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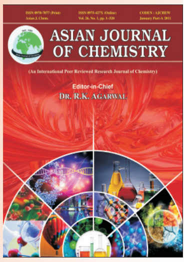
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Role of Liquid Biofuels in Realizing of Global Sustainability

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Liquid biofuels can provide a much needed substitute for fossil fuels used in the transport sector. They can contribute to climate and other environmental goals, energy security and economic development. However, in order to achieve such objectives many difficulties and challenges must be overcome. In the present study, we consider these issues from the view of realizing of global sustainability. In this paper, we first give the definition of sustainable development, then economic and environmental sustainability of biofuel are discussed. Finally, the social dimensions of biofuel sustainability are prospected.

Keywords: Biofuel, Sustainability, Economic, Environmental, Social.

INTRODUCTION

Currently the world is facing a systematic energy and environmental problem of increased CO_2 emissions, decreased soil-carbon content and global-climate change. To solve the massive global energy and environmental sustainability problem, it likely requires a comprehensive portfolio of Research and Development efforts with multiple energy technologies.

Biomass can be used to provide energy in many forms including electricity, heat, solid, gaseous and liquid fuels. These bioenergy options have been actively pursued in both the developed and developing world.

Different people are pushing development of biofuels for different reasons. Some see biofuels as a substitute for high priced petroleum, either to ease the burden on consumers, to diversify the sources of energy supplies, or to reduce escalating trade deficits. Some have focused on biofuels as a way to extend available energy in the context of increasing world demand for transportation fuels. Others target biofuels as a substitute for more carbon intensive energy. Still others see biofuels as an economic opportunity.

Today, plant-based fuels like ethanol and biodiesel seem to be emerging as a serious alternative fuel ahead of technologies like fuel cell vehicles, electric/hybrid vehicles and natural gas vehicles. There are several reasons for the excitement surrounding biofuels[1-5].

Biofuels are replenishable: Biofuels are an inexhaustible resource since the stock can be replenished through agriculture. Technologies like fuel cells and electric vehicles depend on hydrogen and the electric grid, respectively and are effectively dependent on depletable sources like natural gas and coal, respectively.

Biofuels can reduce carbon emissions: Biofuels are sometimes considered as a solution to climate change. While this may be too optimistic, it is true that direct carbon emissions from combustion of biofuels are insignificant compared to fossil fuels.

Biofuels can increase farm income: Today decline in farm income is a problem the world over. With biofuels, most countries will be able to grow one or more types of crops in which they possess a comparative advantage and use them to meet either domestic or foreign demand or both. This increased demand for agriculture is expected to increase farm income.

Biofuels can improve energy security: The above fact also means that countries can produce their own fuel and reduce their dependence on foreign sources for energy.

Biofuels can create new jobs: Biofuels are more labor intensive than other energy technologies on per unit of energy delivered basis. The production of the feedstock and the conversion require greater quantities of labor compared to that required for extraction and processing of fossil fuels or other industrially based technologies like hydrogen and electric vehicles.

Definition of sustainable development: The simplest definition of sustainable development was given by the World Commission on Environment and Development[6]: development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In the bioenergy sector, sustainability is *a sine qua non* for long-term viability for the following reasons[5,7]:

Biofuels are promoted as part of renewable energy precisely to put human society on a sustainable path with respect to energy use as opposed to the continuous dependence on finite and exhaustible fossil energy. Biofuels are aimed at lowering greenhouse gas (GHG) emissions, rendering climate change conditions (*i.e.* rising average atmospheric temperature) more hospitable to human life in the long run. The potentially large share of land, labour and resources required for biomass production may overwhelm what is currently used for food and feed production and hence jeopardize the long-term capacity to meet food and energy needs, even as biofuels could satisfy only 5-10 of total or global energy demand.

Tackling bioenergy sustainability requires dealing simultaneously with its many dimensions-economic, environmental and social. The latter dimension encompasses such considerations as social and gender equity, participation and equal rights[8].

Economic sustainability of biomass-biofuels: Three of the most important criteria for economic sustainability are profitability (the price of the biofuel exceeds the production costs), efficiency (the maximum amount of yield is obtained with a given quantity of resources) and equity (distribution of benefits or value added among actors along a biomass-biofuel value chain or across generations)[4,5]. From the perspective of sustainability, the first objective is to ensure the long-term economic viability of the productive system.

