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# Agricultural residue-based bioenergy

## Regional potential and scale-up strategies

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## Acknowledgements

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# ABBREVIATIONS

| | |
|---|---|
| **ACE** | Asian Centre for Energy |
| **ADB** | Asian Development Bank |
| **APALE** | Ecuadorian Biofuels Association |
| **APPAGRO** | Peruvian Association of Agricultural and Fish Producers |
| **ASEAN** | Association of Southeast Asian Nations |
| **BCAP** | US Biomass Crop Assistance Program |
| **BEFS** | FAO Bioenergy and Food Security Analytical Framework |
| **BFNUF** | Biomass Feedstock National User Facility in Idaho, United States |
| **biochar** | charcoal used as a soil amendment in agriculture |
| **C** | carbon |
| **CAN** | The Andean Community (Comunidad Andina) |
| **CBIO** | Brazilian carbon credit |
| **CEA VALOPRO** | Centre of Excellence in Côte d'Ivoire |
| **CES** | clean energy standards |
| **ECOWAS** | Economic Community of West African States |
| **ECREEE** | Regional Centre for Renewable Energy and Energy Efficiency, a centre created by ECOWAS |
| **EJ** | exajoule - energy equal to 1 018 joules or 1 000 petajoules |
| **FAO** | United Nations Food and Agriculture Organization |
| **FAOStat** | statistical data of the FAO, see www.fao.org/faostat/en/#home |
| **FIAS** | Ecuadorian Environmental Sustainable Investment Fund |
| **FIT** | feed-in tariff |
| **GBEP** | Global Bioenergy Partnership |
| **GHG** | greenhouse gas |
| **GIZ** | German Centre for International Cooperation |
| **GJ** | gigajoule |
| **GPS** | global positioning system |
| **ha** | hectare |
| **HHV** | higher heating value, also called gross calorific value |
| **HTL** | hydrothermal liquefaction, a thermal process converting wet biomass into biocrude, a crude-like oil. |
| **IEA** | International Energy Agency |
| **IFC** | International Finance Corporation, a member of the World Bank Group, which advances economic development by encouraging the growth of the private sector |
| **IRENA** | International Renewable Energy Agency |
| **kg** | kilogram |
| **km** | kilometre |
| **$km^2$** | square kilometre |
| **Lao PDR** | Lao People's Democratic Republic |
| **LEDS-LAC** | A network of organisations and individuals working to promote, design and implement low-emission development strategies (LEDS) in Latin America and the Caribbean |
| **LHV** | lower heating value, also called the net calorific value |
| **MJ** | megajoule |
| **Mt** | million tonnes |
| **N** | nitrogen |
| **OECD** | Organisation for Economic Co-operation and Development |
| **OLADE** | Latin American Energy Organization |
| **PJ** | petajoule - energy equal to 1015 joules |
| **PKS** | palm kernel shells |
| **POME** | palm oil milling effluent |
| **PPP** | public-private partnership |
| **R&D** | research and development |
| **RPS** | renewable portfolio standards |
| **SAF** | sustainable aviation fuel |
| **UNDP** | United Nations Development Programme |
| **VAT** | value-added tax |
| **yr** | year |

# EXECUTIVE SUMMARY

## 1. Introduction

Biomass-derived energy is poised to play a pivotal role in the ongoing energy transition. According to IRENA's 1.5°C Scenario outlined in the *World Energy Transitions Outlook*, bioenergy is projected to constitute 22% of the total primary energy supply by 2050 (IRENA, 2023). This ambitious goal will necessitate a substantial increase in primary biomass resources, requiring up to 135 exajoules (EJ) compared to 56 EJ in 2020. Agricultural residues will play a major role in achieving this target.

This report initially estimates the potential of agricultural residues in three focus regions — Southeast Asia, sub-Saharan Africa and South America. Then it identifies barriers to and highlights best practices for the effective mobilisation of these resources. This is followed by case studies on specific subregional clusters of countries, with specific strategies formulated to address the unique challenges identified within each cluster.

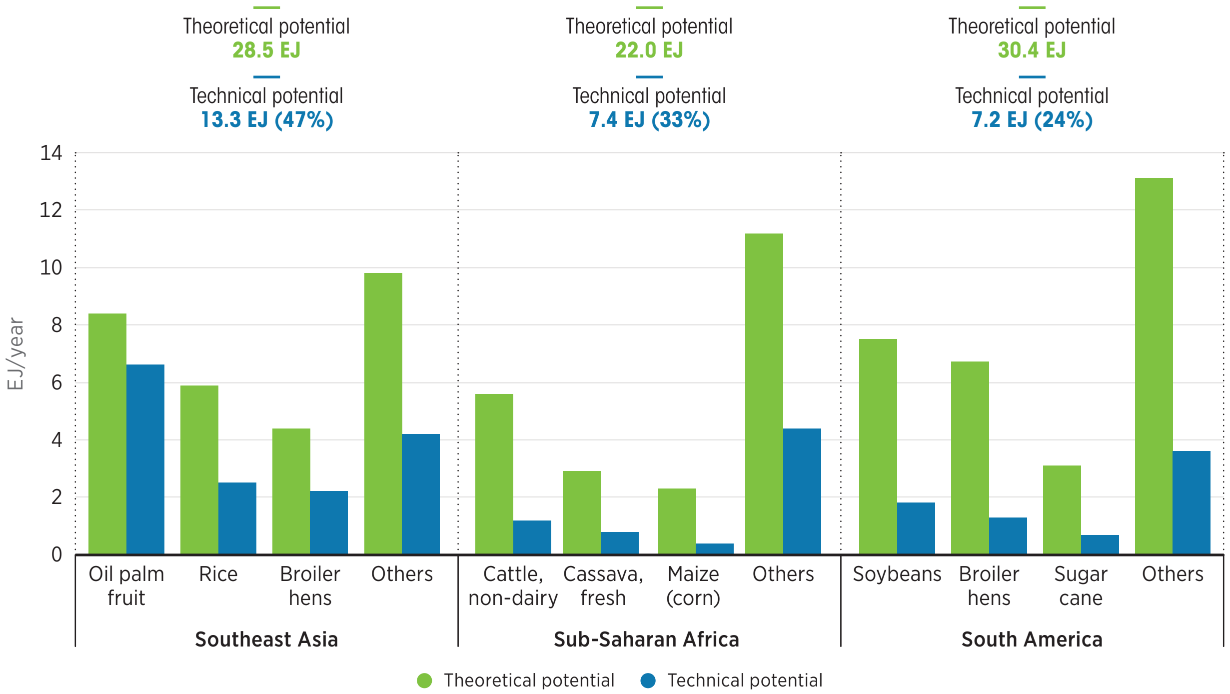
## 2. Regional potential

Analysis of data sourced from the UN Food and Agriculture Organization (FAO) reveals a technically available resource of 28 EJ in agricultural residues in the three regions under consideration, *i.e.* Southeast Asia, sub-Saharan Africa and South America. Notably, the energy contained within the theoretically available agricultural by-products in each of these three regions closely aligns with their respective primary energy consumption levels.

Figure S1 depicts the theoretical potential and technical potential of the three selected regions' agricultural residues, based on this study. In terms of theoretical potential, South America leads with 30.4 EJ per year, followed by Southeast Asia with 28.5 EJ per year, and sub-Saharan Africa with 22.0 EJ per year. However, when considering the technical potential, Southeast Asia emerges as the leader with 13.3 EJ per year, surpassing South America's 7.2 EJ per year and sub-Saharan Africa's comparable 7.4 EJ per year.

The three regions have diverse biomass resources. In South America, soybeans, broiler hens and sugar cane stand out as key residue sources with varying potential. In comparison, Southeast Asia shows significant potential for oil palm fruit and rice residues, while sub-Saharan Africa's notable sources include non-dairy cattle, cassava and maize. Notably, Southeast Asia, despite having the smallest land area of these regions, stands out for its substantial agricultural by-product generation, primarily driven by high estimates of oil palm biomass production.

**Figure S1** Theoretical and technical potential of agricultural residues for Southeast Asia, sub-Saharan Africa and South America



## 3. Barriers

Bioenergy from agricultural residues, while holding great promise in the transition to renewable energy, presents unique challenges that set it apart from other renewable forms. These challenges encompass several dimensions, including supply chain issues related to feedstock quality, quantity and availability. Ensuring a consistent and reliable feedstock source remains a critical hurdle.

Additionally, financial and economic factors come into play, with the cost and competitiveness of biofuels often posing barriers to their widespread adoption. In tandem, technical readiness and infrastructure development are vital components. Legal and regulatory frameworks, as well as political and institutional obstacles, further complicate the path to bioenergy development. These are also linked to public awareness and perceptions surrounding biomass, which need addressing.

In light of these multifaceted barriers, fostering bioenergy development calls for a comprehensive and integrated approach. Such an approach should involve allocating overarching ministry responsibilities that span the entire bioenergy supply chain, from feedstock cultivation and collection to market distribution.

## 4. Best practices in bioenergy policy making

Effective bioenergy development hinges on a comprehensive policy approach and the establishment of a suitable regulatory framework. Successful bioenergy strategies encompass several key aspects:

- fostering market development
- providing project development support
- removing legal and administrative barriers
- fostering collaboration within government and between stakeholders
- focusing on supply chain development, possibly starting with selected industry clusters, from which further development can expand
- promoting the value and benefits of the bioenergy industry
- developing the industry responsibly, securing stakeholder consent and based on sustainable practices.

An overview of best practices is given in Table S1 for all types of agricultural biomass, addressing the six main barriers identified earlier:

**Table S1** Policy best practices for bioenergy deployment

| Technical and infrastructure | Legal and regulatory |
|---|---|
| • Develop government support for pilot and demonstration projects<br>• Develop and test feedstock supply chains<br>• Create training courses through colleges and associations<br>• Consider public-private partnerships to create new infrastructure<br>• Create streamlined electrical grid interconnection rules | • Regulate organic effluents from livestock production and industry<br>• Allow co-processing of organic waste from farms and other sources<br>• Implement regulations to foster markets for bioenergy products<br>• Prohibit or restrict landfilling of organics<br>• Introduce one-window permitting process<br>• Allow re-zoning for agricultural digesters |
| **Financial and economic** | **Political and institutional** |
| • Consider public-private partnerships<br>• Offer grants, low-interest loans and loan guarantees for bioenergy projects<br>• Introduce sales tax exemptions<br>• Implement carbon taxes<br>• Reduce or eliminate fossil fuel subsidies<br>• Introduce targeted financing programmes via banks | • Create research centres of excellence focused on bioenergy<br>• Enhance interministerial co-operation on bioenergy policies and programmes<br>• Create long-term, stable policies such as biofuel blending mandates<br>• Develop a bioenergy strategy with stakeholder co-operation<br>• Create mechanisms to reward greenhouse gas (GHG) emission reductions from biogas and other bioenergy projects<br>• Embed bioenergy in a circular economy policy concept |
| **Information and public awareness** | **Supply chain** |
| • Provide education on organic waste separation<br>• Promote bioenergy and residue collection among farmers, backed by research on nutrient balances and soil carbon stocks<br>• Offer training on project development and operation<br>• Use pilot projects and incentives to demonstrate alternative energy options, such as small-scale biogas or biochar use for cooking<br>• Educate about health and environmental risks related to unsustainable wood use | • Develop nutrient management plans and harvest protocols to account for compost use and residue removals<br>• Optimise transport routes and schedules, including the use of specialist software and global positioning system (GPS) locations<br>• Integrate field residue recovery with compost or other deliveries to close nutrient cycle<br>• Employ baling or densification technologies<br>• Develop a feedstock grading system |

## 5. Case studies: Subregional clusters

This study further selected specific clusters within each continent as case studies, targeting countries with significant untapped bioenergy potential. These groups of countries are referred to as clusters due to their shared characteristics, encompassing similarities in economic development, climatic conditions or cultivated crops. These clusters, as shown below, stand to gain substantially from adopting best practices already employed by neighbouring countries within their respective regions:

- Southeast Asia: non-palm oil producing countries, *i.e.* Cambodia, Lao People's Democratic Republic (PDR), Myanmar, Philippines, Viet Nam
- sub-Saharan Africa: West 14 selected countries[1] situated along the tropical west coast of Africa
- South America: mid-developed Amazonian countries, *i.e.* Plurinational State of Bolivia (Bolivia), Ecuador and Peru

The three clusters under scrutiny exhibit notable differences in their respective agricultural practices, leading to distinct opportunities for bioenergy development. Rice straw emerges as the most readily available residue in the cluster of Southeast Asia. Concurrently, the intensification of meat and dairy production is generating substantial quantities of manure, likely to be one of the fastest-growing resources in the bioenergy sector. In sub-Saharan Africa, agriculture exhibits a greater diversity, with cattle manure and cassava as prominent residue sources. However, the situation differs in Western Africa, where large plantations produce woody biomass as ageing trees are replaced. Meanwhile, in Bolivia, Ecuador and Peru, the highest bioenergy potential stems from manure generated by broiler chickens, dairy cows and layer hens, reflecting the distinct agricultural landscapes in these Andean countries.

The subregional cluster case studies show that bioenergy development requires a comprehensive and strategic approach driven by clear policy signals. Successful bioenergy markets have flourished in regions where governments have implemented long-term policies that foster market development. However, to realise its full potential, bioenergy must operate on a level playing field, free from fossil fuel subsidies that hinder its cost competitiveness. Incentive programmes tailored to bioenergy can play a pivotal role in its growth. This includes both government and private investment, as bioenergy projects often face hesitancy from investors due to perceived risks. To attract the necessary capital, these projects must be de-risked through targeted measures and policy frameworks.

Notably, policies and incentives relevant to bioenergy may extend beyond energy generation, given the benefits available from bioenergy, in particular promoting social and rural development in economies centred on agriculture and addressing environmental concerns like eutrophication, air and water quality, and deforestation. Given its characteristics, bioenergy development can also be seen as sector or even crop-oriented, and may not be directly comparable to other types of renewables.

[1] *Benin, Cameroon, Congo, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Côte d'Ivoire, Liberia, Nigeria, Sierra Leone, Togo.*

In this context, bioenergy projects are inherently complex and involve a multitude of stakeholders. Simplification occurs when the feedstock owner is also the energy consumer, as seen in sugarcane and oil palm plantations and processing plants. However, educating stakeholders, raising awareness, and capacity-building are essential for overcoming misconceptions about agricultural residues as waste.

As also reflected in numerous earlier studies, efficient supply chains for collecting agricultural residue remain absent in many regions. Addressing infrastructure and supply chain challenges, and the need for preprocessing and year-round supplies, will require innovative research and field testing of collection, storage and densification approaches. Developing appropriate technologies like low-cost digesters, small-scale gasifiers and commercially viable second-generation gas and fuel production technologies will further enhance bioenergy utilisation.

To enhance the attractiveness of bioenergy, the circular economy approach should be integral to bioenergy development, focusing on restoring nutrients in agricultural residue to the field. Concepts like digestate field application and biochar can enhance soil properties, fostering sustainability and resource efficiency.

From a regional perspective, collaboration is pivotal in realising the bioenergy opportunity, necessitating co-operation between ministries, different levels of government, academia, industry and agricultural producers. South-South co-operation among the three regions can facilitate knowledge dissemination and the sharing of best practices and technologies, further advancing bioenergy development on a global scale.

