhadol Tehsil, and that this was the most immediate positive outcome of *Jatropha* planting. Programs that aim to recover degraded land can contribute to poverty alleviation and build resilience to natural shocks (Jodha, 2001). But the participants' responses suggest that if re-vegetation and fodder improvement are the primary objectives of common land development, *Jatropha* is likely to be a poor choice. As the *Jatropha* plants have grown in size, so has opposition to the plantations. Local NGOs corroborate these findings and report opposition to *Jatropha* plantations in other locations within southern Rajasthan (e.g., FES, 2008b).

In Jhadol, the loss of grass will likely have a disproportionate impact on the poorest villagers, both because of the loss of fodder on common lands and because BAIF has targeted BPL families in their plantation program. Since *Jatropha* has been planted in many of the areas where farmers normally collect grass or graze their cattle in dry years, the extent of the plantation programs may increase the region's vulnerability to drought.

The exclusion of fodder considerations in *Jatropha* planning is surprising, considering the importance of animal husbandry to rural livelihoods. This exclusion is especially peculiar in BAIF's case, since they have worked closely with BPL families on other projects. As discussed above, a BAIF field supervisor indicated that concern about potential grass reductions was a major reason that some farmers chose not to plant *Jatropha* when presented with the option. *Jatropha* has a long history of wild, though scattered, growth in Jhadol Tehsil, and these farmers may have observed the grass reduction below mature plants.

BAIF's application of grass seeds and their implementation of water and soil conservation methods to improve soil conditions are commendable, but could easily be coupled with other planting efforts that might have less impact on grass cover. The Foundation for Ecological Security (FES) has implemented non-*Jatropha* fodder improvement programs in Bhilwara District, Rajasthan, using saplings of ber, arunja, and babool (FES, 2008). These trees were among those singled out by participants as making important contributions to village life, with most of the harvesting done to satisfy household needs. The selection of such plants for re-vegetation may therefore be of more immediate benefit to rural livelihoods, both in time and space. Even if *Jatropha* has net benefits for rural livelihoods when compared to the status quo, it may not be the best option for re-vegetation. Future research must take better account of such tradeoffs.

One of the most striking features of the *Jatropha* plantations in Jhadol Tehsil is the haphazard way in which planting and management techniques have been applied across and within plantation programs. A large area was planted within a relatively short period of time; long before the first plantations reached maturity. Prior to these plantation programs, the local (and national) experience with *Jatropha* was mostly limited to the sparse growth of individual wild plants and the use of densely planted *Jatropha* along field boundaries to prevent browsing by livestock. The plantation and management techniques need to be better refined and more systematically applied.

The experience in Jhadol Tehsil may well be a cautionary tale for other sub-districts, other states, and other countries. Without refined management techniques and planting materials, the rapid development of plantations may limit local benefits for decades to come compared with other, more cautious approaches. Since individual plants can live for up to 50 years, the impact of poor planting materials and early mistakes in pruning will be magnified in the long term. Anecdotal reports from other areas near Udaipur suggest that farmer groups and NGOs have resisted the planting of *Jatropha* on pasture land. In Jhadol Tehsil, the opposition may have been muted by the involvement of a long-standing NGO in the plant's promotion. Panchayat officials cited BAIF's example as a part – though perhaps small – in their decision to plant *Jatropha*.

As discussed in detail by Achten et al. (2008), the current state of scientific knowledge is seriously lacking. Although many university, government, and industry researchers are working to refine planting materials and management techniques, the plant's five-year maturation period has so far impeded quick progress in this area. The formal, peer-reviewed publication of scientific research has also been slow, which may result, in part, from concerns about intellectual property rights in an industry that has garnered substantial interest from investors.

The central and state governments have shown no significant signs that they are reconsidering the promotion of *Jatropha* biodiesel. It is uncertain whether government officials and decision-makers at higher levels are aware of the local backlash. If they continue to encourage the rapid development of plantations, Jhadol Tehsil will not be an isolated incident of *Jatropha* over-development, and there may be more fundamental and more widespread impacts on land use and fodder security. Any policy shift having such a profound impact on local land use should be deeply examined prior to widespread application.

