



Bioenergy and Its Environmental Impacts

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Abstract: *Energy and environments are cardinal constituents to our daily life and a way forward for our sustainable development. The capitalization for renewable energy is the outcome of diminishing supply of fossil fuels. Bioenergy is the most extensively used renewable source of energy in the world. It provided almost all global energy two centuries ago, and still it dispenses 11% of the world primary energy supplies. A wide range of environmentally sound and cost-competitive bioenergy systems are already available to give a significant contribution to future energy needs. It has been estimated that 25~33% future global primary energy supply is accomplished sustainably through bioenergy by 2050. Bioenergy can have positive and negative environmental impacts and the net impact can be either positive or negative critically depending on how it is generated. Sustainable development usually refers to a development that has economic and social benefits, and that can limit its negative environmental impacts. This paper reviews the impacts of Bioenergy on environment and gives information of the benefits it can provide to the economy, to society and the benefits and detrimental effects it will have on the environment.*

I. Introduction

Sustainable development usually refers to a development that has economic and social benefits, and that can limit its negative environmental impacts. These three criteria, along with the available technologies, are therefore the three most widespread factors that will affect the conduction of a project. Bioenergy projects are, in this way, similar to other projects, and also need to be evaluated based on the benefits it can provide to the economy, to society and the benefits and detrimental effects it will have on the environment.

Economic impacts

The first step in any project always concerns the evaluation of the costs and the expected revenues. Bioenergy projects always need to produce energy in a cost-effective way compared to other conventional methods of energy production. In some cases, bioenergy can be undertaken despite the fact that other options seem, on a short term, to be more profitable, because of declining feedstock's or because of higher social or environmental benefits that will lead to increased governmental contributions.

Social impacts

Bioenergy projects affect the communities in which they are implemented in various ways. This can go from improved water quality to the creation of new jobs in economically depressed regions.

Some uses of bioenergy require a feedstock based on dedicated field production (such as energy crops) or residues from agricultural production. Some agricultural fields are marginal for food production and bioenergy production could improve these marginal lands. However, in some cases, the production of energy crops may have a detrimental effect on food security.

A good example on the social impacts of bioenergy concerns corn ethanol and rising oil prices. Since corn is an energy-intensive crop and requires the use of fossil fuels, an increase in the cost of the barrel of oil also increases the production costs related to corn production. At the same time, this increase in oil prices increases the profits a farmer can make from the production of corn ethanol. Under competitive market conditions, the increase in oil prices limits the supplies of crop feedstock's and favors the transformation of corn supplies to corn ethanol. These consequences limit the supply of corn for animal and human consumption and can affect the global prices of corn, making it a less affordable product.

Ecological and Environmental Impacts

Impacts of bioenergy include affects on ecosystems and species within them (including humans), termed ecological impacts; and affects on geophysical systems such as water and climate, termed environmental impacts. Impacts may be direct, like tailpipe emissions from burning biofuels, or indirect, like soil emissions of carbon dioxide from

biomass production. Bioenergy can have positive and negative ecological and environmental impacts, and the overall net impact can be either positive or negative.

Many of the ecological and environmental impacts of bioenergy are associated with land use and land use change in connection to biomass production. Bioenergy-related land use decisions may affect local, regional and global ecological and environmental systems. Of particular concern are GHG emissions, habitat change, biodiversity, soil quality, and water quantity and quality. These high-priority concerns are detailed below.

Land use and land use change

Land use decisions are affected by many factors from local to global in scope, including public policy, prices of agricultural commodities, prices of petroleum, and land values (figure 1). Profitability of specific land uses and the benefits of competing uses are also key influences on land use decision-making (figure 1). Decision-makers who choose to produce biomass must consider land use and potentially also land use change (LUC). Land use is management of land resources for economic benefit and includes tillage, maintenance and harvest activities as well as conservation practices. Land use change includes conversion of native ecosystems into agricultural use, as well as switching from one crop type to another. Also included in the LUC category is diversion of food crops grown primarily for food into bioenergy feedstock use, for example, corn grain.

