IMPROVING DECISION-MAKING FOR THE ENERGY TRANSITION

Guidance for using Strategic Environmental Assessment

CHAPTER 8

BIOENERGY

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Links to the complete guidance document and to individual chapters are also available.

CHAPTER 8

BIOENERGY

8.1 WHY SEA IS IMPORTANT FOR BIOENERGY

An overall rationale for why it is important to use Strategic Environmental Assessment (SEA) to support the energy transition is provided in the preface to the guidance.

SEA can provide critical information to support better decision-making for bioenergy power planning and development, including identifying where there may be implications for policies, plans, and programs (PPPs) to adequately address significant environmental and/or socioeconomic risks and impacts. This information can be particularly important to identify and assess the scale and significance of possible cumulative impacts of multiple bioenergy power schemes/developments, whether alone or in combination with other renewable energy technologies (e.g., solar, wind energy).

The SEA process will:

- Identify and focus on key environmental and socioeconomic issues and the concerns of likely affected stakeholders, including local communities, marginalized groups and indigenous peoples (issues associated with bioenergy development are discussed in Section 8.5 and summarized in Table 8.2).

- Identify/recommend if there are areas that should be avoided for bioenergy development ("no-go" areas) because of particularly high risk to the environment, habitats/biodiversity, and/or people.

- Identify what changes or additions are required to PPPs governing bioenergy development to address these risks.

- Make subsequent project-level Environmental Impact Assessments (EIAs) and Environmental and Social Impact Assessments (ESIAs) more efficient and cheaper by addressing the big picture regarding potential upstream, downstream, and cumulative impacts and identifying the particular issues that individual bioenergy project EIAs/ESIAs should focus on in more (site-specific) detail. This may also include spatial planning recommendations for optimal siting of bioenergy projects to minimize these risks and impacts.

- Engage stakeholders—including communities, marginalized groups, and Indigenous peoples, which can be particularly affected by bioenergy developments—to be informed early of proposed or possible policy options or plans, and enable them to provide their perspectives and present their concerns as early as possible. This will enable key issues to be identified and verified, help build understanding and support for bioenergy development, and avoid future misunderstanding and possible conflicts.

The steps and methodologies available for use in SEA are common to all SEAs, whatever they are focused on, and reflect internationally accepted standards of good practice. They are discussed in detail in Chapters 1 and 2 and are therefore not repeated in this chapter.

8.2 EXISTING SEA GUIDANCE/GUIDELINES FOR THE BIOENERGY SUB-SECTOR

An international survey of existing SEA guidelines conducted for IAIA was able to identify only one specifically focused on the bioenergy sub-sector. The OECD DAC guidelines on SEA and biofuel development[1] cover generic and specific considerations and questions to be addressed at the broad scale in a typical SEA process for biofuel PPP development at a national or sectoral level. Similarly, no EIA guidelines specific to bioenergy have been identified.

In the literature, a range of academic papers and books cover various aspects of the environmental and socioeconomic impacts of biofuels (e.g., solid biofuels[2], biogas[3], commercialization of biofuels production from feedstocks[4] , and bioenergy production based on compiled and published data[5]).

8.3 BIOENERGY INSTALLED CAPACITY

According to International Energy Agency, the annual global demand for biofuels is set to grow by 28% by 2026, reaching 186 billion liters.[6] Table 8.1 shows bioenergy installed capacity by regions in 2022.

Table 8.1: Bioenergy installed capacity in 2022

Source: IRENA (2023)

Region	Installed capacity (MW)
World	148,912
Africa	1,847
Asia	63,370
Central America & Caribbean	3.040
Eurasia	3.330
Europe	41,694
European Union	33,823
Middle East	101
North America	14,960
Oceania	1,105
South America	19,465

8.4 BACKGROUND TO BIOENERGY GENERATION

Bioenergy use falls into two main categories: traditional and modern. Traditional use refers to the combustion of biomass in such forms as wood, animal waste, and traditional charcoal. Modern bioenergy technologies include liquid biofuels produced from bagasse and other plants, bio-refineries, biogas produced through anaerobic digestion of residues, wood pellet heating systems, agricultural waste, and other technologies.

Modern bioenergy[7] is the largest source of renewable energy globally, accounting for 55% of renewable energy and over 6% of global energy supply[8]. Bioenergy accounted for about 10% of total final energy consumption and 1.9% of global power generation in 2015.[9]

Rural households in Africa, Asia, and other parts of the world use a lot of traditional biomass (e.g., wood, dried animal dung, sugar cane bagasse, crop residues) as a principal energy source (i.e., for heating and cooking). However, this chapter focuses on bioenergy sources that could potentially be

[1] OECD DAC (2011)
[2] Christoforou and Fokaides (2019)
[3] Valerio *et al*. (2018)
[4] Arun and Dalai (2020)
[5] Wu *et al*. (2018)
[6] IEA (2021)
[7] Modern bioenergy refers to biomass use alongside modern heating technologies, power generation, and transport fuels, as opposed to traditional wood-burning methods commonly used for heating and cooking in developing countries.
[8] IEA (2022b)
[9] IRENA (n.d.)

used in utility-scale thermal power plants, primarily the conversion of plants (mainly high energy crops grown at large scale) or wood (from forests) to pellets to be combusted in a thermal power plant.

Bioenergy is generated from the combustion of organic matter from bio-based renewable sources such as biofuel, biogas, biomass, and other bio-organic wastes. Biomass supply comes from a variety of feedstocks—wood fuel, forestry residues, charcoal, pellets, purpose-grown crops and residues, municipal and industrial waste (e.g., food, construction waste, paper), biogas, biofuels, etc. Broadly, the supply can be classified into three main sectors: forestry, agriculture, and waste. It can be used in power generation, heating, and transport. To create pellets for combustion (i.e., to drive a steam turbine and create electricity), plant material is harvested, dehydrated in a processing plant, and pressed. This fuel is used instead of, or as well as, coal in power plants.