3.8 CONCLUSIONS

It is critically important to consider the lost grass production and alternative land reclamation options in planning for the development of pasture land. We cannot simply assume that the loss of forage will have no significant impact since the land is relatively infertile. Since the seed yields are lower than expected and best-practice management techniques have not been developed, the loss of grass may well tip the scale in favour of alternative options. The long lifecycle of *Jatropha* plants means that poor planting material and early mistakes in plant management will continue to affect rural livelihoods for many years.

Following India's example, other governments in Southeast Asia, Africa, and South America have expressed a strong interest in using "marginal" lands to produce *Jatropha* biodiesel, increasing energy security and spurring rural development with little impact on food security. The use of so-called waste land avoids the direct use of fertile cropland for biofuels and may not have as large an impact on food security at the state, national, and global levels. Unfortunately, it may severely impact the resilience of local farmers to adverse climatic conditions that create occasional local or regional shortages of food and animal feed. Given the importance of livestock to rural livelihoods in Rajasthan, the adverse impact of widespread *Jatropha* plantations on animal feed may magnify the effects of periodic drought. This strongly suggests that early plantation programs should be approached with caution, and that widespread planting should not occur until the level of scientific knowledge matches that of the national enthusiasm for *Jatropha*.

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4 CONCLUSION

Our analysis of national biofuel targets shows that the land required for biofuel production is potentially large. Even low blending targets would require a substantial proportion of arable land area. The future contribution of biofuels to energy security and climate change mitigation may well hinge on their potential impact on the availability of arable land for other production. The disruption of other agricultural systems has already resulted in vigorous opposition to biofuels expansion (e.g., Schulz, 2007). The vast land area required to meet high national targets may force some countries to import ethanol and biodiesel to satisfy their domestic demand, nullifying the potential energy security benefits of the biofuel policies. Similarly, unregulated international trade may result in poorly controlled land-use change in jurisdictions with weak or unenforceable environmental laws. Such land-use change may seriously reduce the contribution of biofuels to climate change mitigation (e.g., Fargione et al., 2008; Reijnders & Huijbregts, 2008; Searchinger et al., 2008).

In Jhadol, Rajasthan, the local impacts on animal feed and common grazing land may have serious implications for poor villagers who are highly dependent on their livestock. Since *Jatropha* is planted in many of the areas where farmers and villagers normally gather grass in dry years, the extensive plantation development may reduce the regional capacity to cope with droughts and other environmental stressors (e.g., pests, disease, floods). *Jatropha* plantations may negatively impact the resilience of villagers and farmers with small land holdings. India's strong push for biodiesel production does not properly account for these local impacts. Policy-makers have simply assumed that there are no negative impacts, since it is being planted on so-called waste land (e.g., PC, 2003). Farmers and concerned organizations in other parts of India may learn from the experience in Jhadol Tehsil. It may not be wise to invite plantation development within the current scientific and policy context. Jhadol's climatic suitability and abundance of waste land mean that lessons learned here will be equally applicable in other, less suitable, regions of India. Furthermore, since India is a world leader in *Jatropha* plantation development, Jhadol's example can provide lessons to decision-makers who are considering *Jatropha* biodiesel policies in other developing countries.

Future research must address questions about the land-use impacts of biofuel developments. International trade flows will determine the specific regions in which biofuels are produced and land use is offset by the displacement feed crops. The cascade of direct and indirect land-use change is not well understood, and we cannot be certain of the subsequent impacts without understanding the specific land uses that will be displaced. Serious questions remain about *Jatropha*'s potential as a biofuel crop. The planting materials and management techniques require substantial refinement through research and development programs before it can be a reliable biodiesel feedstock. The planting of *Jatropha* on a commercial scale should be approached with caution, considering that the impacts of low productivity and land-use change will be felt throughout the lifetime of the plant. Further research may estimate the local and regional impacts of the *Jatropha* plantation programs, using an economic model to determine the extent to which the socioeconomic resilience to drought and other stressors may be impacted by widespread planting. Overall, land-use impacts need to be properly integrated into decision-making for national targets and biofuel promotion policies. Without such integration, land-use change may well counteract the very benefits that biofuel programs aim to create.