Profitability and efficiency: The first criterion for long-term viability of a production system utilizing resources to produce a marketable output is that it shows economic profitability: producers will only be willing to pursue biofuel production if it is economically profitable. Key factors that can affect profitability include alternative competitive uses of the feedstocks and energy prices. Alternative uses of the feedstock play an important role in the decision making process of producers. If prices for biofuels fall below the prices of other possible end-products (food, feed, timber, *etc.*) it would be more profitable to cultivate these products than to derive fuel out of the feedstock. Accordingly, their prices determine the price floor for biofuels. To be profitable and competitive with fossil fuels, biofuel production costs have to stay below the price of the oil equivalent. Therefore, oil prices set a price ceiling for the price of biofuels. If costs exceed this value, the biofuels will be automatically priced out of the market.

The economic profitability of biofuels has been invariably attributed to government subsidies or mandates, the only exception being Brazil's sugar cane ethanol. Some argue that biofuels, by pushing prices up through increased demand, could lower the very need for farm subsidies. The problem thus far is that most biofuel programmes in advanced economies are themselves maintained largely through government subsidies and demand-generating mandates.

In general, feedstock costs account for the main part of the production costs, while by-products can increase the economic viability of biofuel production. Two exceptions to this general pattern are ethanol derived from sugar cane in Brazil and from sugar beet in the European Union.

Overall economic profitability and hence long-term viability for biofuels, is a moving target. It depends on cost-reducing technological improvements and relative price competitiveness (with alternative uses of feedstocks). Competition with alternative uses of feedstocks may also be localized and highly determined by the presence or absence of policy incentives or disincentives.

Economic equity: The concept of intra-generational equity, referring to fairness in allocation of resources between simultaneous competing interests, has received relatively less attention than inter- generational equity (between present and future generations). It implies social and economic justice, quality of life, democracy, public participation and empowerment; the incidence and magnitude of unsustainable practices originate from power inequality. It is in this context that the environmental limits of supporting ecosystems are defined[8].

The growing global demand for liquid biofuels and the attendant environmental and socio-economic transformations might have different impacts on men and women in the same household as well as male- and female-headed households, as regards their access to and control of land and other productive assets, their level of participation in decision-making, employment opportunities and conditions and their food security. Both the nature and the magnitude of these impacts will depend on the specific technology and on the socio-economic and policy context.

The potential high land-use requirement for biofuels might put pressure on the so-called "marginal" lands (perceived as less critical for food production), prompting their conversion to biofuels production.

Competition with food: One of the key drivers determining longterm economic viability of biofuels is competition with food. This is because biofuel production (through the use of biomass) may compete with food for the same resources, notably land, labour and water. Food security is a key developmental goal and the potential conflict with energy security can play out at many levels including national and even regional. Which takes priority and to what extent food security could impede large-scale biofuel development depend on the overall balance between size of population, projected growth, availability of land (or its scarcity) as well as its suitability for food crops versus energy crops only. Other contributing factors include prospects for increased productivity and the implications for land availability to meet multiple demands, as well as the relative profitability of feedstock for biofuels *versus* alternative uses of land, water and labour-for food, feed or other industrial uses. In the end, incentives for feedstocks for bioenergy versus food or other crop uses will boil down to which end-product offers greater value added and raises the incomes of farmers, who can then afford greater access to food and nutrition[9-11].

According to FAO's definition, food security exists when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life". In other words, people obtain food security when there is adequate food available, supply is sufficiently stable and everyone has access to the food. When feedstocks are used for food, the availability of food will be constrained by the biofuel supply as long as they compete for the same resources (land, fertilizers, water, *etc*.). The impact can be more or less direct depending on the feedstock and where it is cultivated. There are also non-food feedstocks, most notably Jatropha, under consideration to produce biodieselhere the feedstock is inedible and does not require a lot of input.

Trade competition: Along with economic sustainability, equity of trade refers to the possibilities open to different countries for entering the international bioenergy market. Given the size of the energy market, future energy demand, the distribution of land resources and the environmental priorities, industrialized countries are expected to remain major consumers of biofuels while many developing countries have the potential to become main producers and exporters. But biofuel trade has been restricted in recent years by industrial countries through a combination of subsidies and tariffs to ensure that the support is directed towards domestic producers only. Still, trade is expected to play a significant role in the global development of biofuels[5].