Bioenergy can also be produced from waste streams, such as wood chips left over from manufacturing processes, or sugar cane biomass left over from the sugar refining process. Using waste products such as these as a biofuel can reduce waste sent to landfill. But they are usually used in combustion plants alongside coal or in small-scale power plants. It is not likely that biofuels sourced from waste streams could supply electricity at a utility scale.

Biomass has been promoted as a carbon-neutral energy, but the UK's The Guardian reports doubts about this view (see Box 8.1).

Box 8.1: Biomass is promoted as a carbon neutral fuel. But is burning wood a step in the wrong direction?

Source: Speare-Cole (2021)

Biomass has been promoted as a carbon-neutral energy source by industry, some countries, and lawmakers on the basis that the emissions released by burning wood can be offset by the carbon dioxide taken up by trees grown to replace those burned. Yet there remain serious doubts among many scientists about its carbon-neutral credentials, especially when wood pellets are made by cutting down whole trees, rather than using waste wood products. It can take as much as a century for trees to grow enough to offset the carbon released.

Burning wood for energy is also inefficient. Biomass has been found to release more carbon dioxide (CO_2) per unit of energy than coal or gas, according to a 2018 study[10] and an open letter to the EU signed by nearly 800 scientists.

This CO_2 is theoretically reabsorbed by new trees, but some scientists suggest relying on biomass could actually end up increasing emissions.

An advantage of bioenergy is that it can provide a controllable and continuous supply of power and use waste products. Biomass and biofuel energy tend to have the lowest energy density compared to other energy sources, but they have the highest land-take of any of the renewable energy technologies. To generate 1 gigawatt-hour (GWh) of electricity, 78 hectares of trees need to be harvested each year (this assumes sustainable harvesting that can be repeated each year).[11]

8.5 IMPACTS OF BIOENERGY DEVELOPMENT

During scoping for an SEA, issues associated with bioenergy development should be identified. They will be used to focus the SEA and to help develop environmental and social quality objectives (ESQOs) (see Chapter 2, Section 2.5.1) that address these issues, to be used during the main assessment stage. The key issues will be identified by reviewing relevant documents (e.g., EIA and special subject reports, other bioenergy development applications, environmental/social profiles,

[10] Sterman *et al* (2018)
[11] Freeing Energy (2020)

sector and inter-sector strategies, donor documents, academic papers), interviewing key informants, and holding stakeholder consultations at national to local levels. Many of the issues will be well known as a result of implementing other bioenergy development projects.

At the individual project level, these issues will be the focus of an EIA, which should recommend how to manage or mitigate project impacts that might be likely to arise. Implementing a PPP for the bioenergy sub-sector will involve multiple projects, schemes, and activities, including dispersed individual farmers growing bioenergy crops. Activities may include: land clearing, land use change and growing bioenergy crops; construction and operation of sites and facilities; and development/expansion of associated infrastructure (e.g. transmission lines, access roads). Thus, there is a risk that the impacts of individual developments/projects may become highly significant as they become cumulative. An SEA should address the potential for such cumulative impacts and make recommendations for managing and mitigating them. This may include recommending thresholds for particular factors that should not be breached by an individual project (and which should be addressed by a project-level EIA). Where the risks of cumulative impacts are extremely high, this might provide the basis for the SEA report to recommend an alternative to the PPP or components of it. Often, the timing of individual bioenergy project applications and overarching SEA planning is not synchronized, and SEA may have to “catch-up” to the pace of individual projects rather than providing upstream (pre-project) guidance as to how they should proceed.

Table 8.2 summarizes the range of environmental and socioeconomic issues associated with bioenergy development.

During scoping, a key task is to determine which issues the SEA should focus on.

Table 8.2: Environmental and socioeconomic issues associated with bioenergy power development

ISSUE	COMMENT
Environmental	
Air quality	• Reduction in air emissions through displacement of coal, leading to improved air quality. • Air quality impacts from processing and burning biofuels.
Water quality	• Runoff of biocides used on energy crops.
Water use	• Water consumption of bioenergy crops and conversion of land use can increase demand on water resources.
Greenhouse gases	• Bioenergy can reduce GHG emissions where it displaces coal as a fuel source. • Land clearing for crops can result in release of GHG (e.g., from clearing forests and release from soil). • Biofuels can be carbon neutral in some circumstances but can cause net emissions of GHG in others (i.e. CO_2 from their combustion, although less than from coal).
Land-use change	• Large areas of land required to grow crops that feed into biofuels can displace other land uses, such as food crops and other agricultural practices. • Forest clearance to grow energy crops will lead to habitat loss/degradation, biodiversity loss, and release of carbon stores.
Soil erosion and landslips	• Clearing land can lead to erosion and destabilization of areas, leading to landslips and sedimentation issues. • Can be triggered by an expansion of the area growing fuel crops (particularly corn), residue removal, and land-use change.
Soil quality	• Cropping, overuse of fertilizer, and inappropriate use of pesticides can lead to a reduction in soil nutrients and overall soil quality and result in polluted runoff to surrounding areas. • Soil organic carbon loss due to tillage and harvesting residues.
Loss of biodiversity	• Habitat loss/fragmentation and loss of biodiversity when large areas of land are cleared to grow fuel crops. • Loss of native forests if harvested for wood pellets. • Risk of introducing invasive pests and species. • Energy crops grown as a monoculture can favor some species (often pests) and displace others, leading to loss of native species.
Crop waste products	• If waste products (e.g., sugar cane waste from a sugar mill) are converted to biomass pellets, this can reduce waste in the food chain.
Land and ecosystem restoration	• Forest conversion to grow bioenergy monoculture crops leads to a reduction in biodiversity and resultant ecosystem degradation.
Socioeconomic	
Employment and labor condition	• Employment in the construction and operation phases of bioenergy projects and in associated businesses and activities. • Substandard working conditions. • Worker safety. • Workers have opportunity to learn new skills.
Health and safety	• Increased heavy truck usage to transport biofuels from agricultural areas to processing plants and then to thermal power plants, leading to air pollution, congestion, noise, and safety issues. • Wastes (e.g., contaminated water, particulates from burning biomass materials, etc.) produced by bioenergy projects or plants could cause community health issues, including but not limited to respiratory disease.
Local economy and livelihoods	• Loss of household income from agricultural land acquired by bioenergy companies. • Increased opportunities for small business (e.g., selling energy-related agricultural products to bioenergy projects).