4.1 REFERENCES

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5 APPENDICES

APPENDIX A: FULL RESULTS BY COUNTRY

Table 5.1: Land requirements to meet ethanol targets in full, for each potential feedstock

Country	Ethanol target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Argentina	5% (volume)	0.327	Maize	3440	3.9%	0.3%	35–41%	0.2%
			Wheat	1100	5.3%	1.0%	18–21%	0.8%
			Sugarcane	5850	19%	0.2%	0%	0.2%
			Sorghum	2030	31%	0.5%	25–30%	0.4%
Australia	350 million litres	0.350	Wheat	660	4.3%	1.1%	11–15%	0.9–1.0%
			Sugarcane	7510	11%	0.1%	0%	0.1%
			Barley	650	12%	1.1%	10–14%	1.0%
			Sorghum	1020	51%	0.7%	13–18%	0.6%
Bolivia	-	-	Sugarcane	4240	-	-	0%	-
			Maize	1180	-	-	12–17%	-
			Rice	860	-	-	6.5–9.1%	-
			Potato	660	-	-	7.6–11%	-
			Sorghum	1160	-	-	14–20%	-
			Cassava	1990	-	-	8.5–12%	-
Brazil	25% (volume)	9.84	Sugarcane	6570	27%	2.5%	0%	2.5%

Table 5.1 (continued): Land requirements to meet ethanol targets in full, for each potential feedstock

Country	Ethanol target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Canada	5% (volume)	2.27	Wheat	1070	21%	4.7%	18–21%	3.7–3.8%
			Maize	4300	46%	1.2%	43–51%	0.6–0.7%
			Barley	1180	50%	4.2%	19–22%	3.3–3.4%
Chile	5% (volume)	0.281	Wheat	1970	36%	9.6%	32–38%	6.0–6.5%
			Maize	5780	42%	3.3%	58–69%	1.0–1.4%
			Sugar beet	11900	73%	1.6%	53–62%	0.6–0.8%
			Oats	1630	180%	12%	34–40%	6.9–7.7%
			Potato	2340	200%	8.1%	27–32%	5.5–5.9%
China	10% (volume)	16.6	Maize	2730	24%	4.6%	27–42%	2.6–3.3%
			Rice	2360	25%	5.2%	18–27%	10–11%
			Wheat	1850	40%	6.7%	30–46%	3.6–4.7%
			Sweet potato	2230	150%	5.6%	14–21%	4.4–4.8%
			Sugarcane	6120	200%	2.0%	0%	2.0%
			Potato	1720	160%	7.2%	20–31%	5.0–5.8%
Colombia	10% (volume)	0.880	Sugarcane	8220	25%	5.0%	0%	5.0%
			Rice	2010	89%	21%	15–20%	16–18%
			Maize	1320	110%	31%	13–18%	26–27%
			Cassava	2120	230%	19%	9.1–12%	17–18%
Dominican Republic	15% (volume)	0.294	Sugarcane	4720	62%	7.6%	0%	7.6%
			Rice	1820	120%	20%	14–16%	17%

Table 5.1 (continued): Land requirements to meet ethanol targets in full, for each potential feedstock

Country	Ethanol target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
European Union	10% (energy)	24.7	Wheat	2260	42%	9.9%	37–44%	5.6–6.2%
			Maize	3480	76%	6.4%	35–41%	3.8–4.2%
			Barley	1700	100%	13%	27–32%	9.0–9.7%
			Sugar beet	8790	130%	2.6%	39–46%	1.4–1.6%
			Potato	3040	330%	7.4%	35–42%	4.3–4.8%
Germany	6.25% (volume)	2.42	Wheat	3230	24%	6.3%	53–63%	2.4–3.0%
			Barley	2380	51%	8.6%	37–44%	4.8–5.4%
			Sugar beet	8750	65%	2.3%	39–46%	1.3–1.4%
			Maize	4610	120%	4.4%	46–55%	2.0–2.4%
			Potato	4520	190%	4.5%	53–62%	1.7–2.1%
			Rye	2070	200%	9.9%	30–36%	6.3–6.9%
			Triticale	2170	230%	9.4%	36–43%	5.3–6.0%
India	20% (volume)	4.79	Rice	1140	9.8%	2.6%	8.6–25%	2.0–2.4%
			Wheat	1190	15%	2.5%	19–56%	1.1–2.0%
			Sugarcane	5780	20%	0.5%	0%	0.5%
			Maize	990	68%	3.0%	9.9–29%	2.2–2.7%
Indonesia	5% (volume)	1.48	Rice	1740	7.3%	3.8%	13–28%	2.8–3.3%
			Maize	1770	25%	3.8%	18–38%	2.3–3.1%
			Cassava	2980	40%	2.2%	13–27%	1.6–2.0%
			Sugarcane	6840	61%	1.0%	0%	1.0%