The growth of biofuel production and trade are ultimately interlinked. The potential for biofuel demand growth is huge for much of the world, especially industrialized and large emerging economies, but the inherent imbalances between supply possibilities and demand are also significant. This gives trade a critical role in regulating supply and demand balances globally and between countries with excess production and excess demand.

Overall, a larger growth in biofuel trade could cut both ways. On the up side, trade will offer new and significant development opportunities and new sources of revenues for producers, including small-scale farmers. On the down side, expanding trade in biofuel could unleash huge investments in biofuels in some areas with unintended consequences (*e.g*. overuse of land and water resources) if sustainability safeguards are not maintained. Appropriate trade and development policies must ensure a more balanced outcome from these development strategies. Modalities for such policies can only be specified at a country or even subnational level.

Environmental sustainability of biomass-biofuels[5,12]

Energy balance: One important motivation for bioenergy policies is to increase energy security. Fossil fuels are finite and prices are expected to rise substantially in the future. Renewable bioenergy is seen as a way to diversify the energy sources.

The contribution of any biofuel to energy supply depends both on the energy content of the biofuel and on the fossil energy going into its production. This includes energy required to cultivate (fertilizers, pesticides, irrigation technology, tillage) and harvest the feedstock, to process the feedstock into biofuel and to transport the feedstock and the resulting biofuel through the various phases of production and distribution.

Fossil energy balance, defined as the ratio between renewable energy output of the resultant biofuel and fossil energy input needed in its production, is a crucial factor in judging the desirability of biomass-derived biofuel: this concept measures to what extent biomass is qualified to replace fossil fuels. An energy balance of 1.0 indicates that the energy requirement for the bioenergy production is equal to the energy it contains. In other words, the biofuel provides no net energy gain or loss. A fossil fuel energy balance of 2.0 means that a litre of biofuel contains twice the amount of energy as was required for its production.

Variations in the estimated fossil energy balances across feedstocks and fuels depend on factors such as feedstock productivity, production location, agricultural practices and conversion technologies, including the source of energy used for the conversion process.

Conventional petrol and diesel usually have an energy balance ranging between 0.8-0.9 because some energy is consumed in refining crude oil into usable fuel and transporting it to markets. If a biofuel has a fossil energy balance exceeding these numbers, it contributes to reducing dependence on fossil fuels.

For crop-based ethanol, the estimated balances range from 1.34 for maize to around 2-8 for sugar cane. Put differently, corn ethanol yields 34 more energy than it takes to produce it, including growing the corn, harvesting it, transporting it and distilling it into ethanol, given the following assumptions: fertilizers are produced by modern processing plants; corn is converted in modern ethanol facilities; and farmers achieve average corn yields. It is to be expected that the net energy balance value will rise with increases in corn yield. A higher net energy balance could be due to a higher average corn yield that lowered the energy input used per acre, increased energy efficiency in fertilizer production and other agricultural chemicals, the adoption of energy-saving technologies in corn ethanol conversion and higher co-product credits.

It is generally acknowledged that biodiesel produced from temperate oilseeds, sugar beet, wheat and maize have limited ability to displace other fuels either because of their low yields or their high input requirements. Estimated fossil fuel balances for biodiesel range from around 1-4 for rapeseed and soybean feedstocks, due to the lower biomass yields per ha and the more energy-intense conversion process. Palm oil could reach an energy balance even higher than 9.0 (*i.e*. nine times the energy required for its production).

Conventional biofuels are relatively mature, but overall sustainability of the technologies could be further improved. Conversion efficiency improvements will not only lead to better economic outcomes but also increase land-use efficiency and the environmental performance of conventional biofuels. For conventional biodiesel, key areas for improvement include: More efficient catalyst recovery; improved purification of the coproduct glycerine and enhanced feedstock flexibility.

Further cost improvements could be achieved by maximizing value-added co-product solutions and by better integrating upstream and downstream processes. Producing conventional and/or advanced biofuels in biorefineries would promote more efficient use of biomass and bring associated cost and environmental benefits.