Figures S2 to S4 present recommendations generated from this study for each cluster.

**Figure S2** Recommendations for Southeast Asia: Non-palm oil producing countries (Cambodia, Lao PDR, Myanmar, Philippines and Viet Nam)

**Diverting field residues destined for open burning as fuel to power plants**

1. Implement a feed-in tariff system or equivalent policy to encourage the collection of agricultural residues for use as fuel.
2. Provide education and guidance for farmers on managing crop residues sustainably.

**Enforcing environmental regulations on field burning**

1. Implement stricter enforcement of laws aimed at curtailing open burning practices.
2. Prioritise the needs of farmers by offering subsidies for harvesting equipment, promoting collective purchasing, and facilitating the sharing of expensive harvesting machinery.

**Ensuring fuel supplies throughout the year**

1. Incentivise the purchase of biomass boilers, via *e.g.* tax credits.
2. Create year-long supply chains through *e.g.* field storage

**Developing or adopting proof-of-origin and sustainability certification schemes**

1. Use proof-of-origin tracking to ensure sustainability and avoid unsustainably sourced biomass.

**Figure S3** Recommendation for sub-Saharan Africa: Western Africa (the 15 countries of the tropical west coast)

### Fostering market development

1. Direct grid operators to develop fair grid access rules for independent power producers.
2. Introduce proven regulatory approaches, *e.g.* feed-in tariffs or renewable portfolio standards.

### Creating and enforcing environmental regulations

1. Create and enforce regulations against deforestation and the direct release of untreated wastewater from palm oil processing, industrial livestock farms and similar sources.

### Collaboratively developing and improving residue supply chain

1. Encourage farmers, agricultural associations and regulators to collaborate to develop residue supply chains suitable for bioenergy project development.
2. Promote best practices in agriculture to increase yields and renew ageing plantations.

### Improving access to finance for bioenergy projects

1. Develop agricultural bioenergy-specific government loan and grant programmes in priority areas.
2. Work with the private sector to de-risk and facilitate the financing of bioenergy projects, including the use of loan guarantees, public-private partnerships, tax exemptions or reductions, education and subsidies to level the playing field between bioenergy and fossil fuels, especially during the early years of bioenergy development.

**Figure S4** Recommendation for South America: Mid-developed Amazonian countries (Bolivia, Ecuador, Peru)

### Fostering agricultural residue-based electricity markets

1. Implement policies that foster markets for electricity made from agricultural residues.
2. Design auctions to recognise the added benefits of bioenergy.
3. Consider alternative policies such as feed-in tariffs and renewable portfolio standards

### Optimising operations with multi-feedstocks and integrated processing

1. Increase energy production in the sugarcane and palm oil industries using third-party residues.
2. Consider additional bioenergy production, such as biomethane from currently unused residue streams, possibly through the adoption of new technologies.

### Developing specialised knowledge on field residues and nutrient cycles

1. Undertake long-term studies to determine the impact of increased field residue removal on nutrient balances when digestate or biochar is used to close the nutrient cycle.
2. Develop crop-specific best practices and recommendations.

### Localising bioenergy technology development

1. Redesign or develop bioenergy technologies adapted to local resources, capacities and feedstock, with a focus on lowering capital costs.
2. Promote other technologies, such as small-scale gasifiers, to better utilise agricultural residue for local electricity production and improve soil quality using the resulting char residue.

### Balancing support for fossil fuel and bioenergy

1. Create a level playing field for bioenergy by phasing out fossil fuel subsidies.
2. Provide equivalent support for bioenergy as for fossil fuels and consider protecting local producers against subsidised biofuel imports.

### Empowering farmers for bioenergy

1. Farmers and their associations can establish development companies to build and replicate bioenergy projects.
2. They can form co-operatives to ensure a sufficient feedstock supply year-round.
3. Government support for the bioenergy sector should include loan guarantees and measures to de-risk projects and attract private investment.

# 1 INTRODUCTION

## 1.1 Background

Achieving the climate goals in the Paris Agreement requires accelerated deployment of renewables across all energy end-use sectors. Sustainable bioenergy, which is biomass-derived energy from sources that are determined as being sustainable, will play a vital role in the energy transition. These sources vary widely, and what may be termed a "residue" or "waste" now may soon become a resource.

In IRENA's 1.5°C Scenario in its *World Energy Transition Outlook 2023,* biomass-derived energy represents about 22% of the total global primary energy supply by 2050 (IRENA, 2023). That would require just over 135 exajoules (EJ) of biomass primary supply – a challenging scale-up. By 2050 modern bioenergy[2] could provide 16% of energy end use.[3] See Figure 1.1 below.

Bioenergy (as of 2019) accounts for about 70% of renewable energy use worldwide and 9% of overall energy use. It is the most common renewable energy source, exceeding hydropower and far ahead of solar electric or wind energy. Yet, much of this is unsustainable and relates to traditional uses involving combustion of firewood and inefficiently produced wood charcoal, which may lead to poor indoor air quality and related health problems and causes deforestation in countries where wood harvesting exceeds regeneration rates.

[2] *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; and other technologies. Bioenergy encompasses all forms of energy derived from biomass, including agriculture-based, forestry-based and municipal solid waste-based forms of biomass. This report only deals with biomass obtained from residues of agricultural activities.*

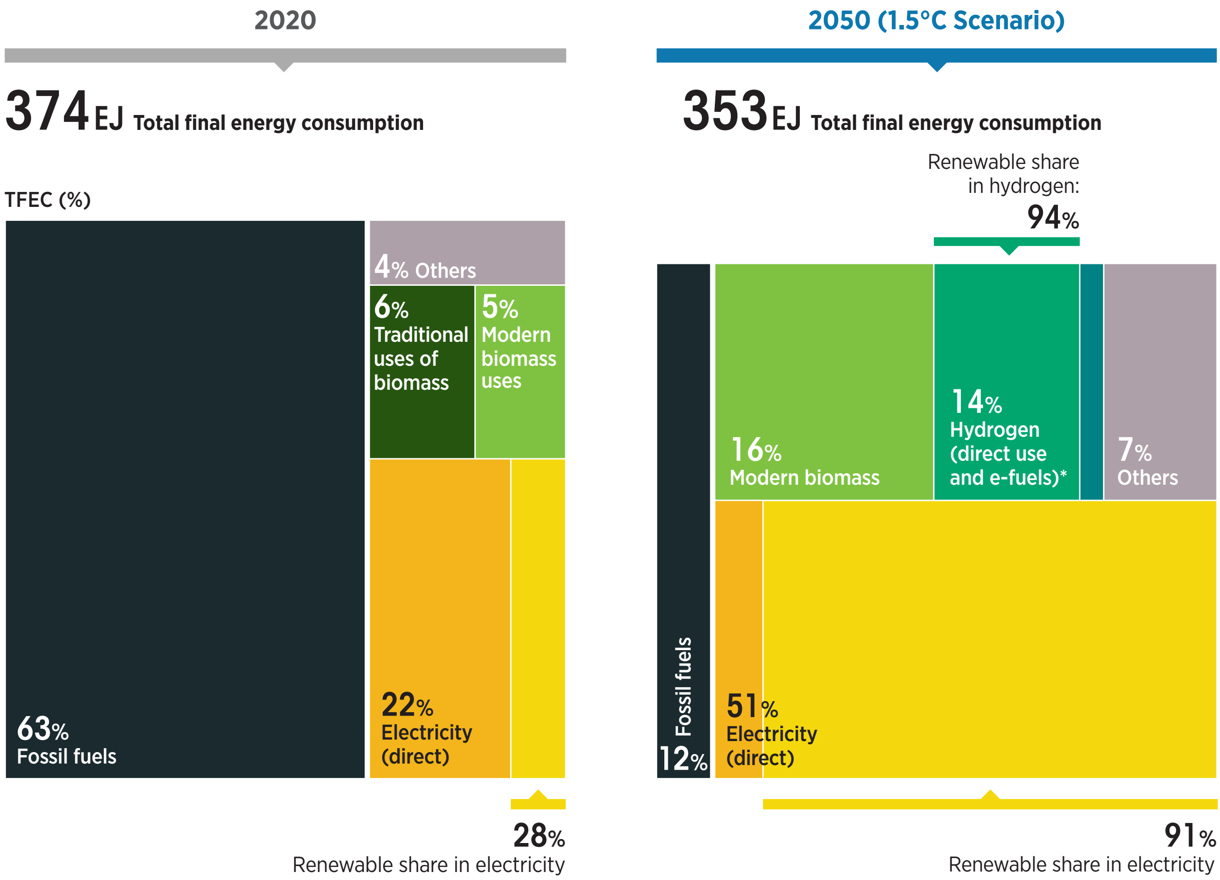
[3] *End-use energy is the energy directly consumed by the user, as opposed to primary energy which is the energy that is harvested directly from natural resources.*

There are concerns about ensuring that biomass is sourced and processed sustainably and does not cause social or environmental harm. Yet sourcing biomass sustainably has considerable untapped potential – especially when a circular economy concept is implemented that recycles nutrients and replenishes soil. A more nuanced and informed global debate around biomass is needed to help decision makers better understand how to source and use biomass responsibly in their energy transitions.

Increasing demand for ethanol, biodiesel and sustainable aviation fuels suggests that bioenergy will make an important contribution to future energy needs. Increasing liquid biofuel mandates and efforts by the aviation industry to substitute 5% of jet fuel with sustainable aviation fuel (SAF) by 2030 (IATA, 2023) suggest that there will be increased competition for biomass, including agricultural by-products. Much of what is considered a disposable "waste stream" today will be a resource or even a commodity in years to come.

From this perspective, a better understanding of bioenergy from agricultural by-products is needed. Numerous studies exist, but there is still much to learn about this potential, especially in developing countries.

**Figure 1.1** Bioenergy share of total final energy consumption by energy carrier, 2020 (left) and 2050 (right), under the 1.5°C Scenario




**Source:** (IRENA, 2023).

**Note:** e-fuels = a class of synthetic fuels manufactured using captured carbon dioxide or carbon monoxide, together with hydrogen obtained from sustainable electricity sources such as wind and solar.

## 1.2 Objectives of this report

This report consists of five chapters. In Chapter 2, we discuss the potential for agricultural residue-based bioenergy in **Southeast Asia, sub-Saharan Africa** and **South America**. Chapters 3 and 4 identify barriers and best practices to scale up bioenergy production from agricultural by-products. Chapter 5 analyses the situation in three selected subregional clusters as case studies by choosing neighbouring countries with similarities in biomass resources. Based on a description of the situation and agricultural by-products available in these clusters, the report makes concrete suggestions to build the bioenergy industry by removing barriers and creating markets. Regional expert panels, who were consulted via web-based meetings, helped develop a series of recommendations to ensure the strategies proposed are as realistic as possible. Case studies for each region provide illustrations of how best practices can be used to foster sustainable bioenergy industry development.

## 1.3 General methodology

This report interchangeably uses the terms “residue”, “waste” and “by-product”. While residue and, more so, waste suggest that these are currently discarded or at least unwanted, the term by-product indicates that they could be used for other purposes, such as bioenergy, even if they are currently not.

Some of these residues may not be available, either because they are already used for other purposes, such as composting, or because of other restrictions, such as logistical problems or access to the residues. For example, manure from free-ranging cattle is challenging to collect. Furthermore, some are not waste but used for other purposes, such as empty palm fruit bunches being used as fertiliser, returning nutrients to the soil. Some field residues, such as cotton stalks, must be burned to keep pests in check. The food processing industry already uses some waste for heating or powering its internal processes, and these resources are then unavailable for scaling up bioenergy production.

Each of these “other uses” is specific to the resource and to the area where it is produced. Field residue from spread-out smallholder farms in sub-Saharan Africa may be less available than from hacienda-style plantations in South America. Cattle in Southeast Asia may be kept in confinement while they are mainly free roaming in South America.

## 1.4 Scope

Focusing on, **Southeast Asia, sub-Saharan Africa** and **South America**, this report highlights four themes:

- Quantifying the potential for using by-products and waste from agricultural activities.
- Informing key stakeholders of the best practices and policies that promote the use of by-products and waste from agriculture activities for bioenergy applications.
- Providing an economic and technical basis at a regional level for upscaling bioenergy production from agricultural by-products and waste.
- Raising awareness of the significant contribution by-products and waste-based bioenergy can make to decarbonising the economy.

Inclusions and exclusions:

The topic of the report is agricultural biomass, which includes field residues from plant cultivation and harvesting and processing residues available from crop transformation. For example, this includes straw from wheat (field residue) and also husks from grain processing and some distillers grain, where a portion of the crop is used to produce ethanol. It also includes animal waste, such as cow, swine and chicken manure, which can be used in anaerobic digesters – but not dead animal carcasses, which require special treatment to control hygiene risks. Palm oil milling effluent (POME) is also included as a digester feedstock.

The scope excludes purpose-grown energy crops, *i.e.* the focus is on by-products generated from ongoing agricultural operations. Municipal organic waste and forestry-based feedstock types are not considered in this report, but may be additional sources for bioenergy production.

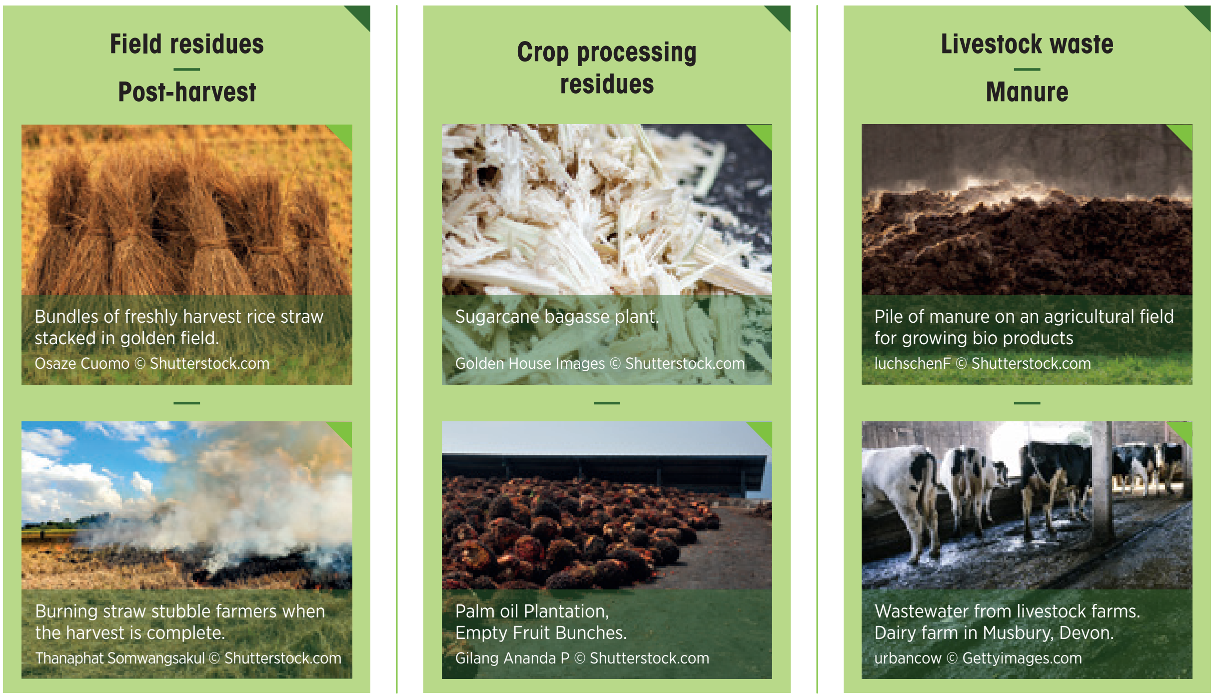
Saverio blasi © Shutterstock.com

**Table 1.1** Examples of the three types of agricultural by-products considered in this report

| Field residues | Processing residues | Livestock waste |
|---|---|---|
| Rice straw | Bagasse | Cattle manure |
| Corn stalks | Corn husks | Swine manure |
| Soybean residues | Coconut shells and husks | Poultry litter |
| Exhausted plantation trees | Palm kernel shells (PKS) | |
| Waste banana stalks | Palm oil mill effluent (POME) | |

This report is largely technology agnostic, *i.e.* it does not select a certain technology or deal with its feedstock requirements. Wet feedstock, such as manure, is better suited for biochemical pathways, such as anaerobic digestion. Biogas production requires the right ratio of carbon to nitrogen (C:N) that is met using a variety of inputs. Lignocellulosic feedstocks are unsuitable for most digesters. Conversely, thermochemical pathways, such as gasification or pyrolysis, generally require dry feedstock. Certain by-products are thus better suited for specific technologies and should be separated accordingly. Finally, some conversion technologies, such as hydrothermal liquefaction, are only starting to be commercialised and might change the use of by-products in the future. This report does not deal with these technological developments. Some of IRENA's recent reports detail the opportunities and potential of new bioenergy technologies, specifically liquid transport fuels (IRENA, 2016a, 2022).