Table 5.1 (continued): Land requirements to meet ethanol targets in full, for each potential feedstock

Country	Ethanol target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Italy	1% (volume)	0.201	Maize	4760	3.7%	0.5%	39–57%	0.2–0.3%
			Wheat	1500	6.0%	1.7%	20–29%	1.2–1.4%
			Sugar beet	9110	11%	0.3%	33–48%	0.1–0.2%
			Rice	2430	37%	1.0%	15–22%	1.8–1.9%
			Barley	1490	42%	1.7%	19–28%	1.2–1.4%
Jamaica	10% (volume)	0.065	Sugarcane	4510	38%	8.3%	0%	8.3%
Japan	500 million litres	0.500	Rice	2420	12%	4.7%	18–32%	3.2–3.9%
			Sugar beet	9370	79%	1.2%	42–72%	0.3–0.7%
			Wheat	1790	130%	6.4%	29–51%	3.2–4.5%
			Potato	3690	150%	3.1%	43–74%	0.8–1.8%
Madagascar	5% (volume)	NO DATA	Cassava	1160	-	-	5.0–14%	-
			Sugarcane	2980	-	-	0%	-
			Maize	710	-	-	7.1–19%	-
Malaysia	-	-	Rice	1260	-	-	9.5–11%	-
			Sugarcane	6740	-	-	0%	-
			Cassava	1970	-	-	8.5–10%	-
New Zealand	3.4% (volume)	0.097	Wheat	3340	75%	3.2%	55–65%	1.1–1.5%
			Barley	2360	68%	4.5%	37–44%	2.6–2.9%
			Maize	5780	110%	1.9%	58–69%	0.6–0.8%
			Potato	5230	170%	2.0%	61–72%	0.6–0.8%

Table 5.1 (continued): Land requirements to meet ethanol targets in full, for each potential feedstock

Country	Ethanol target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Paraguay	18% (volume)	0.033	Cassava	3300	3.5%	0.3%	14–18%	0.2%
			Maize	1290	6.3%	0.7%	13–16%	0.6%
			Sugarcane	4410	11%	0.2%	0%	0.2%
			Wheat	810	14%	1.1%	13–17%	0.9–1.0%
Peru	7.8% (volume)	0.196	Rice	2530	24%	2.1%	19–32%	1.5–1.7%
			Maize	1440	29%	3.7%	14–24%	2.8–3.2%
			Sugarcane	9840	29%	0.5%	0%	0.5%
			Potato	1410	53%	3.8%	16–27%	2.8–3.2%
			Cassava	2140	110%	2.5%	9.2–15%	2.1–2.3%
Philippines	10% (volume)	0.805	Rice	1330	15%	12%	10–22%	9.5–11%
			Maize	1110	29%	15%	11–24%	11–13%
			Sugarcane	5800	36%	2.8%	0%	2.8%
South Africa	10% (volume)	1.55	Maize	1670	30%	6.3%	17–27%	4.6–5.3%
			Sugarcane	4380	83%	2.4%	0%	2.4%
			Wheat	1050	180%	10%	17–28%	7.2–8.3%
South Korea	-	-	Rice	2450	-	-	18–32%	-
Thailand	10% (volume)	0.786	Rice	1060	7.3%	4.9%	8.0–14%	4.2–4.5%
			Sugarcane	5060	15%	1.0%	0%	1.0%
			Cassava	3730	21%	1.4%	16–29%	1.0–1.2%
			Maize	2070	36%	2.5%	21–37%	1.6–2.0%

Table 5.1 (continued): Land requirements to meet ethanol targets in full, for each potential feedstock