Generating ethanol from lignocellulosic wastes through hydrolysis and fermentation has the potential to give encouraging bioenergy yields in relation to the required fossil energy inputs, but the technology has yet to be fully deployed commercially. The conversion of cellulose to ethanol involves two steps: the cellulose and hemicelluloses components of the biomass are first broken down into sugars, which are then fermented to obtain ethanol. The very wide range of estimated fossil fuel balances for cellulosic feedstocks reflects the uncertainty regarding this technology and the diversity of potential feedstocks and production systems.

Greenhouse gas and other air pollutants: Tackling global warming and the possibility of reducing greenhouse gas emissions is the second main driver for biofuel development. The negative effects of greenhouse gas emissions on climate have been known for a long time. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change observed that greenhouse gas emissions need to be reduced by 50-85 % by 2050 in order to stabilize the concentration of greenhouse gases in the atmosphere. Given that fossil fuels used in transport and heating and cooling systems are the largest contributors to global warming (75 % of total CO_2 emissions), one of the most important targets will be to cut emissions in this area. Greenhouse gas emission assessments typically include those of CO_2, methane (CH_4), nitrous oxide (N_2O) and halocarbons. The gases are released during the whole-product life-cycle of the biofuel depending on the agricultural practices (including fertilizer use, pesticides, harvesting, *etc*.), the conversion and distribution process and the final consumption and use of by-products.

Concerns about climate change and the need to reduce greenhouse gas emissions have become increasingly important in continuing policy support for biofuels. The biofuel industry is therefore increasingly required to demonstrate that the net effect is lower greenhouse gases when taken across the whole lifecycle, from crops to cars. While plants absorb CO_2 from the atmosphere when they are growing, which can offset the CO_2 produced when fuel is burned, CO_2 is also emitted at other points in the process of producing biofuels.

Air pollution is related to greenhouse gas emissionsits localized effects contribute to deteriorating local and regional air quality. During biomass production, the major air pollutants emitted include CO_2, N_2O, CH_4, carbon monoxide (CO) and nitrogen oxides (NO_x). Such gases and particles are released when burning practices are applied to clear the fields. Moreover, nitrogen fertilizers are one of the foremost emitters of N_2O, which, besides being a potent greenhouse gas, also causes ozone depletion, which itself contributes to climate change.

During biofuels use in transport, a number of pollutants are released, such as CO, particulate matter (PM), total hydrocarbons (THC), volatile organic compounds (VOC), sulphur compounds and dioxins. These gases can be dangerous both for the environment and human health. However, compared to fossil fuels, biodiesel and ethanol emit fewer pollutants, except for NO, which are higher under biofuels.

Life cycle assessments: In order to determine whether a biomass biofuel system results in a net reduction in greenhouse gas emissions or an improved energy balance (input-output energy ratio), a life-cycle assessment (LCA) is commonly used. According to ISO 14040, an life-cycle assessment is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle."

In an life-cycle assessment, all input and output data in all phases of the product's life cycle including biomass production, feedstock storage, feedstock transportation, biofuel production, biofuel transportation and final use are required. Also, all outputs are accounted for including gases (leaked or captured) and by-products. Many life-cycle assessment approaches are reported but most focus on a few key input categories and two primary environmental criteria: greenhouse gas emissions and energy balance. Few life-cycle assessments encompass additional criteria such as water use, or impacts on soils.

Life-cycle assessments of the environmental impacts of biofuel production and consumption have shown a wide disparity in results, from net reduction in greenhouse gas emissions to a net increase, as well as risks of unintended negative environmental impacts, depending on the kind of feedstock used and how it is produced and processed. Life-cycle assessment analyses are challenging not only because they require large amounts of information, but also because they attempt to combine disparate quantities in ways that require considerable explanation and interpretation. For example, an life-cycle assessment study may examine the energy consumption of a product and combine energy inputs as different as electricity produced by a nuclear power plant, heat provided locally by burning natural gas and the power from a diesel fuel-powered truck which transports the product to market. Some energy sources, such as solar heat, are considered to be available at no cost and with no environmental impact.

Land use change (LUC): The next key challenge facing life-cycle assessments is how to factor in land-use changes. A common method to estimate land-use change is to use remote-sensing images, especially for monitoring deforestation. On the basis of spatial patterns, different techniques are then used to identify the agents involved in the land-use change. Further, the use of primary and secondary data on areas planted and harvested in the past can help predict future land-use patterns-even at the local level, if such data readings can be matched with other crops[13].