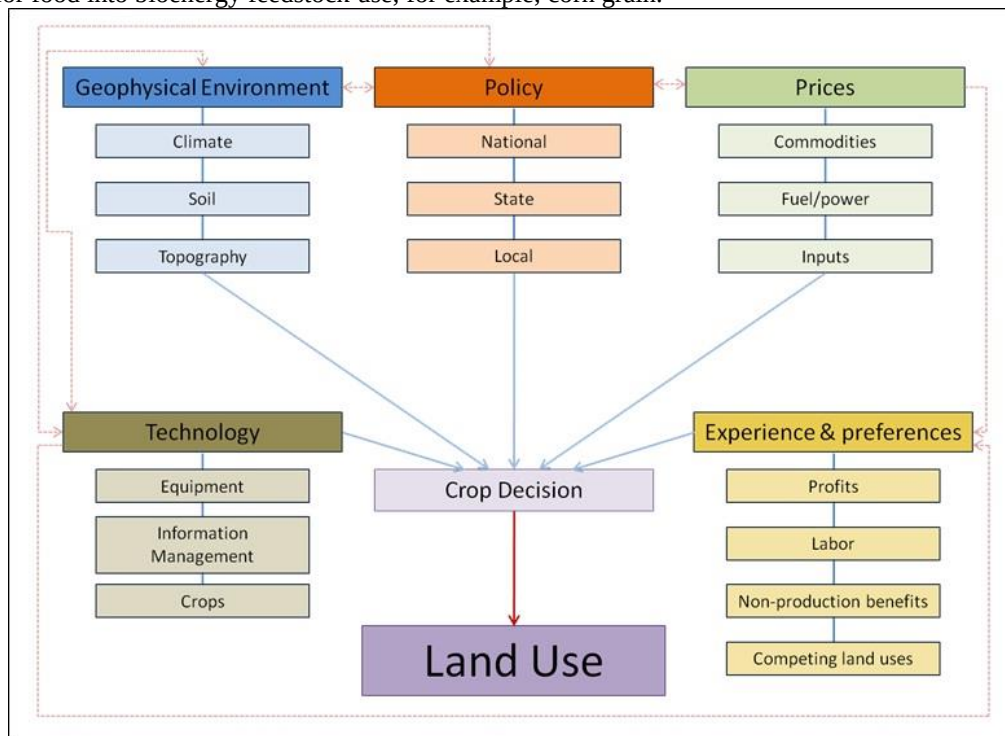


Figure 1. Factors and their interactions influencing land use decisions. (CL Williams, 2011.)

Biomass demand is thought to be a local or regional level influence on land use decision-making. However, competing uses, such as production of conventional commodity crops for example, are driven by complex global financial and trade systems. Land use decisions in response to biomass and bioenergy demand, then, are coupled with local and global economies.

Native and managed ecosystems are sources of financial benefit when materials are removed from these systems and exchanged in markets. Native ecosystems and managed ecosystems also provide many benefits which indirectly affect humans. Water and nutrient cycling are but two examples of the benefits ecosystems provide that have no direct economic value. Land use and LUC associated with biomass production can increase or decrease the direct and indirect benefits of native and managed ecosystems. Whether land use and LUC increase or decrease these benefits depends on the type and amount of benefits occurring prior to LUC.

Greenhouse gases and climate impacts

Greenhouse gases are gases in the atmosphere that absorb and emit thermal radiation in a processes known as the greenhouse effect - the mechanism by which solar radiation is captured and earth is warmed to an extent necessary for supporting life (figure 2, "Natural Greenhouse Effect"). The primary GHGs are water vapor, carbon dioxide, methane, nitrous oxide and ozone. These gases differ in their abundances in the atmosphere as well as their warming

power. The science of global climate change indicates an overall warming trend for the earth as a whole in association with rising levels of GHGs. While natural sources effect the concentrations of GHGs over time, global scientific consensus indicates that human sources of GHGs also contribute to global climate change (figure 2, “Human Enhanced Greenhouse Effect”).