Country	Ethanol target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
United Kingdom	5% (volume)	1.45	Wheat	3530	22%	7.1%	58–68%	2.2–3.0%
			Barley	2370	61%	11.0%	37–44%	5.9–6.6%
			Sugar beet	8570	110%	2.9%	38–45%	1.6–1.8%
			Potato	4830	210%	5.2%	56–66%	1.7–2.3%
United States	136 billion litres	136	Maize	4890	96%	16%	49–58%	6.7–8.1%
			Wheat	1250	540%	63%	20–24%	48–50%
Uruguay	5% (volume)	0.032	Rice	2430	7.5%	1.0%	18–25%	0.8%
			Wheat	1090	19%	2.2%	18–24%	1.7–1.8%
			Maize	2250	27%	1.1%	23–31%	0.8%
			Barley	1030	28%	2.4%	16–22%	1.9–2.0%
Vietnam	500 million litres	0.500	Rice	1810	3.7%	4.3%	14–27%	3.1–3.7%
			Maize	1840	28%	4.2%	19–37%	2.6–3.4%
			Sugarcane	4900	35%	1.6%	0%	1.6%

Table 5.2: Land requirements to meet biodiesel targets in full, for each potential feedstock

Country	Biodiesel target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Argentina	5% (volume)	0.698	Soybeans	600	8.7%	3.9%	56–66%	1.3–1.7%
			Sunflower seed	860	39%	2.7%	18–21%	2.1–2.2%
Australia	-	-	Rapeseed	570	-	-	16–22%	-
Bolivia	20% (volume)	0.109	Soybeans	440	31%	7.1%	41–58%	3.0–4.2%
			Sunflower seed	460	200%	6.8%	9.6–13%	5.9–6.1%
Brazil	5% (volume)	2.47	Soybeans	560	22%	7.4%	53–62%	2.8–3.5%
Canada	2% (volume)	0.326	Rapeseed	870	7.9%	0.8%	24–28%	0.6%
			Soybeans	580	50%	1.2%	54–64%	0.4–0.6%
Chile	5% (volume)	0.380	Rapeseed	1910	2400%	13%	52–61%	5.1–6.4%
			Sunflower seed	760	24000%	33%	16–19%	27–28%
China	-	-	Rapeseed	950	-	-	26–40%	-
			Groundnuts	1280	-	-	32–48%	-
			Soybeans	400	-	-	38–58%	-
			Cottonseed	340	-	-	22–34%	-
Colombia	10% (volume)	0.575	Oil palm fruit	6030	60%	2.6%	6.8–9.2%	2.4%
Dominican Republic	2% (volume)	0.016	Oil palm fruit	4940	31%	0.2%	5.6–6.6%	0.2%
			Coconut	710	61%	1.7%	3.9–4.6%	1.6%
European Union	10% (energy)	25.9	Rapeseed	1660	340%	14%	45–54%	6.6–7.8%
			Sunflower seed	800	850%	29%	17–20%	24%

Table 5.2 (continued): Land requirements to meet biodiesel targets in full, for each potential feedstock

Country	Biodiesel target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Germany	6.25% (volume)	2.48	Rapeseed	1930	97%	11.0%	53–62%	4.1–5.1%
India	20% (volume)	9.76	Rapeseed	570	290%	11%	16–45%	5.9–9.0%
			Groundnuts	440	360%	14%	11–31%	9.6–13%
			Coconut	860	590%	6.7%	4.7–14%	5.8–6.4%
			Soybeans	220	670%	28%	20–58%	12–23%
			Cottonseed	96	1200%	64%	6.3–18%	52–60%
Indonesia	5% (volume)	0.986	Oil palm fruit	5500	5.3%	0.5%	6.2–13%	0.4–0.5%
			Coconut	1080	34%	2.5%	5.9–12%	2.2–2.4%
Italy	1% (volume)	0.297	Sunflower seed	1000	210%	3.8%	17–25%	2.9–3.2%
			Soybeans	760	250%	5.0%	58–84%	0.8–2.1%
Jamaica	-	-	Coconut	600	-	-	3.3–3.9%	-
Japan	-	-	Soybeans	360	-	-	33–58%	-
			Groundnuts	1010	-	-	25–43%	-
Madagascar	5% (volume)	NO DATA	Groundnuts	380	-	-	9.4–26%	-
			Coconut	450	-	-	2.4–6.6%	-
			Oil palm fruit	3770	-	-	4.2–12%	-
Malaysia	5% (volume)	0.352	Oil palm fruit	6480	1.6%	0.7%	3.5–4.1%	0.3–0.7%
New Zealand	3.4% (volume)	0.063	Rapeseed	1110	2800%	6.3%	30–36%	4.0–4.4%
			Linseed	830	7600%	8.4%	25–30%	5.9–6.3%