There is a distinction between direct and indirect land-use change. When newly demanded products-such as biofuel feedstocks-are grown on converted land, this is described as direct land-use change (DLUC) and is typically included in the carbon accounting procedure in most life cycle analyses. Indirect land-use change refers to second, third and higher degrees of land substitutions. This is harder to measure and remains unresolved. There is currently a debate about measurement of greenhouse gas emissions resulting from indirect landuse change that may occur when increased demand for biofuel crops displaces other crops to new areas.

The indirect land-use change impacts (ILUCs) of biofuels describe the unintended consequences of releasing more carbon emissions because of land-use changes induced by the expansion of croplands for ethanol or biodiesel production in response to the increased global demand for biofuels. As farmers worldwide respond to higher crop prices in order to maintain the balance between global food supply and demand, pristine lands are cleared and converted to new cropland to replace the crops for feed and food that were diverted elsewhere to biofuels production. Because natural lands, such as rainforests and grasslands, store and sequester carbon in their soil and biomass as plants grow each year, clearance of wilderness for new farms in other regions or countries translates into a net increase in greenhouse gas emissions. Because of this change in the carbon stock of the soil and the biomass, indirect land use changes have consequences in the greenhouse gas balance of a biofuel.

Other authors have also argued that indirect land-use changes not only release sequestered carbon, but also produce other significant social and environmental impacts, putting pressure on biodiversity, soil, water quality, food prices and supply, concentration of land tenure, displacement of workers and local communities and cultural disruption. Economic models (partial or general) are being used by some researchers to evaluate land demand on a global scale[14].

Biodiversity: Biodiversity, defined as the abundance of species (plants, animals and microorganisms) in a habitat, is essential for the performance of an eco-system. Biomass production for bioenergy can have both positive and negative impacts on biodiversity. When degraded land is used, the diversity of species might be enhanced. Yet, the practices of large energy crop monocultures can be detrimental to local biodiversity, especially through habitat loss, the expansion of invasive species and contamination from fertilizers and herbicides.

The reduction in global biodiversity has emerged as one of the greatest environmental threats of the 21st century. Urban and agricultural development have traditionally been the primary drivers of encroachment on important, biodiversity sustaining ecosystems.

On a global scale, biodiversity is essential for the functioning of eco-systems which in turn ensure diverse gene pools and hydrological cycles which enable agriculture. However, on a field-scale, the most efficient cropping systems have great uniformity and very little biodiversity. The use of plant biomass to provide liquid fuels has the potential to increase agriculture's impact on biodiversity.

Water contamination with fertilizers and pesticides could also be a threat for biodiversity. Leakage of phosphorus and nitrogen into surrounding water can lead to a decrease in the variety of plants and animals, as well as an increase in unwanted algae. This is known as hypoxia, which means low oxygen and is primarily a problem for estuaries and coastal waters. Hypoxic waters contain dissolved oxygen concentrations of less than 2-3 ppm. Hypoxia can be caused by a variety of factors, including excess nutrients, primarily nitrogen and phosphorus and waterbody stratification due to saline or temperature gradients. These excess nutrients-eutrophication-promote algal growth. As dead algae decompose, oxygen is consumed in the process, resulting in low levels of oxygen in the water. Thus high-input managed biomass crops may bring negative impacts on biodiversity. Conversely, native and perennial crops that do not involve much input are likely to be less damaging, especially when crop-rotation is considered[15].

There are obvious potential environmental impacts associated with (over) extraction of fresh water, including salt water ingress into aquifers, ecological damage within surface water bodies and habitat destruction. The possible social impacts include potential conflicts for water management among different users, reduced availability or quality of resources for municipal/domestic use.

In agriculture, crops that require less irrigation, fertilizer and pesticides and that provide better year-round erosion protection will likely produce fewer negative water impacts. Understanding water quantity impacts depends on understanding the agricultural water cycle. Crops can be either rainfed or irrigated. Irrigation water can come from groundwater or surface water; groundwater can either be withdrawn from a surficial aquifer (connected to the surface) or a confined aquifer.