ISSUE	COMMENT
Food security and price	• Less food crops (e.g., corn) available for public sale when purchased by bioenergy companies, driving up the price so that poor people cannot afford to buy food. • Production of energy crops may reduce volume of food crops available and lead to malnutrition in rural areas. • Price of crops grown for energy production likely to increase, presenting an economic opportunity for producers. • Loss of communities' grazing areas when acquired by the bioenergy projects.
Land value	• When land is purchased or acquired by bioenergy companies to grow bioenergy crops, this reduces the amount of agricultural land available for cultivating food crops, and can drive up land prices, making it unaffordable to poor communities. • Increased land conflict over land ownership if land price increases.
Gender and vulnerability	• Vulnerable groups (e.g., the poor, women, persons with disabilities, children, the elderly, and Indigenous communities) may be disadvantaged and at particular risk due to loss of arable land. • Employment opportunities for vulnerable groups within new projects. • Opportunities for vulnerable groups to acquire new skills and learn new technologies.
Public services and infrastructure	• Loss of and relocation of public services and infrastructure on land acquired for bioenergy projects. • Infrastructure (e.g., roads and bridges, schools, health centers, and administrative buildings) will be improved where there is community investment by bioenergy companies. • Pressure on public services and infrastructure will increase as a result of in-migration. • Heavy vehicles and transportation can damage existing roads and bridges. • Increased vehicle traffic during construction.
Access to water	• Bioenergy projects require large amounts of water (e.g., for irrigating energy crops, steaming, cleaning, etc.), reducing water available to communities.
Indigenous peoples	• Acquisition of large tracts of land for bioenergy projects can affect the use of and cause the loss of Indigenous communities' communal land.

8.5.1 Environmental issues

Air quality and greenhouse gases

Bioenergy can have both positive and negative impacts on air quality. The IEA states that bioenergy can contribute to the mitigation of climate change if it is grown sustainably or comes from waste sources, is efficiently converted to energy products, and is used to displace GHG-intensive fuels.[12] Theoretically, net CO_2 emissions resulting from the direct use of biofuels can be less than from the utilization of fossil fuels.

However, the combustion of biomass also creates atmospheric emissions of carbon dioxide, sulphur dioxide, nitrogen oxide, and particulate matter.[13] The severity of the impact on air quality of such emissions depends on the proximity of the power plant to communities, sensitivity of ecosystems, levels of pollutants released, topography, and climatic conditions. Biomass combustion is generally less polluting than coal with lower emissions of nitrogen oxides and sulfur oxides.[14] Table 8.3 indicates the contribution of different pollutants emitted by a bioenergy plant.

Table 8.3: Air pollution from biomass energy
Source: PPFI (undated)

Emission type	Percentage contribution to combustion emissions
Nitrogen oxides (NO_x)	0.03%
Carbon monoxide (CO)	0.06%
Particulate matter	0.02%
Sulphur dioxide (SO_2)	0.02%
VOCs	0.01%
Hazardous air pollutants	0.00%
Carbon dioxide (CO_2)	99.86%

There are also notable indirect impacts of bioenergy with respect to both increasing and decreasing CO_2 emissions.[15] For example, large-scale land clearing specifically to produce biomass and to enable large-scale expansion of growing energy crops would release stored carbon and result in GHG emissions to the atmosphere. The carbon sink capacity of natural forests could be reduced, as cleared areas may be replaced by energy source crops, which may have less capacity to capture carbon than the replaced forest.[16] The volume of CO_2 emissions from bioenergy production will depend on the types of fuel crops grown and the associated management practices.

If land is to be cleared on a large scale for the growing of biofuel crops, and if this also involves the burning of forests, there will be significant negative impacts on air quality—from smoke, particulate matter, and other pollutants—experienced over large distances. For example, forest fires in Indonesia have had major adverse impacts on air quality, which has also affected neighboring countries such as Singapore and Malaysia.[17] The burning of crop waste products on a large scale can also have significant negative impacts on air quality.

There would also be localized negative impacts on air quality from the growing of bioenergy crops. These include dust emissions (from vehicle movements and agricultural practices, like tilling soil) and vehicle emissions (from the transport of crops or forest wood to the processing facility and then on to the powerplant for combustion).