Table 5.2 (continued): Land requirements to meet biodiesel targets in full, for each potential feedstock

Country	Biodiesel target	Projected annual demand (billion L)	Feedstock	Biofuel yield (L/ha)	Proportion of current crop area	Proportion of arable land	Co-product allocation, Scenario A2	Proportion of arable land (net)
Paraguay	5% (volume)	0.037	Soybeans	500	4.2%	2.0%	46–58%	0.9–1.1%
Peru	5% (volume)	0.307	Oil palm fruit	5690	520%	1.2%	6.4–11%	1.1–1.2%
			Cottonseed	150	2500%	57%	9.7–16%	48–52%
Philippines	2% (volume)	0.139	Coconut	780	5.5%	1.8%	4.3–9.3%	1.7%
South Africa	5% (volume)	0.425	Sunflower seed	610	130%	4.8%	13–20%	3.8–4.2%
			Soybeans	380	740%	7.6%	36–58%	3.2–4.8%
			Groundnuts	640	1100%	4.5%	16–26%	3.4–3.8%
South Korea	3% (volume)	0.886	Soybeans	360	2800%	150%	34–58%	63–100%
			Sesame seed	340	7400%	160%	7.5–13%	140–150%
Thailand	10% (volume)	1.63	Oil palm fruit	5260	99%	1.6%	5.9–11%	1.5%
			Coconut	1070	520%	8.1%	8.5–15%	7.2–7.6%
United Kingdom	5% (volume)	1.41	Rapeseed	1780	150%	13.7%	48–57%	5.9–7.1%
United States	-	-	Soybeans	620	-	-	58–69%	-
			Rapeseed	880	-	-	24–28%	-
Uruguay	5% (volume)	0.070	Soybeans	460	82%	12%	43–58%	4.9–6.7%
			Sunflower seed	660	90%	8.1%	14–19%	6.6–7.0%
Vietnam	50 million litres	0.050	Groundnuts	750	26%	1.0%	18–37%	0.7–0.8%
			Coconut	1250	30%	0.4%	6.8–14%	0.4%
			Soybeans	310	90%	2.5%	29–58%	1.0–1.8%

APPENDIX B: UBC RESEARCH ETHICS BOARD CERTIFICATE OF APPROVAL

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - MINIMAL RISK

PRINCIPAL INVESTIGATOR:	INSTITUTION / DEPARTMENT:	UBC BREB NUMBER:
Milind Kandlikar	UBC/College for Interdisciplinary Studies/Asian Research	H09-00258

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
N/A	N/A

Other locations where the research will be conducted:
This study will be conducted in India, and the interviews will take place at the subject's office or workplace.

CO-INVESTIGATOR(S):

Kieran M. Findlater

SPONSORING AGENCIES:

N/A

PROJECT TITLE:
Assessing the Land-Use Impacts of Biodiesel in India

CERTIFICATE EXPIRY DATE: April 8, 2010

DOCUMENTS INCLUDED IN THIS APPROVAL:

DATE APPROVED:

April 8, 2009

Document Name	Version	Date
Consent Forms:		
Main Study Consent Form	N/A	April 1, 2009
Questionnaire, Questionnaire Cover Letter, Tests:		
Sample Interview Script	N/A	April 1, 2009
Letter of Initial Contact:		
Letter of Initial Contact	N/A	April 1, 2009

The application for ethical review and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board and signed electronically by one of the following:

Dr. M. Judith Lynam, Chair
Dr. Ken Craig, Chair
Dr. Jim Rupert, Associate Chair
Dr. Laurie Ford, Associate Chair
Dr. Anita Ho, Associate Chair