**Figure 1.2** Types of agricultural by-products



# 2 REGIONAL POTENTIAL

This chapter assesses the regional potential of by-products and waste from agricultural activities in Southeast Asia, sub-Saharan Africa and South America. The theoretical potential is refined to the technical potential, considering the current uses of these by-products.

## 2.1 Literature review

The following literatures sources were evaluated for regional potential:

- IRENA's report on Southeast Asia (IRENA, 2017a) (covering Viet Nam, Indonesia, Malaysia, Thailand and the Philippines) estimates theoretical and technical (after use for animal feed) by-product availability for the region and the world, based on either a 25% or a 50% residue recovery rate. It does not consider animal manure as a feedstock. The report also estimates worldwide potential.

- A parallel IRENA report on sub-Saharan Africa (IRENA, 2017a) (covering Ghana, Mozambique, Nigeria, South Africa and Uganda) follows the same approach.

- The 2011 US "One Billion Ton Study" finds an overall potential of one billion dry tons (imperial)[4] from US agricultural residues by 2030 in its high-yield scenario (BETO, 2011). The business-as-usual scenario finds a total of 180 million dry tons of corn stover and grain residues by 2030, plus at least 30 million dry tons of animal manure. This can be converted to about 3 EJ, assuming an energy content of 16 gigajoules (GJ) per dry tonne (t). The study reflects the economic potential based on a maximum cost at the farmgate of USD 60 per dry ton. The 2016 update (no later updates available) finds about 200 million dry short tons of agricultural (field) residue by 2040, at a cost of up to USD 80 per ton (U.S. Department of Energy, 2016). At 16 gigajoule per tonne (GJ/t), this results in 3.2 EJ per year from field residue alone (livestock waste is not included in the update).

- For China, Guangling Zhao finds an energy production potential of around 1 EJ from agricultural sources (manure and crop residues) (Zhao, 2016). These numbers cannot be reconciled with the others as they include an energy conversion factor (efficiency) that is not reported.

- An alternative source for China indicates current and future potential for straw and manure, in 2030 and 2060 (BEIPA, 2021). The results align with those of other regions, at about 1.4 EJ of potential in 2020 and around 2 EJ in 2060.

- For India, Venkatramanan *et al.* estimate that 700 million tonnes (Mt) of crop residues are currently generated per year (theoretical potential) and that 210 Mt are available (technical potential), equivalent to 4 EJ of energy (Venkatramanan *et al.*, 2021). Another study arrives at half as much energy being available from surplus residues (technical potential) (Vaish *et al.*, 2022). No projections for future years are made in these studies.

- For the European Union (EU28), Bioenergy Europe refers to a study that estimates that 146 Mt of residues are available per year without affecting soil carbon levels, equivalent to 2.3 EJ per year (Bioenergy Europe, 2018).

- For sub-Saharan Africa, Röder *et al.* determine the technical agricultural resource potential, estimating total production, recoverable amounts and competing uses (Röder *et al.*, 2022).

- For Southeast Asia, Tun *et al.* estimate the amount of solid agricultural residues produced per country, deriving the energy equivalent (Tun *et al.*, 2019). It is not clear whether this is wholly or partially the technical or theoretical potential as several sources are used and no explanation is given. For unknown reasons, the source did not quantify the Philippine residue as energy potential, which was done for this report using the same factors used by Tun *et al.*, to complete the data.

- A regional estimate for Southeast Asia arrives at a biogas potential of between 1 EJ and 1.5 EJ for crop residues and livestock waste for now and 2040 (Bioenergy Insight, 2020).

[4] *In this specific context, it's important to note that all references to 'tons' are based on the US ton as sourced from the cited report. For conversion, 1 tonne = 1.1 ton. However, there is one exception: the energy content assumption of 16 GJ per tonne (metric).*

The results are presented below in Table 2.1. Despite the differences in agricultural land size and productivity, the results are similar for individual regions, at between 2 EJ and 4 EJ per year for the first period to year end 2030. For those sources making assumptions for 2040 and beyond, amounts only increase slightly from the first period.

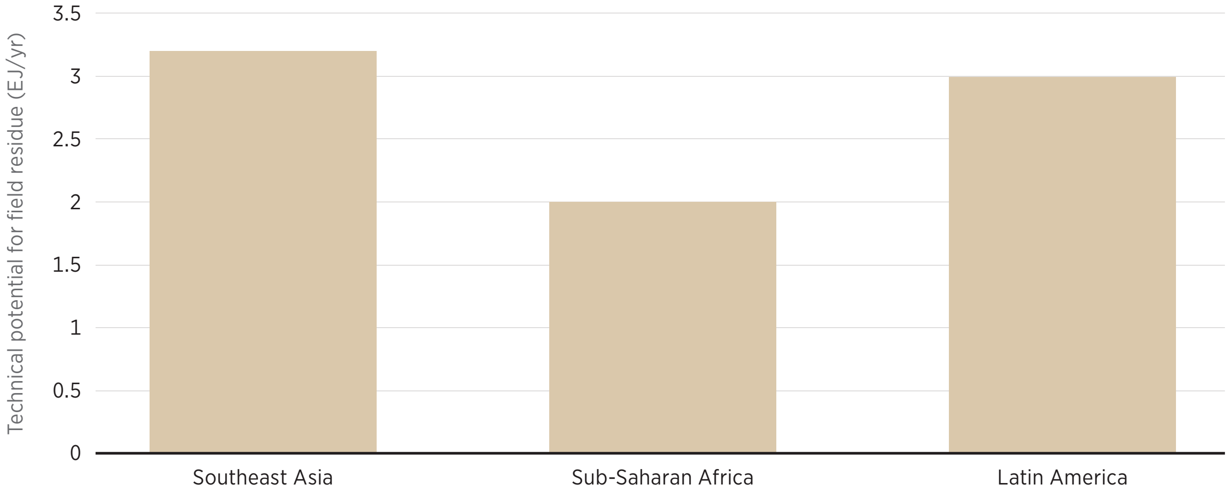
**Table 2.1** Current and future regional agricultural biomass estimates

| Source | 2018-2030 (EJ/yr) | | 2040-2050 (EJ/yr) | | Manure included? | Comments |
|---|---|---|---|---|---|---|
| | Low | High | Low | High | | |
| (Zhao, 2016), **China** | 0.65 | 1.2 | 1.5 | | YES | Energy in fuels, not in feedstock |
| (Brandes *et al.*, 2020), **China** | 1.4 | | 2.0 | | YES | Biogas and straw, 2030 and 2060 |
| (Venkatramanan *et al.*, 2021), **India** | 4.0 | | | | NO | Technical potential for 2021 |
| (Vaish *et al.*, 2022), **India** | 2.0 | | | | NO | Technical potential for 2022 |
| (BETO, 2011), **United States** | 2.6 | | 3.2 | | NO | Economic potential (base scenario), numbers for 2040 used for 2050 |
| (Bioenergy Europe, 2018), **Europe** | 2.3 | | | | NO | Sustainable potential for 2018 |
| (IRENA, 2017a), **Southeast Asia** | 3.2 | | 3.3 | 6.0 | NO | Southeast Asia, technical, five countries only |
| (Tun *et al.*, 2019), **Southeast Asia** | 2.9 | | | | NO | Potential for 2018 |
| (IRENA, 2017b), **sub-Saharan Africa** | 2.0 | | 2.2 | 2.8 | NO | Sub-Saharan Africa, technical, five countries only |
| (Röder *et al.*, 2022), **sub-Saharan Africa** | 2.9 | | | | YES | Technical potential for 2018 |

**Note:** EJ/yr = Exajoule per year

Based mainly on the sources stated above, Figure 2.1 combines the various estimates of the technical potential for present or near-term agricultural residues available. No source was identified that only covers South America, but the Latin American[5] results indicate resource potential similar to the other regions, with lower potential in sub-Saharan Africa than in South America and Southeast Asia.

**Figure 2.1** Literature values for current technical potential of field residues




**Sources:** (ARENA, 2021; Bahadiroglu *et al.*, 2022; Barahira *et al.*, 2021; BETO, 2011; Bioenergy Europe, 2018; Brandes *et al.*, 2020; Ferreira-Leitao *et al.*, 2010; IRENA, 2014, 2017a, 2017b; Molina-Guerrero *et al.*, 2020; Murmis, 2015; Namsaraev *et al.*, 2018; Vaish *et al.*, 2022; Wu *et al.*, 2020)

## 2.2 Methodology

This study calculated the potential for agricultural by-products in various steps using multiple data sources based on reported, estimated or imputed[6] crop volumes or heads of livestock (for manure). The main data source is FAOStat[7] (FAO, 2023). The study is constrained to the 20 largest crops per country and to crops with an annual production of 40 000 t/yr or more. Some small countries have fewer than ten top crops because not all crops meet the 40 000 t/yr threshold. All data are for the year 2020.

Multiplying this crop production data with typical residue-to-crop ratios yields the theoretical potential for agricultural residues. Data assessment and plotting were conducted to generate this database with detailed sources and referenced publications, and data were expanded with consideration from local experts. The said potential in each case is the energy input or maximum theoretically available rather than the achievable energy after conversion of the residue into a fuel. This input energy potential does not account for conversion losses or efficiency related to transforming feedstock to biofuel products or their use.

[5] *Latin America includes South America and Spanish speaking countries of North and Central America.*

[6] *Imputed data involves replacing missing data with plausible, coherent values, facilitating subsequent analyses and data aggregations. This might be done by multiplying the harvested area by a yield typical for this crop and this region. See FAOStat, www.fao.org/3/cb9339en/cb9339en.pdf.*

[7] *See: www.fao.org/faostat/en/#home*

Most data sources, such as FAO, only provide information on crops produced rather than residues or by-products. This study estimates residues by multiplying annual crop production amounts with common crop-to-residue factors reported in various publications. The crop-to-residue ratio is specific to a crop and is assumed to be the same for all regions, regardless of climatic conditions, crop specifics or agricultural practices.

The theoretical potential includes field or farm residues, such as rice straw, and processing residues, such as rice husks. Some crops, such as oil palms, have up to four types of processing by-products. Each of them is quantified separately. This study applies crop-specific processing ratios, accounting for the fact that some crops are used unprocessed. Wherever such factors are unavailable, the database assumes a ratio of 25% processed versus 75% sold as an unprocessed product.

Manure volumes rely on data supplied by FAOStat (FAO, 2023). To quantify the climate change impacts from farming, FAOStat quantifies manure volumes for each livestock type and each country, precisely the amount of nitrogen contained in the manure left in the field versus the waste collected in shelter, such as stables. This study uses these data and ratios to determine the amount of manure produced and recoverable.

This chapter estimates the residues theoretically available in dry tonnes per year.[8] It converts all residue weights into dry tonnes using literature data on the moisture content of fresh crops. The database then multiplies these dry tonnes by their calorific value to estimate their energy potential. A lower heating value (or net calorific value) of 16 GJ/t (dry) is applied as an average for cellulosic biomass.

### Moisture and dry matter content of residues

Wet residue has less calorific value than dry residue. This is because a larger share of the residue's weight consists of water, and water does not burn and has no calorific value. The study only accounts for residue dry matter content to compare or add various residues, even if the waste material is wet.

Many conversion processes require dry feedstock, while others require a slurry. Mechanical drying might require as much energy as is contained in the residue. The need for drying feedstock depends on the conversion process. The moisture content of the feedstock changes from species to species and changes when exposed to wind and sun after harvesting.

**This study only considers the dry matter content of a by-product, regardless of whether it is dry or wet.** This simplification is necessary for accounting purposes.

The estimates produced in this publication do not represent the amount of resources ready to be used for energy purposes, as such decisions need to be made based on local contexts, such as logistics, competition, etc. While this report considers bioenergy based on residues as sustainable per se, the sustainability and knock-on effects of using a particular agricultural residue should be examined according to local conditions and on a case-by-case basis to determine which best practices can ensure that by-products are harvested and used sustainably.

*[8] Data in this report uses metric, rather than imperial units. Tonnes, therefore, refers to metric tonnes rather than "short" or "long tons" used in the imperial measurement system.*

**Lower heating value versus higher heating value**

The calorific value of hydrocarbons, whether of fossil origin or made of biomass, can be expressed in two ways: the lower heating value (LHV) (or net calorific value) and the higher heating value (HHV) (or gross calorific value).

The LHV is the energy after subtracting the latent heat released when condensing the steam in the flue gases produced by combustion.