[12] IEA Bioenergy (2020)
[13] USEPA (2018)
[14] Ren *et al*. (2017)
[15] Wu *et al.* (2018)
[16] World Bank (2010)
[17] Sheldon and Sankaran (2017)

Water quality

The production of crops for biofuels can lead to a decrease in water quality due to:

- Poor agricultural practices that result in fertilizer runoff into waterways, causing algal blooms and nutrient loading in waterways.
- Pesticide runoff from agricultural land, leading to contaminants and biocides entering waterways.
- Land clearing and changes to vegetation cover that result in increased erosion and sedimentation of waterways.
- Spills of fuels and oil from vehicles, agricultural machinery, or machinery used in clearing forests.[18]

The reduced water quality can then cause:

- Health impacts on communities as a result of using polluted water for drinking, cooking, irrigation, washing, and bathing.
- Direct loss of biodiversity and degradation of aquatic ecosystems.

Risks of climate change

The risks to bioenergy production associated with climate change are potentially significant. For instance, droughts, floods, strong winds, and forest fires (due to extended droughts) will affect/disrupt the cultivation of energy feedstocks (i.e., reducing or destroying energy crops), grower incomes and livelihoods, and supply chains to power stations.[19] Power plants may be forced to run at lower utilization rates due to reduced feedstock.

There could also be a higher biomass production and harvest due to an increased growing season and more rainfall. Rainfall quantity could affect the moisture content of the soil or feedstock quality, which, in turn, could result in lower yields and reduced feedstock inputs at the power plant.

Wind velocities can affect the dispersion characteristics of pollutant emissions (i.e., increased winds and wind variations can alter the impact of pollutants on nearby sensitive receptors).

With the increase of CO_2 concentration in the atmosphere, some (potentially less dense) quick-growing varieties of energy crops could out-compete more dense crop species and, over time, reduce the energy content per unit area of land.[20] The energy density of biomass can vary due to variations in photosynthetic interactions driven by CO_2 concentration changes.

Increased droughts may limit cooling water available to power plants.[21] This risk could, at least in part, be offset by growing drought-tolerant biofuel crops. Several promising lignocellulosic crops are emerging that have no food role (e.g., fast-growing trees and grasses) but are well-suited as bioenergy feedstocks, including *Populus, Salix, Arundo, Miscanthus, Panicum* and *Sorghum*.[22]

Water use

The majority of water used in bioenergy production is for the growing of energy crops. These are generally selected for optimal growth, which can mean that they have a high-water demand (i.e., require irrigation). Energy crops consume more water than natural flora and many other food crops.[23] Irrigation water is drawn from either surface water sources or groundwater, which can reduce surface water yields and make groundwater wells unreliable when water sources are over-extracted.

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[18] Wu *et al*. (2018)
[19] Hoover *et al*. (2019)
[20] ADB (2012)
[21] CFR (2019)
[22] Taylor *et al*. (2019)
[23] Berndes *et al*. (2011)

The extraction of underground or surface water may put pressure on existing irrigation infrastructure and reduce fresh water available to host communities and farmers for subsistence crop cultivation, drinking, sanitation, and the support of environmental functioning and services. This is a particularly significant concern when water is scarce, especially during dry seasons. In Brazil, one of the world's largest sugar cane producers, there are well-documented impacts on the availability of freshwater in the Sao Paulo region.[24]

Land use change

Bioenergy production can lead to both direct and indirect changes to land use.

- *Direct land-use changes* relate to changing land use to produce bioenergy crops, including:
  - Changing the types of crops being grown.
  - Converting grazing land to growing biofuel crops.
  - Removing forest or naturally vegetated areas and converting them bioenergy crops.

- *Indirect land-use changes* can occur if bioenergy crops displace food crops, such as when forested areas are cleared to grow food crops. The overall impact would be like what has been experienced in parts of Southeast Asia because of palm oil production (see Box 8.2).[25]

The conversion of land to biofuel production will likely result in the clearing of very large areas of forests and/or habitats with high biodiversity value, resulting in significant habitat and biodiversity losses. This has already occurred where other industries have been promoted, such as with palm oil plantations in Indonesia (see Box 8.2) and the production of other agricultural products.

A review of the literature indicates that there are differences in opinion regarding bioenergy crop production and effects (positive or negative) on biodiversity.

Soil quality, erosion, and landslips

Bioenergy projects usually cause an increase in erosion and sedimentation associated with land clearing for crop production. Clearing can cause a decline in overall soil stability and health and can lead to landslips, sedimentation of waterways, and changes to the amount of water that land can hold, potentially increasing flood or landslip risks. This may also occur when there is poor crop cover, poor agricultural practices, and poor soil conservation on sloping land. Poor soil management can also lead to the loss of nutrients when existing grasslands are converted to biofuel production.

Disturbance to vegetation and soils adjacent to creeks and rivers (e.g., due to tilling soils for fuel crop production) can lead to an increase in erosion and sedimentation in the waterways. If the local geology is unstable, landslips, mudflows, and debris flows can all contribute to watercourse sedimentation.

[24] IATP (2007)
[25] Berndes *et al*. (2011)

Box 8.2: Land use change from palm oil in Indonesia

Sources: Duke University (2019); ICCT (2016); Uryu et al. (2008)

Palm oil plantations in Indonesia claim roughly 50,000 hectares of land per year. The carbon footprint of the palm oil industry has two components: emissions from deforestation, and emissions from the processing of palm oil. Converting forests to palm oil plantations results in the loss of large amounts of carbon from biomass and from the disturbed soil. Studies and estimates indicate that any carbon savings associated with palm oil expansion are far outweighed by the losses. It is estimated to take between 75 and 600 years for the carbon savings of petroleum displacement by palm oil biofuel to balance the carbon lost during the growth and manufacturing of the product.