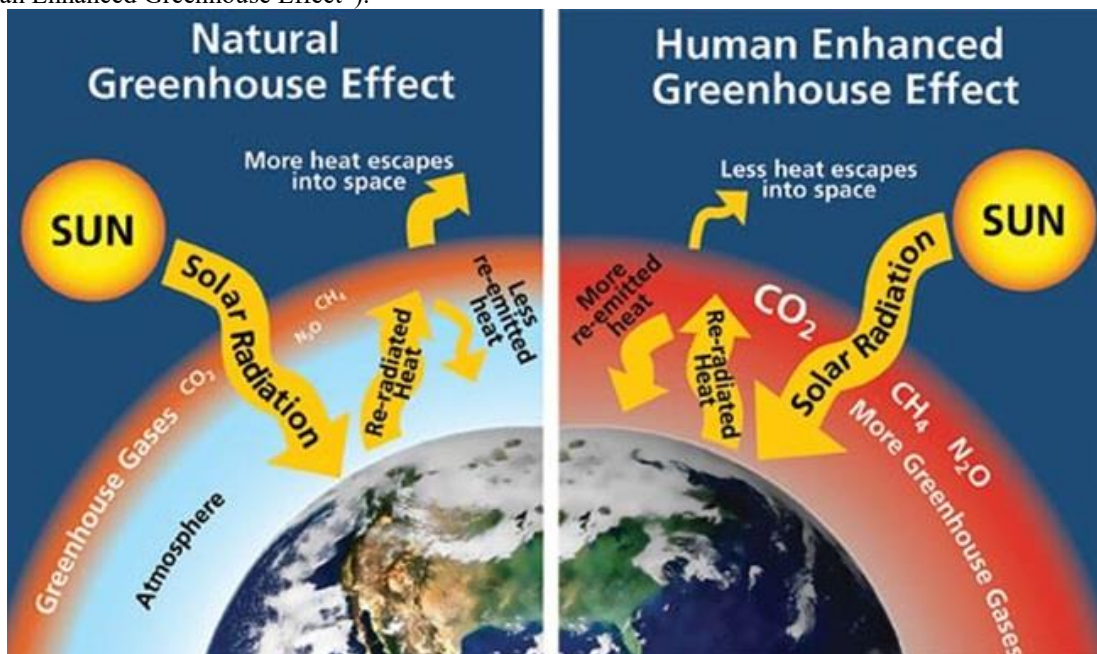


Figure 2. The greenhouse effect is the primary mechanism by which solar radiation is captured by earth’s atmosphere. Human activity has enhanced the warming ability of this mechanism. (Will Elder, U.S. National Park Service.)



Figure 3. The carbon cycle and biofuels: carbon dioxide (CO_2) from the atmosphere is taken up by plants and converted into plant tissues.

Plants are harvested and converted into fuels which are burned, where it becomes available again for plants. However, instead of a “closed loop”, as depicted here, emissions of CO_2 from conversion of untilld soil and

emissions from use of fossil fuels in fertilizer production and diesel use in farm equipment can increase the amount of atmospheric carbon dioxide from bioenergy systems rather reduce it.

Bioenergy has the potential to be carbon-neutral by balancing the amount of carbon released in use of bioenergy products with an equivalent amount put into and stored in soils, plant and animal tissues, or other material such as the ocean floor. That is, bioenergy is part of a global carbon cycle (figure 3) where plants take up atmospheric carbon dioxide and convert it into plant tissue. That is, they sequester carbon (figure 4). The carbon is later released back to the atmosphere as carbon dioxide when the plant biomass is burned directly or after it has been converted into a fuel and used – called emissions (figure 4). From there the carbon dioxide is available again for plant sequestration. However, land use, and more specifically LUC, effects the flux of GHGs between the atmosphere, soils, water, and tissues of living things (figure 4). Converting native habitats to croplands, for example, can lead to releases of CO₂ into the atmosphere due to burning of vegetation for land clearing. Carbon dioxide can also be released by microbial decomposition of organic matter leading to release CO₂ into atmosphere. In the case of clearing of new land (i.e., native habitat) for biomass production, the amount of GHG emissions will depend on the ecosystem being converted (figure 4). In some cases, the amount of CO₂ emitted will be large and will require decades if not hundreds of years to be sequestered again by bioenergy crops or native vegetation.

Carbon sequestering potential of some biomass systems is much less than some native ecosystems at the same location. The reverse can also be true though, where some biomass cropping systems are capable of sequestering more carbon than a native ecosystem at the same location.

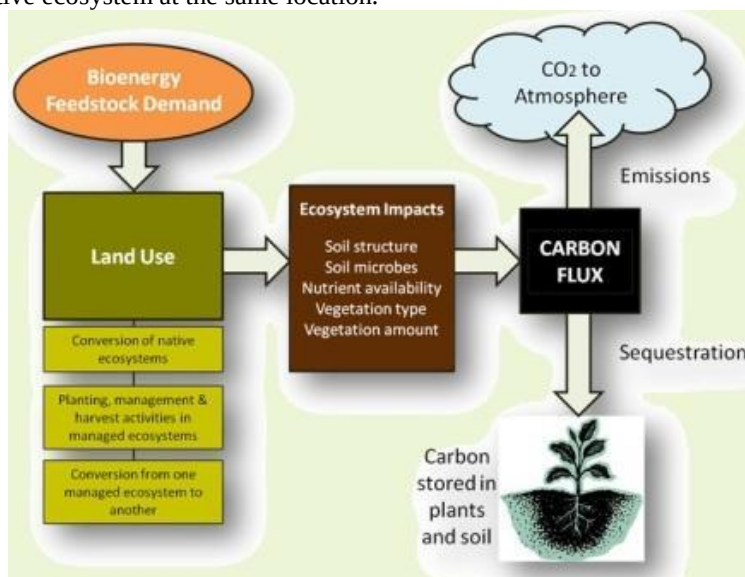


Figure 4. Land use impacts on carbon flux and the ecosystem mechanisms that regulate carbon emissions and sequestration. (CL Williams, 2011.)