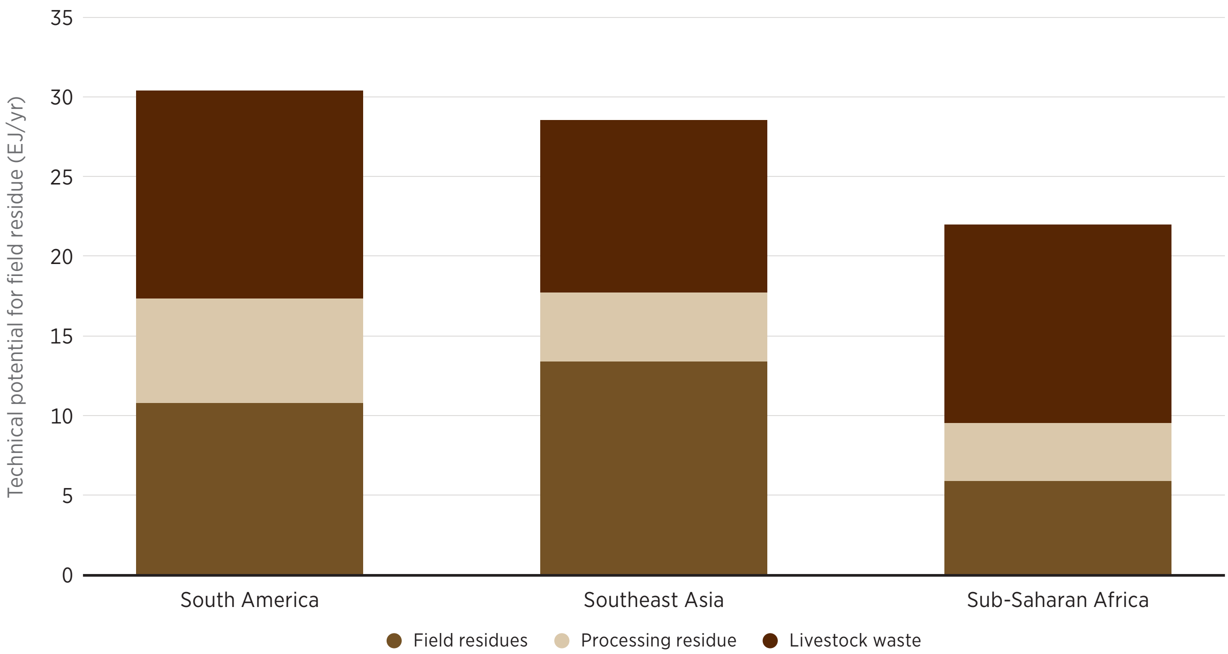
For biomass, this value is more representative than the HHV as few technologies, such as condensing boilers on the market, can use the energy contained in the steam.

## 2.3 Estimates of theoretical potential by region

The three regions of focus in this study, Southeast Asia, sub-Saharan Africa and South America, vary significantly in the volumes of agricultural by-products produced, partly due to the extent of land cultivated, the types of crops grown and the type of farms prevalent.

Large farms process crops in industrial-scale facilities, often for export, while smallholder farms frequently produce for subsistence or local markets. Residues in the latter instance are less likely to be collected or even available. Field residues generally have the largest theoretical potential, containing more energy than processing residues and similar in size to manure from livestock (see Figure 2.2).

**Figure 2.2** Theoretical potential of the three main types of agricultural residues in the three regions




**Based on:** FAOStat (FAO, 2023) combined with residue-to-crop factors.

Each of the three regions has traditional, stable crops that create a specific type of by-product. In South America, the stalks, husks and cobs of maize are a significant resource. In Southeast Asia, rice straw and rice husks are prevalent. Sub-Saharan Africa has more diversified agriculture with several types of crops, including but not limited to maize, rice and cassava.

## Southeast Asia

Oil palm residues are the major category of agricultural residues found in Southeast Asia. Indonesia and Malaysia are the world's two largest palm oil producers, with remarkable amounts of biomass generated from the sector as waste and by-products. In addition, rice is the traditional and most common food staple, with significant field residues. Farmers in Southeast Asia frequently burn rice straw on-site, leading to air pollution. Of the three regions studied, Southeast Asia has the smallest agricultural land area, yet has considerable agricultural residue available, amounting to around 17 EJ a year.

Due to its size, Indonesia is the most significant country in Southeast Asia in terms of bioenergy potential, followed by Viet Nam, Thailand and Malaysia. Myanmar, Lao PDR, Cambodia and especially Timor-Leste only produce minor biomass residues. Singapore and Brunei are not included in the analysis due to their relatively small agricultural sector.

### Calorific value versus usable energy – input versus output

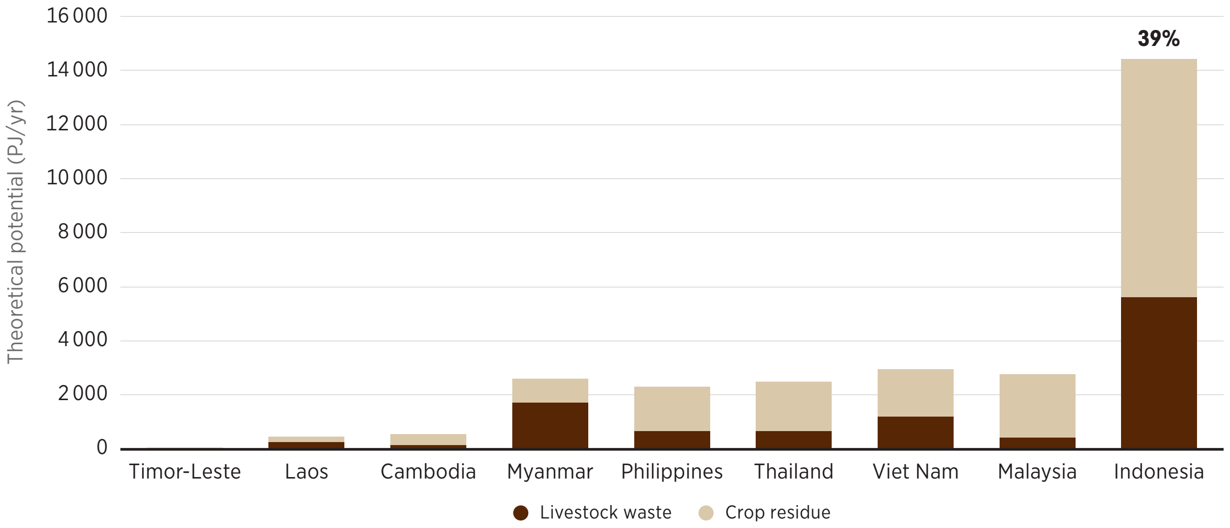
Energy data in this report refers to the "calorific value" of the residue, *i.e.* its chemical energy. Not all this energy is available – there will always be losses when converting it to other forms of energy. The percentage of usable energy mainly depends on the conversion process and the type of energy produced.

Combusting biomass to turn it into electricity, for example, usually has a net efficiency of 10-35% of the fuel's calorific value. A solid-to-liquid process, such as in a Fischer-Tropsch reactor, has a typical efficiency of 60-90% of the feedstock input. Combined heat and power applications can have a total combined efficiency of up to 90%.

**This report only states the calorific value of the residue, not the final product that can be made from it,** such as electricity, a combustible gas or a liquid fuel. The conversion process, size and feedstock play a large part in determining how much energy can be obtained. The reader should not confuse calorific value or input energy with usable energy or output.

Figure 2.3 compares nine Southeast Asian countries' energy potential from livestock (dark brown columns) and from crop cultivation and processing (light brown columns). Livestock waste is less abundant than crop residues. Southeast Asia has about 20 EJ of theoretical potential, about the same as South America.

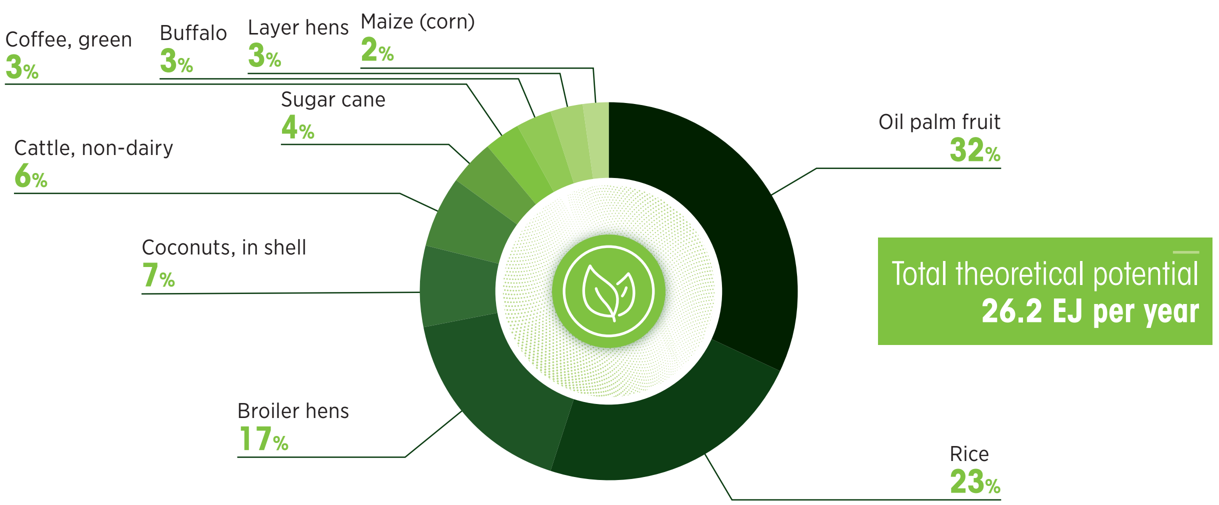
**Figure 2.3** Theoretical livestock waste and crop residue energy potential in Southeast Asia




**Based on:** 2019 FAO livestock and 2020 FAO crop production data (FAO, 2023).
**Note:** PJ/yr = petajoule/ year.

Palm oil and rice production residues comprise about three-quarters of the region's agricultural by-products, followed by coconut (Figure 2.4). Other agricultural residues offer much smaller amounts of energy production potential. These numbers must be used with care as some of the residues are not recoverable. For example, residues with smaller theoretical potential may still have a higher technical potential than rice.

**Figure 2.4** Theoretical potential of the top ten agricultural residues in Southeast Asia




**Based on:** 2019 FAO livestock and 2020 FAO crop production data (FAO, 2023).
**Note:** The items shown in the chart indicate the categories of crop or animal residues.

## Sub-Saharan Africa

Sub-Saharan Africa consists of 43 countries, some of them relatively small. Following the UN classification for sub-Saharan Africa, South Sudan is included but Sudan is not. Nigeria, one of the largest countries in the region, generates 20% of the region's residues (2.2 EJ/yr), yet far less than Indonesia (10 EJ/yr) or Brazil (14 EJ/yr) (see Figure 2.5).

Agriculture in sub-Saharan Africa comprises mainly smallholder farms that produce a diverse set of foods and products. Maize and rice are the two staple foods. Cassava is also cultivated extensively. The amount of liquid residues, mainly from livestock, is smaller than in the two other regions, yet sizeable.

**Livestock waste:** Generally, livestock numbers and related potential are smaller than for South American countries. The region has a theoretical potential for biogas of only 1.2 EJ, compared to more than 2.6 EJ in South America. Most countries of Africa, being less affluent than South America, prefer crops over livestock raising for meat and dairy. Most countries thus only show small energy production potential from manure, *i.e.* less than 50 petajoule per year (PJ/yr). The two countries with the most significant potential for livestock waste, both around 150 PJ each, are Tanzania and South Sudan.

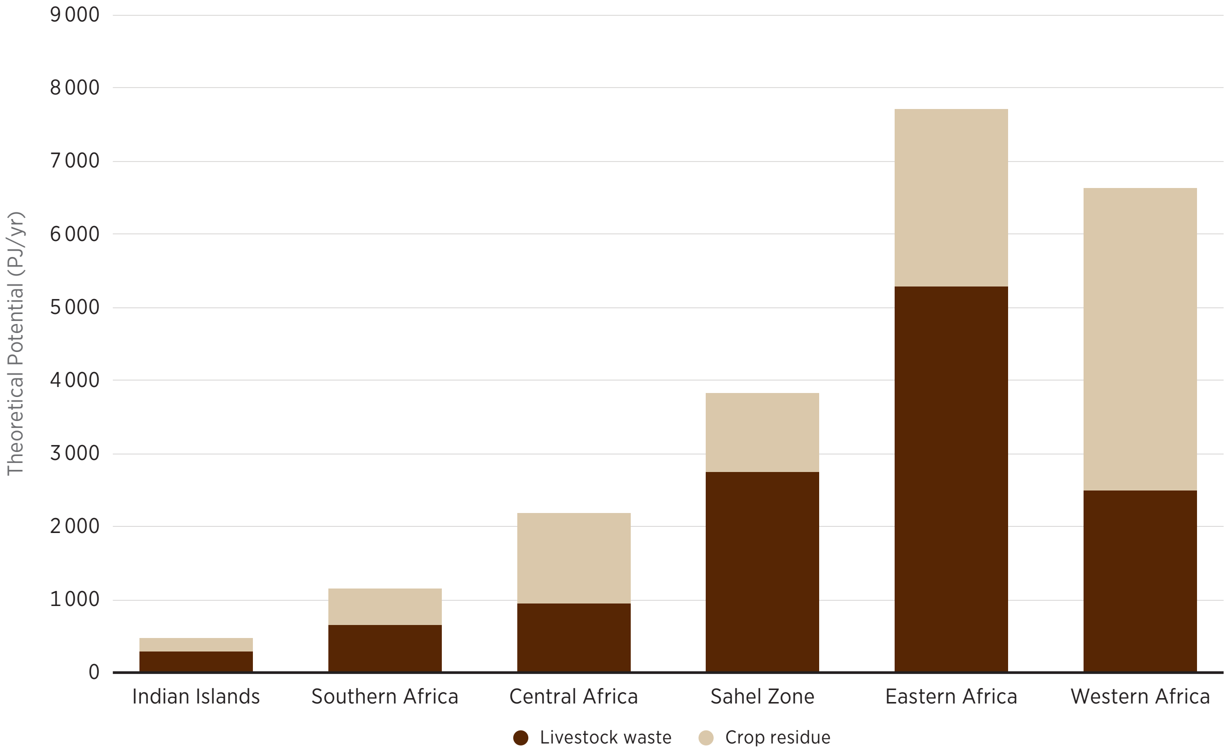
**Crop by-products:** The theoretical energy available from livestock waste compared with that from crop residues varies widely. For some countries, such as Namibia, this ratio shrinks to 1:1, while others, such as Nigeria, have a ratio of 1:25, energy potential from manure versus from crop residues. That country produces the highest amount of solid biomass residues, about four times as much as any of the next-largest countries. Namibia, Somalia and South Sudan have higher amounts of manure than crop residues. The analysis disregards Djibouti, Cabo Verde and the Seychelles because they do not produce the minimum threshold of 40 000 t/yr of any crop.

### Sustainability of biomass

With bioenergy demand estimated to double between 2010 and 2030, concerns about the sustainability of its supply will grow. Biomass is frequently termed "carbon neutral" as the carbon released during the processing and combustion of the residues was previously absorbed by the plant and would be released again when the plant decomposes. For many agricultural residues, this process takes place within a year, rather than decades (or centuries) as with forestry biomass.

However, sustainability issues related to biomass use are beyond emissions and can include multiple aspects covering the economic (*e.g.* financing needs and energy security), environmental (*e.g.* land use, water, biodiversity and soil quality) and societal (*e.g.* food security and jobs).