Forests are usually cleared for palm oil plantation by logging and burning. In Katapang, Indonesia, fire was the cause of 90% of deforestation between 1989 and 2008, while 20% of wildfires across Indonesia can be attributed directly to palm oil plantation practices. Burning has adverse effects on human health, as the subsequent smoke can cause respiratory and cardiovascular disease and even death.

Deforestation through these processes in Indonesia is a leading cause of biodiversity loss. There has been a significant reduction in population densities and species richness for birds, mammals, bees, butterflies, moths, termites, dung beetles, and ants. Additionally, iconic species like the orangutan, found only on Sumatra and Borneo, are rapidly declining due to forest loss. In Riau, Sumatra, Sumatran elephants have declined by up to 84%, from >1000 in 1984 to approximately 210 in 2007. Sumatran tiger populations declined by 70% over a similar timespan. Although these statistics on biodiversity loss in Indonesia are not entirely directly attributable to palm oil plantations, palm production has been found to reduce biodiversity more than other types of crop plantations.

When forests and other natural vegetation are cleared for biofuel production, agrochemicals associated with such cultivation can pollute both land and water, have harmful impacts on terrestrial and aquatic ecosystems, and filter into groundwater.

During large-scale forest clearing, earthmoving activities and road construction can increase erosion, particularly if there is inadequate attention to access road design and drainage. This often happens when temporary, lower cost, and lower quality roads are built.

Increased erosion and sedimentation are common issues for poorly planned and managed agricultural areas.[26] This, in turn, affects water quality and can modify the riverbed composition and geomorphology and cause the degradation or loss of habitats for fish and other aquatic life. An increased sediment load can affect a river a long way downstream and can choke aquatic vegetation and habitats. Very high sediment levels can smother aquatic invertebrates and coat the gills of fish, causing suffocation.

Impacts on the quality of soil due to biofuel crops can degrade soil quality over time, lowering soil nutrient levels or changing soil chemical composition due to the inappropriate use of fertilizers and pesticides.[27] Changes in soil quality can result in:

- Abandonment of areas of land (i.e., once land is degraded, farmers may move to new areas, abandoning farms rather than rehabilitating them).
- Making land unsuitable for future agricultural use (i.e., severe impacts on soil can prevent the land from being used for different agricultural purposes without extensive rehabilitation).
- Additional clearing for more fertile soils (i.e., when farmers are forced to move, they must prepare new areas for growing crops).[28]

[26] Berndes *et al*. (2011)
[27] IFC (2016)
[28] Wu *et al*. (2018)

Loss of habitats and biodiversity

Clearing of land for large-scale biofuel crop production can cause significant loss of habitat and a decrease in biodiversity.[29] Fauna, including protected and threatened species, are displaced when land is cleared (e.g., forests or other natural vegetation), forcing them to seek alternative suitable habitats where available. This has a knock-on effect, as the displaced individuals may then cause increased competition for food resources or out-compete other less dominant species when they relocate.

The building of access roads in a once undeveloped and relatively inaccessible area can also lead to habitat fragmentation, an increase in illegal hunting or poaching of wildlife species, and an increase in illegal harvesting of timber and other forest products. Increased access may lead to further in-migration and conversion of natural habitats to agricultural practices.

The conversion of environmentally sensitive and high-biodiversity-value lands to biofuel cropland can result in associated negative environmental impacts. Apart from loss of biodiversity, it can also result in increased CO_2 emissions from the loss of forests, an increase in weed species, the introduction of alien species, and runoff into waterways impacting aquatic flora and fauna.

Biodiversity can also be affected or killed as a result of using pesticides and herbicides on biofuel crops, which can runoff from fields and enter waterways.

The loss of biodiversity and habitats can disrupt and unbalance the overall function of ecosystems and delivery of ecosystem services.

Crop waste products

If biofuel crop waste product residues (e.g., left over leaf material, roots, and other plant parts after harvesting) are not collected and transported to power plants, or when suitable storage facilities are not available, most farmers will have no option but to openly burn the residues. This has various health risks and can significantly raise levels of air pollution, particularly smoke and particulate matter. Smoke problems are commonplace in Indonesia, India, and other crop-producing developing countries and can have cross-border impacts on neighboring countries.[30] [31]

The burning of crop residues has an impact on soils. When the residues are not reincorporated in the soil, nutrients are lost and cannot benefit the next crop cycle, increasing the requirement to apply fertilizers. Organic matter is also lost, leading to the deterioration of soil structure.

Rice is a common crop in Asia. Once the rice grains are removed from the stalks, the rest of the plant is usually discarded. Demonstration projects in India have started creating a crop residue supply chain so that rice husk waste is collected, stored, and turned into briquettes and pellets, which can replace coal in power plants.[32] There can be an environmental benefit from providing an economic incentive to farmers to stop burning crop waste and increase their incomes.

Land and ecosystem restoration

While bioenergy crops may be grown on existing agricultural land, areas of existing forest may also be cleared to create new land for bioenergy crops. Where these are grown as a monoculture, such conversion can lead to significant biodiversity loss and land degradation as discussed above.
On marginal lands, the establishment of bioenergy crops (e.g., perennial grasses and short-rotation woody crops) offers possibilities for both successful eco-restoration and energy production.
Forest landscape restoration (FLR) is being promoted as a means for reversing land degradation while providing multiple products and services, including bioenergy. FLR using biofuel-friendly trees

[29] IFC (2016)
[30] Bhuvaneshwari et al. (2019)
[31] Sheldon and Sankaran (2017)
[32] FAO (2010)

under climate smart agroforestry practices and utilizing fruits, nuts, and biomass for energy could solve multiple issues by:

- Turning unproductive degraded lands into productive landscapes.
- Preventing further conversion of natural vegetation for other uses.
- Compensating for the high initial investments required for FLR.
- Providing multiple ecosystem services, including climate regulation.[33]

8.5.2 Socioeconomic issues

Employment and labor conditions

Increasingly, the deployment of renewable energy is recognized as an opportunity that helps to diversify a country's skill base and expand industrial development. Bioenergy also offers significant employment opportunities in the emerging renewable energy sector.