To-date, there is no scientific consensus on whether bioenergy as a whole contributes to or abates global climate change. Rather, scientific evidence appears to indicate that “it depends”. First generation biofuel systems, such as ethanol made from corn grain, tend to emit more GHGs than cellulosic ethanol systems, particularly CO₂. Compared to perennial biomass production, corn cropping requires more fertilizer and pesticide inputs, and results in greater soil disturbance leading to land use- induced carbon emissions. Moreover, when agricultural commodity prices are high, marginal lands and lands set-aside for conservation purposes tend to be converted into row-crops such as corn and thus lead to LUC-induced CO₂ emissions. In comparison, second and third generation biofuels offer greater potential for GHG mitigation through use of cellulosic feedstocks which originate from production systems that tend to have less land-use related GHG emissions. Additionally, biochar – the co-product of pyrolysis, is carbon rich and stable, and when added to soil it serves as a long-term carbon bank. While second, third, and even fourth generation biofuel systems potentially reduce GHGs they are not yet widely available at commercial scales and future demand is uncertain.

Wildlife habitat and biodiversity

Bioenergy and biomass crops are often promoted by environmentalists and government leaders as having the potential to provide tremendous amounts of wildlife habitat and to support biodiversity. Several important studies provide evidence of the negative impacts of first generation biofuel on wildlife and biodiversity (e.g., Brooke et al.,

2009; Meehan et al., 2010) while others provide evidence that biopower and second generation biofuels have positive effects on wildlife and biodiversity (e.g., Meehan et al., 2010; Robertson et al., 2011; Roth et al., 2005). However, policies to outline environmental standards for bioenergy production are lacking, and financial programs for compensating land owners and farmers for habitat- and biodiversity-protecting land practices are also lacking. Most significantly, land conversion could decrease native habitats, reduce biodiversity and decrease ecosystem services. Key issues are habitat loss and fragmentation with expanding corn and soybean acres; loss of Conservation Reserve Program land; persistence of pesticides in the environment associated with conventional row crops; timing of harvest of perennial crops and forests; and impacts to water quality associated with agricultural run-off.

Water quantity and quality

Bioenergy potentially impacts water resources through two pathways: water use in biomass production and water use during feedstock conversion. Emission of air pollutants from biopower combustion and burning of biofuels also potentially impacts water quality mostly via precipitation. However, water use potentially has the greatest effect on water availability and water quality. The impact of bioenergy to water is often referred to as the “water footprint”.

In areas where there is sufficient precipitation biomass yields may be close to yield potential. However, in areas lacking sufficient precipitation irrigation is required for achieving commercially viable yields. Use of irrigation water has the potential to depress groundwater supplies, divert water used to grow food crops to the growth of energy crops, and contribute to soil salinization. In both irrigated and rainfed systems, crops that remain longer on the landscape (i.e., perennial) and crops which provide good ground cover increase structural filtering of precipitation promoting more rainfall interception and retention and better control of sediment run-off. Grasslands once established may provide better water services than traditional annual row crops because of greater soil coverage and root density.

In addition to sediment run-off, pesticides and fertilizers associated with conventional row crop production threaten water resources. One of the top pollutants to aquatic ecosystems, as recognized by the U.S. EPA, is nitrogen. Nitrogen in excess can be harmful to both ecosystem and human health. Nitrogen (N) and other agronomic pollutants like phosphorous (P), can enter water resources through runoff and leaching. Nutrient pollution is a leading cause of water quality impairment in lakes and the Gulf of Mexico. The major concern for surface water polluted with N and P, is the promotion of algal growth (eutrification) accompanied by aquatic oxygen depletion, fish mortality, clogged pipelines, and reduced recreational values.

Water use in conversion of feedstock to bioenergy also has potential negative impacts on water availability and quality. Biopower generation requires use of water to produce high-pressure steam to drive turbines and low-pressure steam to deliver heat/cooling in centralized heating/cooling districts. Some biopower plants also use water for cooling, particularly in co-firing of coal or natural gas with biomass. Water is also required during fermentation of ethanol and in post-transesterification of biodiesel. Also, effluents from these processes must be treated before being discharged to nearby surface waters. Water use for fermentation may deplete surrounding surface or groundwater supplies and limit their availability for other uses including drinking water, wildlife habitat, and recreation.

II. Conclusion

In general, environmental impacts of bioenergy are considered smaller than those of conventional (fossil and nuclear) energy systems, as renewable biomass is CO₂-neutral when burnt, the resource base can be maintained if harvested biomass is re-grown, and residues easily decompose or can be recycled. Bioenergy can have positive employment and income effects, and could increase security of supply. Still, bioenergy crops can cause land-use change with severe environmental impacts, e.g. biodiversity loss and increased greenhouse gas emissions, and might negative impact water resources and soil. Thus, decision-makers in (national) governments, business, and societal stakeholders need to carefully elaborate the environmental pros and cons of bioenergy in order to develop this resource sustainably

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