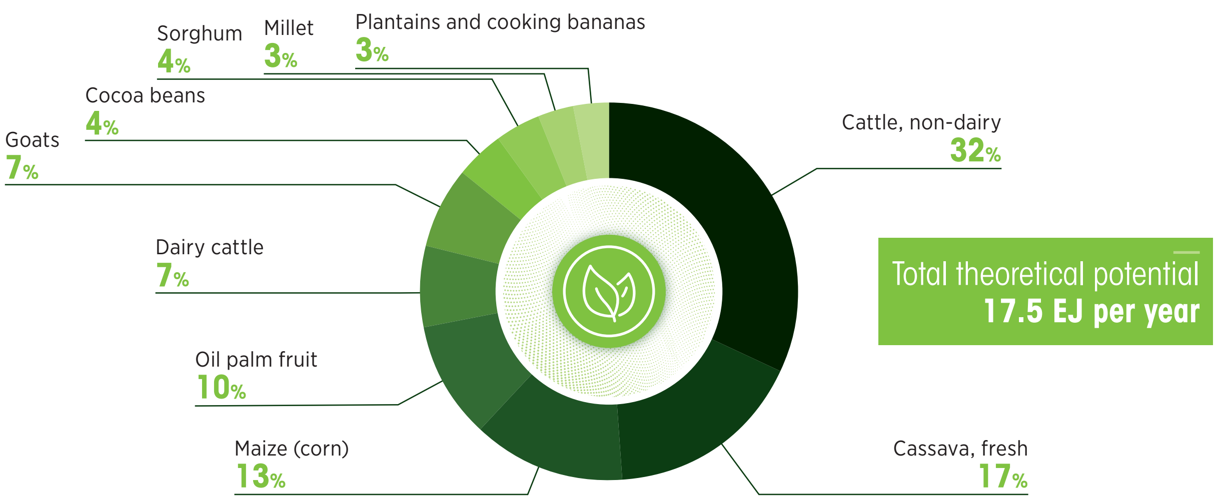
**Figure 2.5** Theoretical livestock waste and crop residue potential in sub-Saharan Africa




**Based on:** 2019 FAO livestock and 2020 FAO crop production data (FAO, 2023).

The top ten agricultural residues in sub-Saharan Africa contain 17.4 EJ per year, less than what is available from the top ten residues in South America or Southeast Asia. Figure 2.6 shows that three residues – from cattle, cassava and maize – make up half of the bioenergy potential from agricultural residues. The remainder is composed of a relatively even share of residues from field crops.

**Figure 2.6** Theoretical potential of the top ten agricultural residues in sub-Saharan Africa




**Based on:** 2019 FAO livestock and 2020 FAO crop production data (FAO, 2023).

## South America

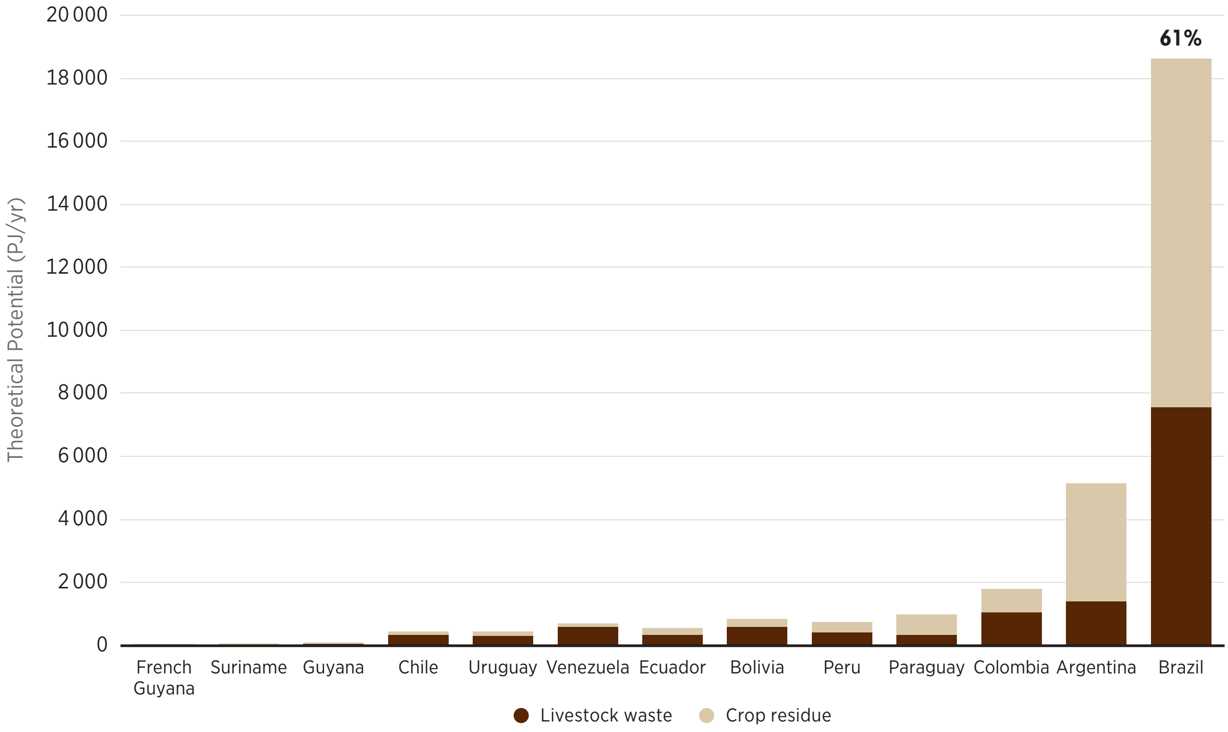
South America's agriculture is dominated by export-oriented products, such as soybeans and sugarcane grown in large hacienda-style farms. Maize (corn) is the traditional and most common food staple.

Brazil produces the most agricultural by-products, followed by Argentina and Colombia. These three countries make up 70% of the land area of South America and generate 88% of the total agricultural residues theoretically available on the continent. In contrast, Suriname and Guyana have a relatively small agricultural sector with a negligible amount of residues.

South America's theoretical potential for agricultural residue is the largest of the three regions. This enormous potential is mainly due to extensive soybean and sugarcane cultivation that generates high-energy residues. Livestock waste is also significant. Figure 2.7 shows the theoretical potential for biogas production from livestock waste and the energy in theoretically available crop residues.

The type and volume of agricultural by-products differ strongly between countries. Brazil, the largest country, shows the largest potential in terms of livestock waste. Most countries only have small energy production potential from manure, *i.e.* less than 50 PJ/yr. Generally, livestock waste is less significant that crop residues. Exceptions are Chile and Bolivia, where livestock manure is larger than crop residues. Both countries have extensive animal husbandry.

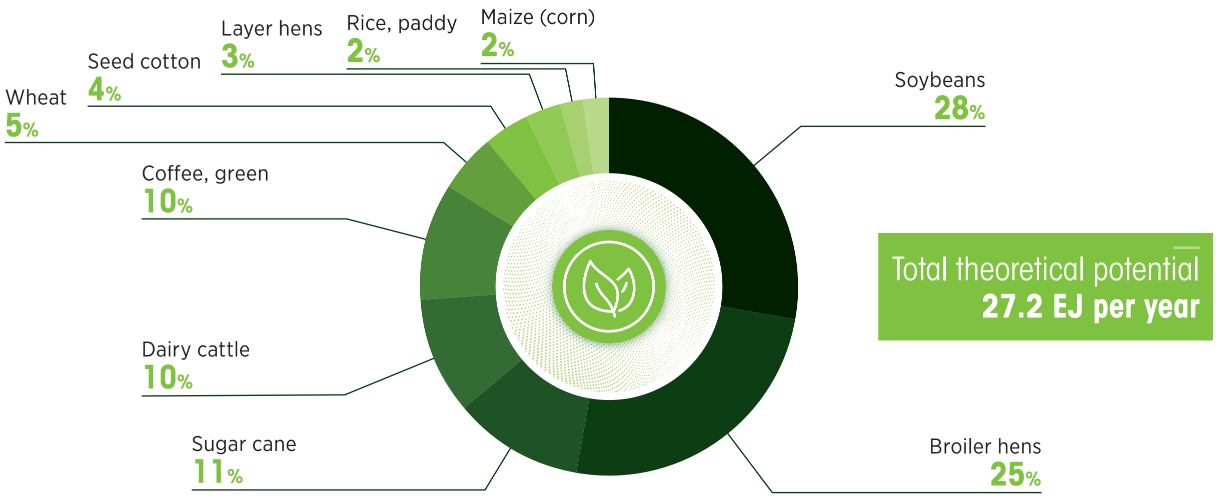
**Figure 2.7** Theoretical livestock waste and crop residue energy potential in South America




**Based on:** 2019 FAO livestock and 2020 FAO crop production data (FAO, 2023).

The total energy content of the top ten agricultural residue streams was 27 EJ in 2020, more than the region's total primary energy consumption (21.6 EJ)(World Bank, 2022). Replacing some of the region's fossil fuel consumption is possible even when considering conversion losses. Figure 2.8 illustrates the pre-eminence of certain crops, such as soybeans, sugarcane and maize, in residue production and energy potential. These are also among the most important crops in South America. Livestock waste from cattle (non-diary) shows relatively large theoretical potential.

**Figure 2.8** Theoretical potential of the top ten bioenergy residues in South America




**Based on:** 2019 FAO livestock and 2020 FAO crop production data (FAO, 2023).

## Comparison between regions

South America, Southeast Asia and sub-Saharan Africa produce similar volumes of agricultural by-products. The theoretical energy content in these by-products is of the same magnitude as the amount of primary energy consumed in these areas. Southeast Asia is the most productive of the three regions. It has the smallest agricultural area producing almost similar volumes of agricultural by-products as South America and more than sub-Saharan Africa (Figure 2.9).

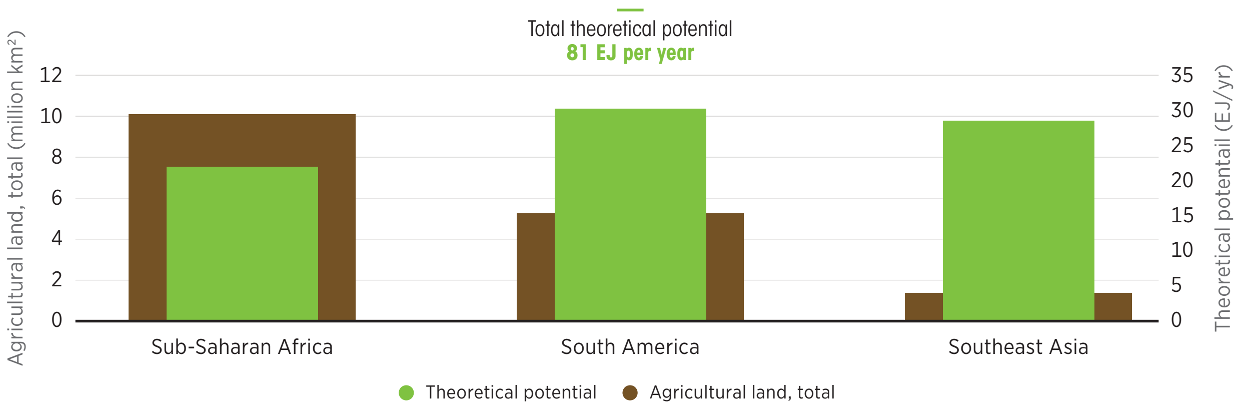
A number of factors may explain these differences:

1. For several reasons, such as the need for fertiliser, crop yields are lower in sub-Saharan Africa, leading to less residue production per hectare. Sub-Saharan Africa often has only half the crop yields, sometimes just one-quarter, of those obtained in Southeast Asia or South America.

2. Sub-Saharan Africa and South America include more arid areas outside the tropical zone. The sub-tropical or moderate climates will offer only seasonal crops and may have lower yields due to the dry weather.

3. Finally, certain crop groups produce more residue per hectare than others. Crops like sugarcane, rice, oil palm, banana, coffee and coconuts are high residue producers, at around 200-300 GJ per hectare, per year (/ha/yr). Other crops, such as millet, corn, sorghum and other grain crops, only yield about 50-100 GJ/ha on average, partly because they can be grown on less fertile land or in more arid areas. Some crops, such as yams, plantain bananas and cassava, are harvested unprocessed, including shells etc., and brought to households with little or no field residues and no subsequent industrial processing residues. Direct consumption and subsistence farming are essential in sub-Saharan Africa, where cassava, plantains and yams are common. Southeast Asia has three of the highest-yielding crops among the three most important cultivates, which account for 70% of its field crop production. In contrast, sub-Saharan Africa has a very diverse crop mixture and only some of them are high yielding in residues. Many are tree crops where residue mainly comes from replacing aged trees every 25-30 years. South America lies between the two (Table 2.2). Table 2.3 provides the estimated volumes and energy content of field and processing residues from the three main crops in each region.

**Figure 2.9** Agricultural land area and theoretical potential for agricultural residues in the three regions




**Based on:** 2020 FAOStat data on livestock and crop production and World Bank statistical data (FAO, 2023; World Bank, 2022).
**Note:** km² = square kilometre; EJ/yr = exajoule/year.

**Table 2.2** Nine most important crops per region ranked by total energy contained in residue produced

| Rank | Southeast Asia | South America | Sub-Saharan Africa |
|---|---|---|---|
| 1 | 🟢 Oil palm | ⚪ Soybeans | 🔴 Maize |
| 2 | 🟢 Rice | 🟢 Sugarcane | 🟢 Rice |
| 3 | 🟢 Coconut | 🔴 Maize | 🔴 Cassava |
| 4 | 🔴 Maize | 🟢 Oil palm fruit | 🔴 Sorghum |
| 5 | 🟢 Sugarcane | 🟢 Coffee | ⚪ Groundnuts |
| 6 | 🟢 Coffee | 🔴 Wheat | 🟢 Bananas |
| 7 | 🔴 Cassava | 🟢 Rice, paddy | 🟢 Oil palm |
| 8 | ⚪ Rubber | ⚪ Seed cotton | 🔴 Millet |
| 9 | 🟢 Banana | 🟢 Bananas | 🟢 Sugarcane |
| **GJ/ha** | **244** | **128** | **32** |

🟢 Crops yield around 300 GJ/ha 🔴 Crops yield 50-100 GJ/ha ⚪ Crops were not evaluated

**Based on:** 2020 FAO crop production and World Bank statistical data (FAO, 2023; World Bank, 2022).
**Note:** GJ = gigajoule; ha = hectare.

**Table 2.3** Theoretical potential of the top three agricultural residue sources in the three regions

| Region | Top three residue sources | Dry residues (million t/yr) | Theoretical potential (EJ/yr) | Percentage |
|---|---|---|---|---|
| **South America** | Soybeans | 412 | 8 | 25% |
| | Sugarcane | 412 | 7 | 22% |
| | Maize (corn) | 188 | 3 | 10% |
| | **All agricultural residues** | | **30** | **100%** |
| **Southeast Asia** | Oil palm fruit | 468 | 8 | 30% |
| | Rice | 285 | 6 | 21% |
| | Coconuts | 258 | 4 | 15% |
| | **All agricultural residues** | | **29** | **100%** |
| **Sub-Saharan Africa** | Cassava | 345 | 6 | 26% |
| | Maize (corn) | 234 | 3 | 13% |
| | Oil palm fruit | 137 | 2 | 11% |
| | **All agricultural residues** | | **21** | **100%** |

**Based on:** 2020 FAOStat data on livestock and crop production (FAO, 2023)

## 2.4 Discussion

### From theoretical to technical potential

Even though desktop analysis shows that the agricultural sector has vast bioenergy potential, this will rarely be fully available to bioenergy producers. This may be due to economic factors, sustainability concerns, distance to users, losses, economies of scale and competing uses. The resulting technical potential is lower. It is often estimated based on typical percentages or by using scenarios. For example, previous IRENA reports (IEA, 2020; IRENA, 2014; Jain, 2019) use either 25% or 50% for the rate of recovering field residues and assume a 90% recovery rate for processing residues. Andrews (2006) finds that 70% of crop residues should to be left in the field to maintain healthy crops. This, of course, assumes that the nutrients in processed residues are not returned to the soil, *e.g.* in the form of ash, digestate or pyrolysis residues.