IRENA reports that in Southeast Asia, Indonesia, Malaysia, Thailand, and the Philippines have seen increasing employment in the biofuels sub-sector, while a national review in the Philippines indicates that the growing, collecting, and marketing of biomass fuels are handled by the informal sector and are labor-intensive.[34] The same study found that fuelwood and crop residues are a significant source of income and employment, particularly in rural areas. Approximately 700,000 households are involved in commercial biomass gathering and/or production in the Philippines.[35] Similarly, Latin America has approximately two million people working in the renewable energy sector, with biofuels in the lead (Brazil is the leading producer).[36] While employment within the biofuel sub-sector is largely benefiting rural areas of low-income countries, it also boosts employment in higher-income cities like Stockholm, Sweden.[37]

Biofuel crop production, like other agricultural practices, can be associated with the unacceptable use of forced and child labor (see Box 8.3).[38] In 2020, a human rights coalition was working to end forced labor in the palm oil industry[39], which contributes to bioenergy. The ILO reports that, worldwide, 60% of all child laborers in the age group 5 to 17 years work in agriculture, including farming, fishing, aquaculture, forestry, and livestock.[40]

Box 8.3: Child Labor in the sugar cane sector in Asia
Source: ILO (2017)

Child labor in the sugar cane sector is evidenced in three key sectoral studies conducted in the Philippines, India, and Cambodia. In 2016, the United States Department of Labor also reported the issue in Myanmar, Pakistan, and Thailand. The evidence from Asia shows that children working in sugar cane are employed both on smallholder farms as family helpers and on larger commercial plantations.

A survey conducted by the ILO in two sugar-growing regions in Cambodia in 2015 found that the incidence of child labor was more prevalent on smallholder farms than on commercial plantations (64% compared to 26%) and that children on smallholder farms tend to be younger (12 compared to 15 years old, on average). In the Philippines in 2015, it was estimated that over

[33] Baral *et al*. (2022).
[34] IRENA (2017b)
[35] Remedio and Domac (2003)
[36] IRENA (2017b)
[37] Remedio and Domac (2003)
[38] The ILO defines forced labor as situations in which persons are coerced to work through violence or intimidation or by more subtle means such as accumulated debt, retention of identity papers, or threats of denunciation to immigration authorities.
[39] See for instance CGF (2020)
[40] ILO (undated)

13,500 children worked in the sugar cane sector (2.5% of children working in the agricultural sector). Most were thought to be unpaid family workers.

Reports indicate that ethanol production in Brazil (based on sugar growing) is associated with significant labor abuse practices, including child labor, employing children as young as seven years old.[41] Brazil is the main producer of ethanol, with Thailand, the Philippines, and Indonesia also in the top 10 sugar-producing countries.[42]

Among renewable energies, bioenergy is the most labor-intensive sub-sector.[43] Like with other technologies, employment opportunities range from manual labor to engineering. As bioenergy production from agricultural waste increases, there will also be potential to boost employment in the sub-sector, especially managing crop residues and wastes.

Jobs are created all along the bioenergy chain, from the production of biofuels to their transportation, distribution, and marketing. Employment can be direct (i.e., resulting from operation, construction, and production phases) or indirect (i.e., resulting from expenditures related to biomass fuel cycles). The impacts and potential benefits of employment also depend on the country context and type of biofuel used in energy production (see Box 8.4).

Box 8.4: Employment in the biofuels sub-sector in Thailand

Source: Silalertruksa et al. (2012)

A recent study in Thailand found that producing ethanol and biodiesel requires about 17 to 20 workers and 10 times more workers than gasoline and diesel per energy content, respectively. In 2022, approximately 300,000 people were engaged in ethanol production. While there are significant differences in employment characteristics in the agriculture and biofuel processing sectors, direct employment in agriculture contributes to more than 90% of total employment in Thailand.

Local economy and livelihoods

In addition to providing employment, bioenergy projects can impact livelihoods and local economies. They may require large tracts of land to grow energy crops. This may result in land acquisition, leading to the physical and economic displacement and subsequent relocation of people, including Indigenous communities.[44] It may also lead to loss of income, such as from rice cultivation or other farming activities.

A study by the United Nations Food and Agriculture Organization focused on employment and the socioeconomics of bioenergy systems found that, from a macroeconomic perspective, bioenergy contributes to:

- Import substitution with direct and indirect economic effects at the national, regional, and local levels.
- Economic growth through business expansion.
- Mobilizing investments for rural areas.

The study notes that the human resources required to produce biofuels is about five times more than for fossil fuels.

[41] Teixeira and Sherfinski (2021)
[42] ILO (2017)
[43] EUBIA (undated)
[44] Karekezi and Kithyoma (2006)

Increased employment opportunities in the bioenergy sub-sector could help to address adverse social and cohesion trends, such as high unemployment levels, depopulation, and out-migration, which are more prevalent in rural areas. Bioenergy production tends to be in rural locations and may be beneficial there, helping rural areas and indirectly supporting related industries and services.[45]

Food security and prices

Bioenergy projects may cause both positive and negative impacts on food security and prices.[46]

Bioenergy requires a large and continuous supply of energy crops. Where many of these are also food crops (e.g., corn), their cultivation to meet the demand as a biofuel can lead to a reduction in their availability for public sale as a food. The increase in prices can consequently make consumable energy products unaffordable to disadvantaged people and the lower socioeconomic demographic who rely on the crops for food. The production of energy crops may also reduce the volume of food crops available, leading to malnutrition in rural areas.[47] Women, who are often responsible for sourcing family food supplies, may be affected more than men. Bioenergy demand may also increase the price of biofuel products, creating more commercial opportunities for medium-scale producers or wealthy farmers.