Some of the applied water is incorporated into the crop, but most of it leaves the fields as evaporation from the soil and transpiration from plants (evapotranspiration), runoff to rivers and streams and infiltration to the surficial aquifer[16].

Social factors in biofuel sustainability: The social dimension of biofuel sustainability relates to the potential for rural development, poverty reduction and inclusive growth. It can touch on many potentially interlinked issues. This raises a number of methodological difficulties including the challenge of distinguishing between direct and indirect social issues. In this section, we focus on three aspects of social sustainability[17,18]: land ownership rights, local stewardship of Common Property Resources and labour rights. All these issues more or less tackle a common goal-the need to integrate small-scale farmers within biofuel development and ensure inclusive benefit sharing, safeguarding of basic rights and local means of livelihood consequent to the introduction of biofuels.

Land ownership rights: Climate change and expanding biofuel production are likely to lead to greater competition for access to land. This increased competition poses a threat to the livelihoods of the millions of farmers, pastoralists, fisherfolk and forest dwellers living in areas with no formal land tenure rights. Sound land tenure policies and planning will be crucial.

Given that land is a limited resource, the appropriate use of land depends on the value it can provide to those who hold rights over it. The value can be measured in many ways-*e.g.* wealth generation, conservation and ecosystem servicing. Biofuels are believed to offer commercial opportunities to enhance the contribution of land to individuals, groups and governments. Access to land (usage or ownership) depends on the decisions of those who hold rights over the land. Those rights may relate to entitlement of ownership or use (*e.g.* grazing, water) and may be based on national legislation, customary law or combinations of both. In reality, land rights and the processes to gain access to land are often unclear.

Local stewardship of common property resources: For many developed countries, the goal of sustainable rural development implies preservation of local productive capacity and natural resources. Mechanization, while generating higher returns on land and labour, has lowered agricultural prices. As a result, government subsidies have been established to prop up farm incomes and, in the process, have became a constant feature of agriculture in rich countries. In developing countries, safeguarding local productive capacity and natural resources implies local stewardship of Common Property Resources.

Property ownership is a key to stewardship. Common property resources (CPRs) are usually non-exclusive resources where a well-defined property regime may not exist and to which rights of use are distributed among a number of co-owners, generally identified by their membership in a community or a village. Common property resources may include community forests, common grazing grounds, threshing grounds, rivers and riverbeds. Common property resources occupy an important place in the economy of the landless and land-poor, whose employment and income generation opportunity from private property are limited: this is the resource to fall back upon during times of need.

Against the historical and sociopolitical backdrop of foreign oil operations in Latin America and the competitive drive for greater access to new oil fields in sensitive areas, the oil industry finds itself re-thinking traditional approaches to operations in these particular locations.

Labour effects: For many developing countries, the chance to spur rural employment by producing biofuels has acted as a major driver. Biofuels can spur rural development and stimulate local employment by attracting capital to the agricultural sector and a flow of new technologies including better access to fertilizers, infrastructure and highyielding varieties. Biofuels production could also increase access to energy services with positive effects on welfare (*e.g.* by expanding access to electricity and pumped potable water, reducing the workload of women and children who are usually in charge of collecting firewood and improving health by reducing indoor air pollution). All of these imply new employment opportunities and higher rural wages with positive spillover effects for the local economy.

On the down side, biofuel development could also bring into focus a number of labour-related problems, depending on the type of farm operations and the quality of management. Granting foreign investors a free hand over biofuel-linked production systems carries the risk that they may bring their own manpower along with them, thus negating any employment benefits for local communities. If the local labour force is employed, worker abuse issues that may be prevalent in developing countries could be perpetuated. These may include high seasonal fluctuations in employment, long working days under difficult conditions and weak labour rights (especially in the case of paperless guest workers).

Overall, the social dimension of sustainable biofuel production, trade and use requires adhering to a number safeguards, such as ensuring human rights to local communities when investments in land and potential relocation and compensation are required; integrating small-scale farmers and the local population, including women, in the biofuel supply chain throughout-growers schemes ensuring that new biofuel developments bring maximum employment opportunities for local populations and ensuring that international standards for workers' rights, including those enshrined in the concept of "decent work", are fully respected and maintained. These prerequisites improve the chances of social acceptance and hence place the local communities on a path towards social sustainability.

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