Photoongraphy © Shutterstock.com

**Bioenergy potential**

**Theoretical potential:** Supply of biomass is limited only by biophysical conditions, representing ultimate (rather than achievable) levels of biomass supply.

**Technical potential:** Potential supply in view of limiting agronomic and other factors that suppress yield levels, competition for other uses and land requirement for non-agricultural use.

**Sustainable potential:** Potential supply given sustainability constraints, such as those relating to nature conservation and biodiversity preservation, soil and water protection and constraints on land use due to concerns about emissions and competition with food and fuel production.

**Market or economic potential:** The amount of biomass that can be produced for energy under certain economic criteria – for example, with a maximum fuel price or consistent with a certain carbon price. Such estimates depend on a range of assumptions about biomass supply costs and prices, the costs and efficiency of conversion and the costs and prices of the competing energy options, including fossil fuel pricing (IRENA, 2022b).

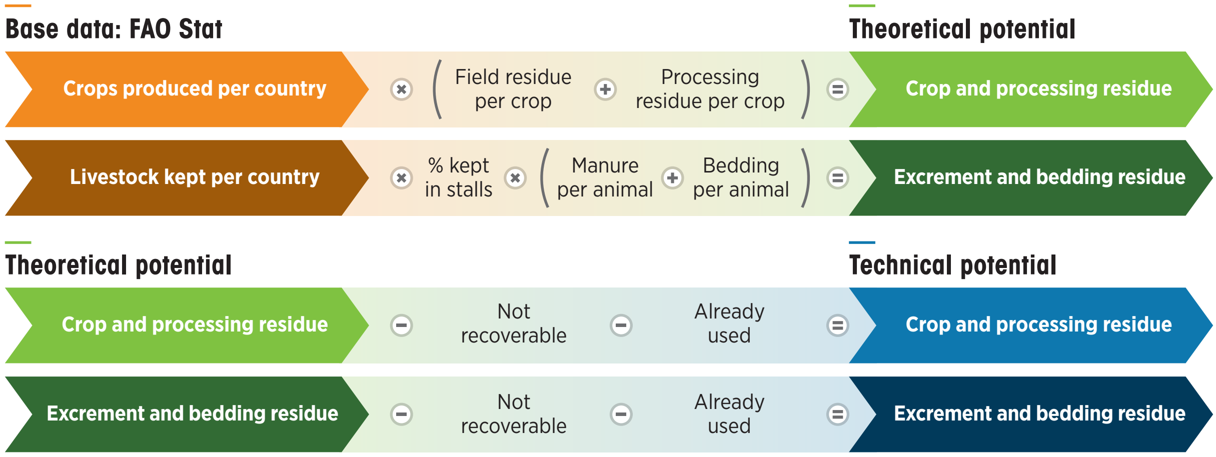
**The stated potential is the energy input or maximum theoretical potential rather than the achievable energy after conversion of the residue into a fuel. The potential does not account for conversion losses or efficiency.**

Whereas the numbers stated above may be realistic, they also oversimplify. A more advanced feedstock assessment would need to investigate the situation in each region, confirm the amounts of residues generated and look at their current use or destination. The results may differ between crops and between locations in the same country. They often vary between nations or between regions due to different practices and situations. They also do not consider the application of compost or other organic residues to maintain soil carbon and mineral levels. Both are important for the soil's fertility. This study assumes recovery data for each type of residue based on literature data or information from local experts.

In South American countries in the tropical Amazon region, the fast metabolism of the tropical forest in cluster countries has led researchers to recommend that at most 50% of field residue be removed to avoid affecting the nutrient cycle and soil quality. This value has become a generally accepted limit or recommendation for field residue removal; removing more biomass would require the study of nutrient cycles and a circular economy approach that includes returning nutrients to the field after harvest, such as through the application of a digester.

Some regions may already use much of their residues. This is the case in Nepal where many small digesters use manure from livestock. In some countries, industry may use some or all of the processing residues for internal energy production or may use readily available competing fuels instead. Such differences are not captured when using fixed percentages to estimate technical potential. Yet, at a global level, this technical potential provides a more realistic picture than the theoretical potential would suggest. This was therefore the approach used to derive technical potentials for this study (see Figure 2.10).

**Figure 2.10** From crop data to theoretical and technical potential



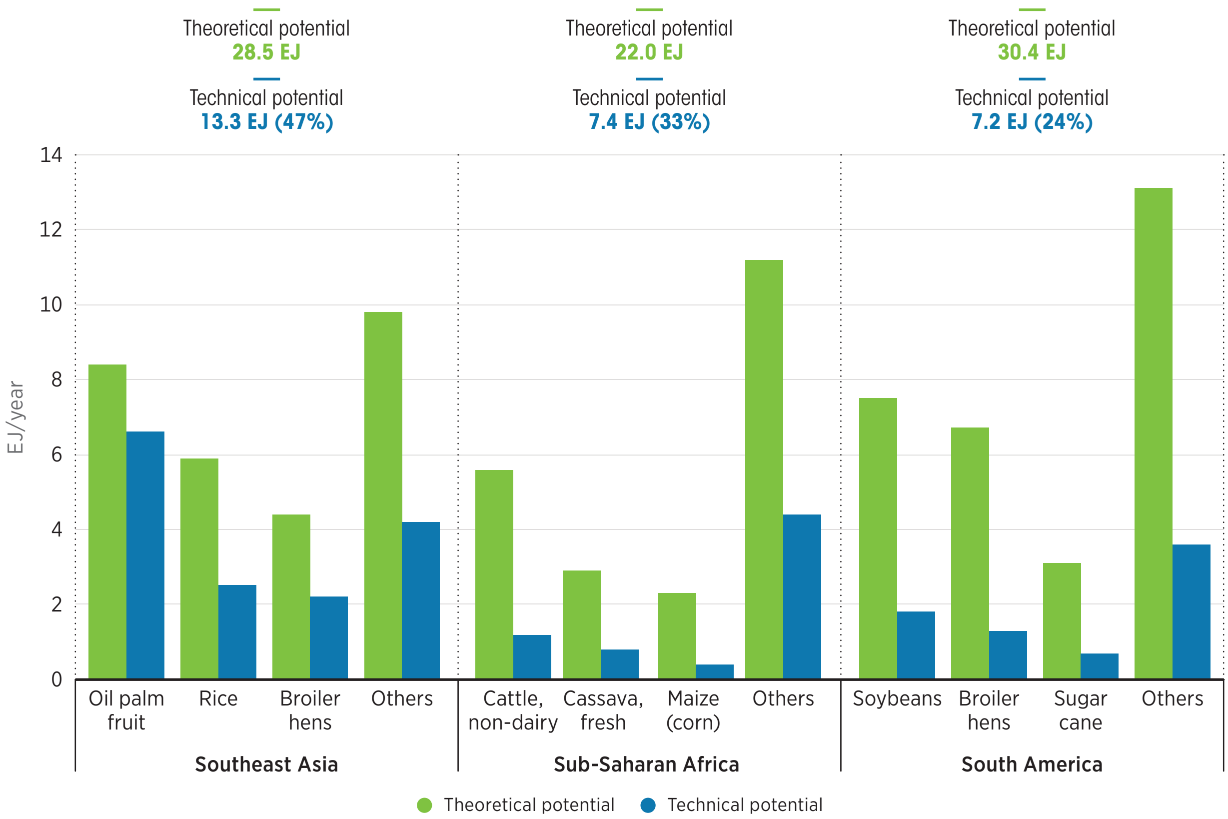

Monforti (2015) determined sustainable field residue removal rates for Europe (EU27) for eight different crops and found the results to vary significantly between countries (Monforti *et al.*, 2015). Several countries could safely remove more than the default values. In contrast, others would experience severe losses in soil carbon even at the default removal rates. These results refine previous numbers where the sustainable removal rates were based on current practices and expert advice. A study in Ontario, Canada, found that soil type has a significant impact on sustainable residue removal rates and that no residues were sustainably available from soy, fodder corn or bean plantations (Oo, 2012). Kalt (2020) discusses sustainable removal rates and refers to the literature, indicating rates between 15% and 82%, depending on crop and tillage practices (Kalt *et al.*, 2020). Most sources suggest numbers between 30% and 60% (IRENA, 2016b).

Such results indicate there is no one-size-fits-all approach to recovering field residues. Default collection rates may be different to the values used here. One source reports 8% for sugarcane (IRENA, 2016b). However, this work did not consider the application of either compost or charcoal from biomass pyrolysis processes.This practice could compensate for soil carbon and mineral losses from residue removal, allowing it to remove more than what is currently considered sustainable for soil fertility. Finally, some farmers remove residues and dump or burn them to kill off pathogens. Using this biomass for energy would impact the soil no more than current practices.

Competing uses for processing residues may be more important than those for field residues. In Ethiopia, all available by-products of cereal, pulse and oilseed milling units and brewery by-products are used as animal feed. The country also uses half of the bagasse, molasses, sugarcane tops and fruit peel (FAO, 2018). A global 90% recovery factor for processing residues, as used to represent collection rates in a previous IRENA publications (IRENA, 2017b), would vastly overestimate amounts technically available for bioenergy unless corrected for current uses.

Similar considerations apply to livestock waste. Some solid manure is in high demand from horticulturists or even for making bricks for house construction. Liquid manure is often applied to fields directly, often to the detriment of groundwater and air quality. Use in anaerobic digestion will stabilise the material and reduce odour and pathogens. The potential from agricultural residue in the three regions of the Global South are summarised in Figure 2.11.

**Figure 2.11** Theoretical and technical potential for agricultural residue determined for Southeast Asia, sub-Saharan Africa and South America

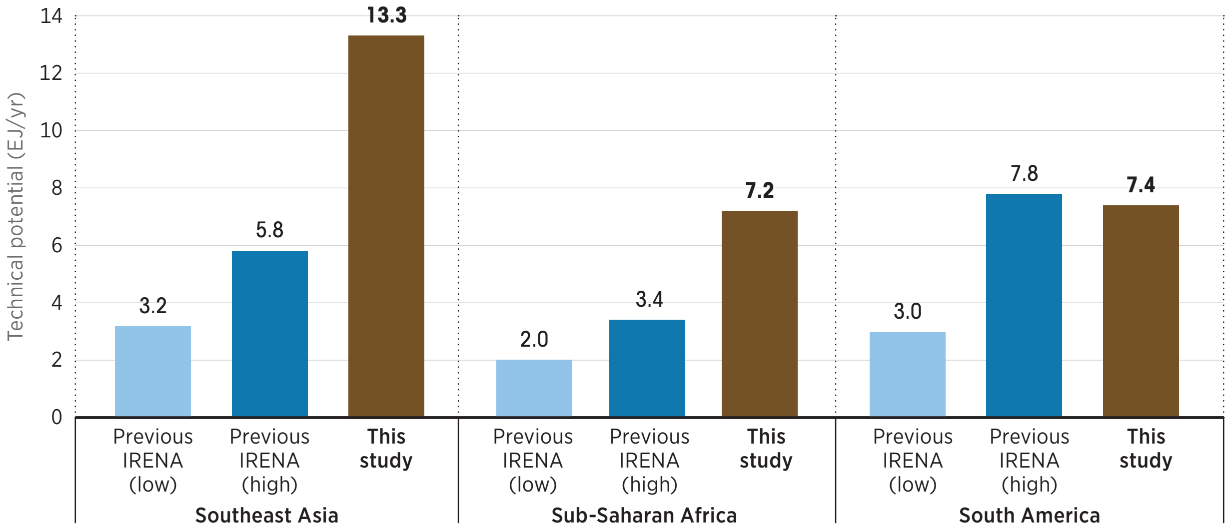



## Comparisons with previous estimates

This chapter compares the results from the underlying database with figures published in previous IRENA reports. Figure 2.12 compares the technical potential of the database for Southeast Asia, sub-Saharan Africa and South America with the technical potential from the literature, for crop residue only and not including livestock waste. Note that the literature source for the technical potential in South America includes all of Latin America, leading to a higher estimate for that region. For Southeast Asia and sub-Saharan Africa the potential determined in this study is higher. The IRENA Southeast Asia and sub-Saharan Africa studies only determined field residue amounts for five countries, whereas the current study does so for all of countries in those regions.

Another difference is the approach to wood waste estimations – these are not included in the field residue numbers cited from the previous IRENA studies on Southeast Asia and sub-Saharan Africa. Those studies determined an additional wood potential in Southeast Asia of 0.9 EJ from ongoing forest industry harvesting and processing operations. They did not determine any wood potential for sub-Saharan Africa. Conversely, this study accounts for the regular long-term renewable nature of plantations and deems wood from such renewals as being available for bioenergy, arriving at greater amounts of wood availability. As such, the sub-Saharan Africa results seem rather conservative for this study, given only five countries were included in the IRENA study.

**Figure 2.12** Technical potential for crop residues according to previous IRENA estimates compared to the potential in the three regions determined in this study




**Sources:** (IRENA, 2014, 2017b, 2017a and FAO, 2023) (see Table 2.1).
**Note:** The potential is stated as input energy, disregarding conversion losses.

The comparison is complex, even if done at a country level, and comes with methodological disparities and assumptions that make an accurate comparison difficult. Determining the technical potential from the theoretical potential requires a detailed analysis of current uses, accessibility and sustainability. These are crop- and region-specific and are best carried out at the local level. General residue recovery factors are good for approximating technical potential, but also introduce errors into the estimates as these factors do not apply to all residues equally. For example, most straw should be left in the field to maintain soil fertility. By comparison, when orchard trees are pruned annually and removed at the end of their productive life, they are usually fully available for bioenergy or other purposes.

Notably, the elevated figures observed in Southeast Asia can be attributed to the allocation of a substantial 80% weighting to empty palm fruit bunches. However, in practice these figures could be much lower due to the prevalent practices of either reintegrating these palm fruit bunches into the soil or utilising them for combustion to generate power for the mills.

**Key takeaways:**

1. Various literature sources state that the world's technical potential for energy contained in agricultural by-products amounts to between 30 EJ and 60 EJ per year.
2. The three regions, South America, Southeast Asia and sub-Saharan Africa produce about 20% of this potential while combined accounting for 29% of the world's population and 14% of global GDP. There is an opportunity to turn this resource into revenue.
3. For each of these three regions the amount of energy contained in their theoretically available agricultural by-products are of the same magnitude as the region's primary energy consumption.
4. Amongst the three regions, Southeast Asia has the smallest land area and produces the most agricultural by-products due to high estimates of oil palm biomass generated.

# 3 BARRIERS

Bioenergy production based on agricultural feedstock faces numerous barriers, just as most forms of renewable energy do. There are, however, obstacles that are specific to bioenergy as a whole, and specifically to bioenergy from agricultural residues. This chapter lists the most common challenges that participants of three regional workshops identified.