Drawing on global data on food prices, food consumption, and land-use change (especially in European countries), research shows that bioenergy projects and the increased use of biofuels causes competition for resources and lowers food crop yields.[48] This is because overall capacity to produce both biomass and food is limited to the amount of available arable land.

A balance is required between food and energy production, especially to meet the demands of the ever-increasing population and to minimize pressure on natural resources and ecosystems. Large-scale biofuel and bioenergy production also increases the demand for arable land, raising the unit cost of food production. It is argued that increased population and demand for food has already led to higher food prices, reducing resource availability (e.g., land for agricultural cultivation) to fulfill everyone's needs.[49] This trend could cause adverse impacts on poor and vulnerable communities.

Indonesia is among the world's largest palm oil and biofuel producers. The country has seen steep increases in food prices and supply shortages from 1990 to 2013[50] and from 2020 to present, including for basic and staple ingredients and commodities. A study of the use of biofuel from agricultural crops for transportation in Indonesia showed that widespread bioenergy generation and the growing of biofuel have the potential to result in food crises if mismanaged.[51] The study also showed that smallholder farmers in Indonesia are more willing to sell their crops to international biofuel companies, largely driven by the higher price and income potential, adding further challenges to food security and sustainable management of resources.

Health and safety

Biofuel production can have negative health and safety impacts. Traffic levels can increase due to the transportation of fertilizers and other crop inputs, and the transport of harvested crops to processing facilities and pellets to powerplants can lead to increased risks of accidents and localized pollution. The increased traffic and operation of machinery can cause congestion and increase noise levels that can disturb local communities and wildlife.

Farm workers will also face health impact risks from using pesticides and fertilizers, which contain hazardous chemicals. Communities can also face health risks due to air emissions from biofuel combustion, the management of waste pesticide containers and packaging, and the pollution of

[45] GNESD (2011)
[46] FAO (2012)
[47] IFPRI (2008)
[48] Muscat, A. *et al*. (2020)
[49] Hasegawa et al. (2020)
[50] DKP, KP and WFP (2015)
[51] Colbran and Eide (2008)

waterways from runoff of biocides. Such pollution can also put downstream communities and aquatic environments at risk.

For agriculture production, the IFC EHS guidelines[52] identify various OHS issues, including:

- Physical hazards (e.g., overexposure to noise vibration and extreme or adverse weather conditions; use of machinery and vehicles; potentially confined spaces; and exposure to organic dust).
- Risk of fire and explosion from combustible dust.
- Safety when working in silos.
- Biological hazards (e.g., contact with venomous animals).
- Exposure to chemical hazards (e.g., fuels, pesticides, and herbicides).

For community health and safety, the guidelines recognize that changes to land use may affect natural buffer areas and result in increased community vulnerability to manage weather patterns. There may also be exposure to potentially harmful chemicals in post-harvest products and risks of vehicle or machinery injuries on roads and access routes used around local communities.

The operation of bioenergy power plants can cause noxious odors that require managing and mitigation.

Health problems can arise from poorly designed bioenergy plants that produce high levels of specific emissions.[53] When biomass replaces coal in a modern power plant, there can be some reduction of the emission of sulphur dioxide or particles.[54]

Land use and value

Growing crops for biofuel production is land-intensive and can put significant pressure on the land used for conventional agriculture, forest production, and conservation. When existing arable land is converted to biofuel production, competition for land generally increases.

In Thailand, land used for sugar cane and palm oil cultivation is expected to increase significantly by 2026. Promoting sugar cane and palm oil cultivation has been a controversial policy decision due to the increasingly limited yields per area and to the conflict between crop supply and increasing demand for land for biofuel production.[55]

Global analysis of biofuels and land-use change has found that biofuel production will account for approximately 20% of global land-use change between 2006 and 2035. [56] In Southeast Asian countries such as Indonesia and Malaysia, this could translate into the expansion of biofuel production and cultivation of large areas of agricultural land and the clearance of forest land by bioenergy companies, further limiting the ability of communities to purchase and make use of land locally.

In addition, land value is also expected to climb sharply, potentially resulting in land disputes and conflict between stakeholders over licenses to operate.[57] A report in 2021 by the Carbon Disclosure Project highlights the lack of transparency by biofuel producers in Indonesia. It is reported that there is continued illegal use of land and transformation of forests and arable land to biofuel production, infringing the land rights of local communities.[58] The project claims that the Government of Indonesia has committed to allocating over 4 million hectares of land to support biodiesel production by 2025, with a list of Singaporean, Dutch, and Indonesian energy companies.

[52] IFC (2016)
[53] Stashwick (2016)
[54] Air Quality Expert Group (2017)
[55] Jusakulvijit, *et al*. (2021)
[56] IEA (2022b)
[57] Bruce and Boudreaux (2013)
[58] Jong (2021)

Gender and vulnerability

The transition to bioenergy is a land-intensive process and therefore requires access to and availability of large quantities of arable land. This can lead to heightened vulnerability among communities currently reliant on land access for much-needed subsistence crop cultivation.[59] As with other renewable technologies, there can be asymmetrical impacts on women and vulnerable groups (e.g., persons with disabilities, older people, Indigenous peoples) associated with displacement and access to land benefits.[60]

As affected households become exposed to greater economic pressures and food insecurity, the social risk factors identified in other renewable technologies are heightened, with differential impacts felt by women and vulnerable groups. For example, there are increased financial and domestic burdens on women, a risk of sexual harassment and gender-based violence, and resulting physical and mental health issues experiences by the communities affected. Often women have the main responsibilities for sourcing food and making meals. Changes of land use that affect food availability may change—often increasing—the amount of time they need to spend on these activities.

The potential environmental risks associated with bioenergy (e.g., reduced air quality and impacts on water quality from pesticides usage[61]) may also decrease the resilience of rural communities and individuals to external shocks and hinder their ability to cope with climate change impacts. Women and girls in rural areas may thereby be affected by a double burden of intersecting disadvantages.[62]

In 2019, IRENA conducted a survey of gender in renewables with 1440 global respondents.[63] The participating organizations and individuals rated bioenergy as the second most relevant renewable technology for their work after solar, and among the top three renewable energy types. This technology is therefore ripe with opportunity and has real potential to promote sustainable and inclusive growth for women and vulnerable communities through local employment generation, training, and skills development.

Indigenous communities

Subsistence-based Indigenous peoples rely on the land and natural resources for their livelihoods and cultural practices, such as communal land use.

Bioenergy development projects can require large amounts of land to grow energy crops. The acquisition of land for these projects can cause the loss of Indigenous communities' communal land and traditional use practices.[64] The development of bioenergy projects also has the potential to physically restrict access by Indigenous people to their natural and cultural resources, such as sacred forests, burial grounds, and animistic sites (see Box 8.5).

[59] Remedio and Domac (2003)
[60] Differential impacts of displacement and access to any resulting benefits are explored in greater detail in the Gender and Vulnerability subsection of Chapter 5.
[61] See more in the Bioenergy Research at McGill University (https://www.mcgill.ca/bioenergy/impact).
[62] Rossi and Lambrou (2008)
[63] IRENA (2019)
[64] Zurba and Bullock (2020)

Box 8.5: Impacts of biofuel production on Indigenous people of Guaraní in Mato Grosso do Sul, Brazil

Sources: EJ Atlas (2017); BBC News (2012)

In Brazil, the activities of a multinational energy corporation growing sugar cane for biofuel is alleged to have caused severe negative impacts on the Indigenous Kaoiwá and Guaraní community near Dourados in the southwestern state of Guaraní in Mato Grosso do Sul. The community suffered the use of forced labor, conversion of agricultural lands to monoculture sugar cane farming, and illegal land grabbing, which displaced the community from their ancestral lands, limited access to important cultural resources, and consigned them to small reserves. After two years of protests, the company signed an agreement to forgo buying sugar cane grown on the Indigenous communities' lands.

Public services and infrastructure

A supply-side opportunity associated with local bioenergy production is the potential for the improvement of infrastructure for the local community.

Large biofuel plantations can offer an alternative to subsistence farming for the rural poor and can provide public infrastructure and amenities for employees and their dependents, including housing, water, electricity, roads, and medical care.[65] Road networks are often built to access plantations, as well as additional public infrastructure such as schools and hospitals for employees. Oil palm plantations in Malaysia employ over half a million people, with the provision of infrastructure that Malaysians and foreign workers benefit from and have grown dependent on.[66] The financial support for local communities provided by biomass companies can also be used by local authorities to enhance existing public infrastructure services, such as schools or hospitals.

However, an OECD/IEA publication in 2013 focused on bioenergy project development and biomass supply around the world, especially in Australia, UK, and Norway, identified some negative impacts as a result of improved and new access roads used for the collection and transportation of biomass. These included higher local air pollutant emissions due to increased vehicular traffic (i.e., from exhausts), increased accidents, decreased pedestrian safety, and greater wear and tear of roads themselves.[67]

Infrastructure provision may also not always happen without concrete commitments, and community infrastructure improvements require large sums of upfront investment which can present challenges, particularly in rural low-income locations (see Box 8.6).

Box 8.6: Inadequate infrastructure for biofuel production in rural Myanmar

Source: Cushion et al. (2010)

In 2005, in response to rising energy costs and protests over cuts in diesel subsidies, the government of Myanmar established a project to produce biodiesel from Jatropha, a shrub tree. Various reports estimate that the planting area ranged from 200,000–400,000 hectares, with a planned expansion to 3 million hectares.

Production occurred on large, centrally planned plantations, on military sites, and in rural villages. Farmers with more than 1 acre (0.4 hectares) of land were directed to plant Jatropha on their landholdings and often were required to pay for the seeds. Human rights groups claimed that farmers who refused to plant Jatropha were at risk of being jailed. Other reports suggested that military rulers had confiscated land and used forced labor in some locations. Another

[65] Koh and Wilcove (2007)
[66] Cushion *et al.* (2010)
[67] IEA (2007)

concern was that the required planting of Jatropha crops displaced food production in the poor, rural areas of Myanmar.

The directive was not matched by adequate infrastructure (e.g., collection mechanisms, processing plants, distribution systems) to process the Jatropha crop. As a result, Jatropha seed production did not translate into increased fuel production. In response, on 27 February 2009, a Japanese company, the Bio Energy Development Corp (JBEDC), announced that it would establish a joint venture with a Myanmar private company for biofuel development. The new company, Japan-Myanmar Green Energy, aimed to export 5,000 metric tons of seeds in 2009 and start operating its first oil mill plant in 2010. It also planned to distribute and export Jatropha-derived fuel in addition to its seed. Globally, Jatropha has not met expected yields or investor returns.