## 3.1 Supply chain-related barriers

While wind and sun are free resources; biomass is not. Agricultural biomass comes at a cost due to the need for collection, handling, storage, transport and preprocessing from relatively larger areas. These logistical challenges put the resource at a disadvantage compared to fossil fuels. Some countries with domestic fossil fuel resources may have less of an incentive to develop a biofuel industry, as energy security and availability are less of an issue. There are exceptions that stand out, exemplified by Indonesia and Malaysia. Despite their substantial reserves of petroleum and coal, both nations have made substantial investments in the realm of biofuels and bioenergy.

The following factors tend to increase the cost of agricultural biomass as a feedstock:

- **Low density:** Agricultural biomass, such as straw, is often bulky and tends to have a lower physical and energy density (Scarlat *et al.*, 2010) than wood and much lower than coal. Large volumes have to be transported for comparatively little energy content.

- **High moisture content:** Green (fresh) biomass may contain as much moisture as fibre (*e.g.* banana residue or corn stover). Moisture is undesirable for most biofuel production processes and many advanced conversion technologies require moisture be removed before processing (Scarlat *et al.*, 2010). High moisture content also adds to transport costs. Various methods exist, including pretreatment to increase density through air-drying, grinding, pelletising or even decentralised thermal treatment, but all these pretreatments come at a cost.

- **Decomposition:** Most agricultural residues, especially if green or wet, are susceptible to rot, vermin or decomposition, leading to mass losses and handling challenges (Oo, 2012).

- **Feedstock quality:** Other issues are linked to the chemical and physical properties of biomass itself. High ash, chlorine and sulphur content of agricultural residues are examples for this. Undesirable chemical composition or impurities can result in ash melting, low calorific values, polluting flue gases and so on. Figure 3.1 compares woody or lignocellulosic biomass with herbaceous or cellulosic biomass.

**Figure 3.1** Quality comparison between woody and herbaceous bioma

- **Variety and inconsistency:** Every crop and type of animal husbandry produces different types of biomass residues. The properties of even a single feedstock might change with supplier and season. Quality may also vary from one year to another or from one field to another. Harvesting and storage practices can lead to contamination with soil and lead to impurities. Biomass quality may vary over time due to changes occurring during storage. Changing chemical composition makes it necessary to adapt the conversion process constantly or add costly preprocessing, or may lead to lower outputs and technical issues (Lan *et al.*, 2020).

- **Uncertainty of supply:** Agricultural activity is weather-dependent and can also be affected by diseases or fire. Natural disasters such as hailstorms, insect infestations, floods or drought can lead to much-reduced harvests and therefore reduced residue production. Bioenergy producers are exposed to this risk.

- **Dispersed availability:** Agricultural biomass may be dispersed across very large areas (IRENA, 2022a). Industrial-scale biomass energy technologies require substantial amounts of feedstock – several hundred thousand dry tonnes of material per year. To procure these quantities, residues need to be collected and transported from a large catchment area. The prevalence of smallholder farmers in many countries makes collecting and procuring the residues more difficult. The transport of small amounts over long distances is usually not cost-effective. From an administrative perspective the need to contract with multiple feedstock providers is cumbersome and creates large administrative overhead costs per unit of energy contained in the material.

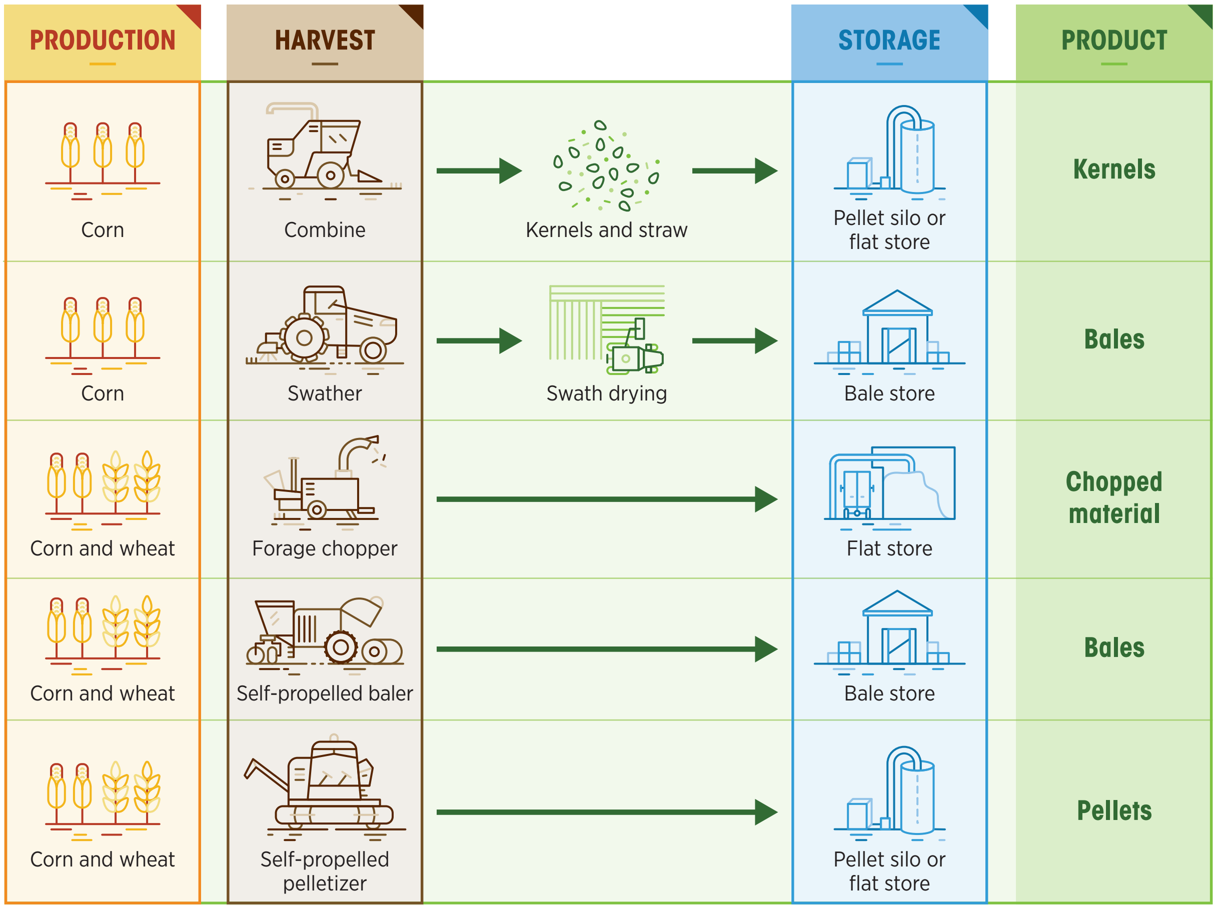
- **Need for a variety of feedstock**: In certain types of setups, feedstock needs be mixed to meet the demand or to achieve the desired properties. For example, agricultural digesters require a specific carbon-to-nitrogen balance that requires a "cocktail" of ingredients (Induchoodan *et al.*, 2022). A variety of feedstock, some liquid, some solid, needs to be sourced, requiring additional on-site storage, more transactions and on-site management to achieve the desired feedstock properties. The logistics of this increases transaction and production costs.

- **Seasonality:** Agricultural biomass may not be available throughout the year, being seasonal (Oo, 2012), so storage may be required (World Bank, 2022). Storage again implies higher costs as the biomass needs to be moved to storage areas and later be picked up, increasing the number of movements needed to reach the plant. The feedstock needs to be protected from the elements and preferably stored in a fashion that allows wind and sun to dry out the biomass. Additional capital is required for the construction of barns, silos, sheds or other structures to protect the biomass during storage. Any storage will lead to some biomass losses – for example, due to decay – which will decrease the yield and increase the delivered net costs.

- **Pretreatment:** Depending on the feedstock type and specifications, agricultural residue requires pretreatment before the actual conversion to a fuel (Oo, 2012). This may include comminution (chopping, grinding, chipping, hammer milling) or drying, washing, screening or another treatment to remove impurities. Pretreatment can result in significant costs. For example, drying feedstock is the single largest capital and operational expense in making pellets.

- **Missing supply chains:** Farmers may have to invest in new equipment or material to effectively collect, store, pretreat and deliver field residue (IEA Bioenergy, 2017). Concepts for in-field storage and scheduled pickups are required. Unless there is a guaranteed and profitable market, such investments are unlikely to be made.

**Figure 3.2** Harvesting options for field residue




**Source:** (WBA, 2018).

- **Competition for feedstock:** There is competition for feedstock with other sectors, such as livestock breeding, which uses some agricultural feedstock for feed and bedding (IRENA, 2016a). Composting operations may also use agricultural residues. In many cases, the non-energy use of residues (*e.g.* field burning, use as feed) is the option of choice, either to follow traditional practices, to control pests, due to a lack of alternatives or for the field application of manures. Finally, as biofuel production increases, so will competition for feedstock.

- **Absence of a grading or sorting system:** Unlike for forestry, there are no equivalents to a log sorting system or log grading yards that allocate feedstock to a certain use depending on its properties, quality and suitability (Hoover *et al.*, 2019). While woody biomass has a classification system defining standards and minimum properties, a similar approach is still uncommon for agriculture-based feedstock around the world. It is then up to the buyer to assess the biomass for each seller and sort it according to its quality, type or moisture. Fluctuating feedstock quality is one of the most common problems when operating a bioenergy plant.

- **Multiple feedstock providers:** Many smallholder farmers may have to collaborate, for example by forming a co-operative, to combine the relatively small amounts of residue they may each produce into a larger total in order to reach the volume necessary for assuring the feedstock needs for a new project.

## 3.2 Financial and economic barriers

Apart from direct costs of biomass feedstock, economic barriers may also come from structural issues relating to starting a new business or problems not necessarily linked to bioenergy, such as:

- **Supply chains and feedstock costs:** A previous IRENA report on second-generation biofuels identified feedstock costs as a key barrier. Feedstock costs are responsible for about half (40-70%) of production costs. This strongly suggests that supply chain optimisation will be key to reducing the cost of biofuels (IRENA, 2016a).

- **Price competitiveness:** A significant economic barrier for renewable fuels is the frequently subsidised price of competing fossil fuels (Oo, 2012; World Bank, 2022). Countries that have abundant resources of fossil fuels especially struggle to introduce bioenergy options, which do not have any price support structures and are thus more expensive than fossil fuels. In addition, unwanted competition for bioenergy from lower-cost renewable energy from wind and solar is a barrier to its adoption for power generation, as discussed in the case study on Colombia.

- **Access to finance:** Access to financing can be difficult or cumbersome for renewable energy projects (Oo, 2012; World Bank, 2022). This is more so for agricultural bioenergy as the feedstock may only be seasonally available or require multiple feedstock sale agreements with many farmers. Investors and lenders often require long-term feedstock supply agreements that are difficult to obtain. Sourcing and contracting for large amounts of feedstock and for a long period of time is often not easy. The risk of droughts, pests and other events are beyond the control of farmers. Lenders will often want to see that 100% of the feedstock for a project has been secured through contracts, possibly even demanding that more than 100% is available, in case existing sources fall short. This can make it difficult to fulfil the conditions required for project financing or may lead to a higher risk profile and therefore higher financing costs.

- **Unfamiliar technology:** In many countries (advanced) biofuel production is not yet a mainstream business practice and the financing industry and regulatory bodies may be unfamiliar with projects of this nature, adding to cost and timelines (IRENA, 2018).

- **Markets:** Unless markets for bioenergy products already exist, a project may not be deemed viable. This may be the case with introducing biodiesel where no mandates exist, or direct sales of electricity to a customer without any regulatory regime for selling renewable power to the grid, or introducing pellet cooking stoves into a region that has been using other devices in the past. Where these markets need to be created in parallel with the project itself, risk increases and financing will be more difficult to obtain (Oo, 2012). Many bioenergy technologies create two or more products, all of which need a market.

- **Grid access:** Whenever there are monopolies, as with gas and electric utilities, it can be difficult or impossible for independent power or gas producers to feed and sell into the existing distribution grid.

- **Costs of keeping soil fertile:** Farmers may need to supplement artificial fertiliser or organic sources of nutrients to compensate for the removal of residue that usually is tilled back into the soil, unless a circular economy concept is applied that returns minerals to the soil (Sung, 2016). The use of additional inputs, especially from fossil sources, may then defeat the purpose of biofuels as a sustainable alternative to fossil fuels.

- **Lack of data:** Good, recent data on feedstock availability is paramount for bioenergy project development. Yet, this is not always available and project developers must often rely on estimates or outdated sources when exploring possibilities (IRENA, 2022a). A detailed resource assessment is always needed to develop a project, and government data, collected regularly and publicly available, helps enable the planning and development process and carries weight with investors.

## 3.3 Technical and infrastructure-related barriers

Some bioenergy technologies are still pre-commercial. Even with mature technologies, many barriers can hinder bioenergy development. Some of these include:

- **Compatibility of biofuel with existing fossil-based systems:** Biofuel may not be compatible with existing technology or infrastructure. For example, blending limits may reduce the potential for liquid biofuels when car engines are not equipped to operate on 100% ethanol or biodiesel. Coal power plants can usually co-fire up to 5% wood pellets before major investment is required (Ashizawa *et al.*, 2022). With more coal-like black pellets, up to 15% co-firing may be achieved (Proctor, 2021), but major modifications are required to move to higher shares of biomass firing in coal plants, as with the DRAX plants in the United Kingdom (Drax, 2018).

Similar concerns apply to steel plants using biochar or natural gas-based systems that cannot be operated on syngas made from solid biomass. Finally, aviation fuel is subject to the strictest quality controls that SAF may not yet meet.

- **Compatibility between different feedstocks:** Although, in theory, biomass can be described in terms of its energy content, producing bioenergy with different feedstock types poses challenges. A facility that can use one or two types of feedstocks may not be suitable for many other feedstock types or will require re-tooling to do so. This lack of feedstock flexibility reduces resilience and challenges operators trying to control the quality of the final product. Solid supply chains must be in place to support a larger industrial plant and different feedstock types need to be taken to different processing plants, depending on their specifications and quality.

- **Infrastructure:** The lack of good road networks and transport infrastructure can make bioenergy project development more (Oo, 2012; World Bank, 2022). In addition, rural areas may not be electrified. The lack of infrastructure, such as waste management and water provision, may make industrial development more difficult and less likely. Infrastructure is also required to take products to market. Landlocked countries will find it more difficult or expensive to export bioenergy products and even those that have deep seaports may need to invest in new loading, storage and unloading infrastructure to handle bioenergy products, such as pellets.

- **Human capacity:** A lack of technical professionals to carry out the construction and operation of a bioenergy plant is a constraint impeding the adoption of bioenergy production (Oo, 2012; World Bank, 2022). Industrial operations only function well when they have access to qualified and trained personnel. Certain bioenergy technologies (*e.g.* gas-to-liquids or biogas-to-biomethane plants) are complex and demand essential technical skills, a high level of training and experience of their operation (see also Section 5.3, Recommendation 3, with respect to "Adequate Technologies"). Where few qualified personnel can be sourced, bioenergy development is less likely to occur.

- **Technology development:** Although the potential for bioenergy is high, some applications, such as second-generation biofuels, are still at the pre-commercial stage (ETIP Bioenergy, 2020; IEA, 2017; World Bank, 2022). Their costs are high, technology risk continues to apply or the technologies may not be flexible in terms of feedstock. The technology may even not be able to use some types of agricultural residues. For example, pyrolysis oil for refineries may be better made from wood than from agricultural biomass with high levels of chlorine, sulphur and ash, and high ash levels can also preclude agricultural biomass use in power generation equipment. Biofuels generally have high oxygen content and need upgrading to become refinery feedstock or a drop-in fuel. This introduces more technical complexities and increases costs and carbon intensity.

- **Technology adoption:** Some technologies, such as pyrolysis or gasification, may need to be adapted, cannot operate with high-ash fuels or may experience rapid degradation with high-chlorine fuels due to corrosion. High-temperature corrosion of boiler tubes is a well-known problem with straw combustion. Moisture can also lead to serious problems with storing and using biomass, such as the development of fungi or mould, which can create serious health hazards for those handling the biomass. Stored biomass attracts rodents or other pests. In addition, animal farming value chains have been through epidemics that have heightened biosecurity measures and limit the possibility of transporting and storing biomass. New technologies take time to become mainstream. At the beginning, it is necessary to gain familiarity through pilot and demonstration projects, often only possible with some government support. These then serve as showcases that can be replicated throughout the country. A lack of such demonstrations or an accumulation of projects that fail because of inadequate planning, technological problems or bad management may hinder the development of the bioenergy sector (Peters, 2023).

- **Harvesting approaches:** There is also a lack of knowledge and protocols to ensure residue removals can be undertaken sustainably (see executive summary). Farmers may be reluctant to sell residue that was previously left in the field if they are worried that this may impact yields and soil quality.

## 3.4 Legal and regulatory issues

Bioenergy development can be difficult or hindered both due to existing regulations and to the lack of them. Some examples to illustrate this conundrum are:

- **Hygiene laws and practices:** Wherever there are obligations to burn field residues – for example for disease prevention – that residue becomes unavailable for bioenergy processes, even when the process would effectively address the concerns around pathogens. Concerns around diseases related to field crops and residues may also limit or prohibit any trans-border or even interregional transport of agricultural biomass residues (IRENA, 2022a).

- **Waste management regulations:** There is a clear difference between waste, which usually means specific regulations must be followed, and residues, which are usually a by-product. Whenever regulatory definitions designate agricultural or processing residues as waste, strict limitations on transport may come into action that can increase the cost of taking the material to the processor (Eriksen *et al.*, 2017)

- **Lack of environmental regulation or enforcement:** The lack of regulations limiting the discharge of nutrient-rich effluents or dumping waste, or the lack of enforcement (Dislich *et al.*, 2017) removes the incentive to use these residue streams for bioenergy. Whenever an effluent producer is prohibited from discharging an effluent or is charged high fees to do so, this creates markets for alternative disposal, such as bioenergy production. Likewise, lack of enforcement of rules against deforestation reduces opportunities for alternative fuels (Yeboah, 2017)

- **Lack of bioenergy regulations:** It is difficult to develop and raise financing for a bioenergy project without the backing of an appropriate legal or regulatory framework. This includes renewable fuel mandates, low-carbon fuel standards, feed-in regulations and related rules that create a market. Without such regulations, bioenergy may not be able to compete with cheaper fossil fuels or may not have access to markets (Scarlat *et al.*, 2010). In Colombia, inadequate design of auctions for renewable electricity, where bioenergy producers are not remunerated for the social benefits and grid stability they offer, has been a major issue.

- **Sustainability certification:** International certification schemes are key to developing a stable business case for bioenergy development. They require chain-of-custody tracking to certify the sustainability of bioenergy products for export or even for local use at industrial facilities. This adds another layer of administrative burden on bioenergy producers and can lead to the product being disqualified if even a small percentage of the feedstock cannot be properly traced (Wunderlich, 2019). ISO Standard 13065 on Sustainability Criteria for Bioenergy (ISO, 2015) may help streamline the criteria used, which can then be integrated into supply chain management approaches.

## 3.5 Political and institutional barriers

Political barriers are mainly related to project development. These barriers can often be traced back to a lack of political will. Government red tape is often cited as a hindrance to economic development. Governments need to create regulatory frameworks to guide industrial development, ensuring environmental protection and respect for social and economic concerns. Yet, overly lengthy or complex administrative processes involving multiple agencies or government departments can lead to frustration and, eventually, stifled industrial development. Examples of this include:

- **Import barriers:** Onerous procedures and tariffs to import equipment to build and install bioenergy facilities can make development more difficult and more costly (ALER, 2018).

- **Cross-ministerial responsibilities:** Project developers may have to deal with several ministries at once – such as agriculture, energy and others – to obtain permits and authorisations This adds complexity, costs and delays to project development (IEA, 2021).

## 3.6 Information and public awareness-related barriers

In addition, cultural issues may discourage bioenergy adoption. These barriers are often the hardest to overcome. As a minimum, project developers and policy makers need to be aware of these barriers to consider them in their approaches. Some barriers identified in the context of this work include:

- **Lack of awareness:** Important stakeholders may not be aware of existing government programmes to support bioenergy projects or may not be able to access them due to a lack of capacity.

- **Food versus fuel dilemma:** Use of edible food crops for biofuels raises concerns over impacts on food security, even if degraded food is used as a feedstock (Oo, 2012). This can extend to residues not currently used as food but with proven food potential elsewhere.

- **Cultural preferences, such as charcoal for cooking:** Both in Africa and Southeast Asia, a cultural preference for using firewood and charcoal exists and has led to deforestation. Bioenergy approaches may be better oriented towards replacing firewood and charcoal currently made from wood, rather than trying to change the practice of cooking with charcoal to cooking with other fuels.

- **Lack of entrepreneurship:** Either due to a prevalent mindset or to a low degree of education, few members of a society may come forward to propose, and then develop, bioenergy projects (Souza *et al.*, 2015). Creating support structures, such as training courses and local bureaus to assist with new projects (*e.g.* the ECOWAS entrepreneur support facility (IRENA, 2015)), may help identify and equip potential project developers.

- **Lack of awareness of residue value:** Farmers may not be aware of the value that lies in the residues they produce or may have other misconceptions that keep them from looking for alternative uses (Oo, 2012; Shahzad *et al.*, 2023)

- **Failure to separate organic waste:** Very often, plastics and other waste is discarded together with organic waste collected from residences, at food markets and even at food processors (Bong *et al.*, 2017). This requires pre-sorting of incoming material at digesters or may preclude the use of that material for biogas production. Changing these habits and creating a culture of waste separation at the source has proven difficult in many contexts so far and requires a broad and continued education effort in addition to functioning financial incentives or deterrents.

- **Trust in established supply chains:** Customers, markets and investors tend to trust established energy sources, supply chains and markets. Drop-in fuels, such as ethanol, are less risky than biofuels that need technology change. An example is ammonia as a fuel. A ship converted to ammonia-fuelled engines cannot run on established fuels and will need to source ammonia from new supply chains. New developments, such as advanced bioenergy, may need to be demonstrated via successful projects and supported through government programmes before being accepted by stakeholders (IEA Bioenergy, 2017).

**Key takeaways:**

1. Bioenergy faces barriers that other renewable energy forms do not.
2. Common issues are:
   - Supply chain-related barriers: Feedstock quality, quantity and availability.
   - Economic barriers: Cost and competitiveness of biofuels.
   - Technical and infrastructure: Technology readiness.
   - Legal and regulatory barriers.
   - Political and institutional hurdles.
   - Information and public awareness: Cultural preferences and perception of biomass.
3. These barriers require a comprehensive approach to foster bioenergy development that includes overarching ministry responsibilities and addresses the entire bioenergy supply chain, from feedstock to markets.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# 4 BEST PRACTICES IN BIOENERGY POLICY MAKING

This chapter describes the regulatory and socioeconomic framework needed to develop the bioenergy sector in a jurisdiction and identifies best practices in policy making from different parts of the world. A wide variety of practices, tools and mechanisms enable the development of a bioenergy sector. Some practises overlap in how they address the barriers identified in the previous chapter. Due to the overlap, the categories in this chapter do not fully coincide with those of Chapter 3. A synopsis of enablers at the end of this chapter regroups measures according to the aforementioned barriers. The feedstocks and challenges for biogas production are different from field residue and are therefore discussed in a separate section below.

## 4.1 Supply chain development

Supply logistics typically account for around 40% of the delivered cost of biomass (Souza *et al.*, 2015). Optimising the supply chain can have significant impacts on bioenergy production costs. The agricultural biomass supply chain needs to address several issues, including:

- Maximising recovered amounts.
- The choice between manual and mechanised harvesting.
- The choice and availability of harvesting and baling equipment for different crop residues.
- Adapting collection to scale and cultivated surface.
- Seasonality and related storage needs (open versus covered).
- Prevention of diseases, mould and rodent infestations within the storage concept.
- Minimising storage and transport losses (baled or piled versus wrapped storage).
- Weather impacts on harvesting, including quality and moisture control.
- Weather impacts on transport, including flooding and rural road conditions.
- Sustainability issues to maintain soil carbon levels and protect against erosion (partial residue harvesting versus use of compost and/or biochar, crop rotation and choice of cover crops).
- Preventing contamination with soil and foreign plant material.
- Optimising transport routes and schedules.
- Co-ordination between field crop and residue harvesting and management (timing, single or multi-pass harvesting).
- Integration with crop rotations, cover crops and application of compost.
- Additional manpower needs for residue recovery and transport.

The many considerations involved in supply chain optimisation indicate that there is no one solution that applies to all regions, and supply chains need to be optimised for each crop residue. Some residues may require original research and testing as they may not be currently used as bioenergy feedstock. General best practices will optimise agricultural biomass recovery:

- **Baling** increases the bulk density of harvested biomass, makes handling and storage easier and reduces the risks of deterioration.

- **Transport** should take place with the largest vehicle possible. Small vehicles, such as converted motorbikes, can only transport small amounts of biomass but require the same amount of manpower as a truck. Whenever the road quality permits, large vehicles should be used to bring biomass from the field to the factory. Low biomass density and more frequent trips increase the carbon footprint of the biomass, reducing the value of the biofuel produced. Smaller vehicles and tractors may be used for local transport to take biomass residues to a pickup point accessible to larger vehicles.

- **Third-party harvesting or storage** may offer advantages, compared with farmers acquiring their own equipment where harvesting occurs infrequently. A contractor may be able to maximise the use of the harvesting or storage equipment (*e.g.* silos), thus lowering average costs. An alternative is farming co-operatives that may acquire and lease equipment to their members or use the same equipment for different crops or to collect from many fields with staggered seeding and harvesting periods.

- The use of **in-field storage**, using a two-pass harvesting system and leaving biomass in the field until it is harvested, has been identified as the cheapest storage option. This is, however, only possible with some types of residues and may not be suitable for all climates. It can lead to higher biomass losses or mould problems.

- **In-field drying** can improve the value of the residues by naturally reducing its moisture content. This usually requires a two-pass harvesting system where the residues are left in the field for days or weeks after the cash crop has been harvested. The practice does, however, presume infrequent rainfall to allow for the moisture to be reduced over time.

- **Densification** beyond baling and any preprocessing steps (washing, drying, milling, chemical pretreatment) are best accomplished at the bioenergy facility as they can be done more efficiently and with cleaner energy sources. Chipping and densification in the field usually requires diesel-operated equipment, which again increases costs and the carbon intensity of the biofuels produced.

- **Enhanced densification** is indicated for large transport distances, usually above 200 km. This refers to pelletisation or pyrolysis to increase the bulk and energy densities of the feedstock. Although pelletisation is usually restricted to overseas transport of biomass for co-firing in coal power plants, pyrolysis could also be used regionally wherever the pyrolysis oil can be used in refineries or by other users. This reasoning also suggests locating bioenergy processing facilities close to where the feedstock is collected, thus minimising the transport distances for low-density feedstock while shipping high-density bioenergy products over longer distances to the users.

- A **quality grading system** allows farmers to identify residues suitable as feed, as bioenergy, for ploughing under as a soil improver or to be eliminated by burning.

- Developing **harvesting protocols** can assure the sustainability of residue removals and preserve soil carbon and mineral levels, also accounting for the use of compost or biochar, where applicable. Several modelling approaches exist to manage sustainable residue removal levels at the landscape level.

- Use of **scheduling and logistics software** allows for crop optimisation and the identification of loading points. An app-based information system that leads drivers to Global Positioning System (GPS)-based loading points and advises residue producers that a pickup is imminent can increase flexibility and reduce overall transport costs.

- **Feedstock mixing** at the bioenergy facility can help reduce feedstock supply risk and reduce the need for seasonal storage of biomass. Switching from one type of residue to another over the course of the year may enable the immediate use of delivered quantities, thus avoiding or reducing the need for in-field storage.

- **Smaller bioenergy production facilities** lead to lower feedstock costs. If processing (capital and operating) costs are similar, the reduction of the radius necessary to collect sufficient feedstock will have a positive impact on bioenergy pricing as the delivered feedstock cost is smaller than for large, centralised plants (León-Olivares *et al.*, 2020). A decentralised option is creating several small preprocessing plants throughout the region that subsequently feed a larger processing facility. These preprocessing plants may also be mobile plants.

- **Achieving consistent feedstock quality** may call for the pre-sorting of residues. The Idaho National Laboratory in the United States conducts research into feedstock quality at its Biomass Feedstock National User Facility (BFNUF). For corn stover, they found that only 30% of the material corresponds to the physicochemical specifications of a biorefinery user. To achieve more consistent quality, the laboratory recommends a mechanical deconstruction approach that separates incoming feedstock into different groups with different properties, which can then be recombined as different feedstock types to achieve the desired specifications (INL, 2021).

Bioenergy producers need to implement quality control for any incoming biomass to facilitate processing and guarantee a uniform product quality. This means quality controls at the plant gate, as well as separate storage areas for different types of feedstock. At the plant, feedstock needs to be compartmentalised for mixing different feedstock types in a consistent manner that is suitable for the process at hand.

Governments and industry need to prioritise research on optimising supply chains as the bioenergy industry is built. Knowledge sharing between industries and at the international level will be important to arrive at the best concepts suited to each crop residue and each region. Educational efforts starting in schools can help raise awareness about the circular economy and are needed to motivate the population to separate different types of waste at source. This, in turn, facilitates their use for bioenergy production and recycling.


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## 4.2 Enablers

### Bioenergy-related policies

Policies and related regulations are critical tools for creating a bioenergy industry (IRENA, 2022a). According to a report by the International Energy Agency's Bioenergy Task Groups (IEA Bioenergy, 2017).

> ***[...] all globally significant bioenergy development has been underpinned by political backing, which is necessary for passing legislation in the form of mandates, renewable energy portfolios, carbon trading schemes and the like.***

Before developing supporting policies, a country typically produces a plan or at least a goal or target. This may be part of a wider renewable energy, carbon mitigation or energy security policy. Usually, a jurisdiction will start this process by assessing its bioenergy potential and then developing a national (or regional) bioenergy strategy. Once priorities are determined, regulations can be designed that help implement this strategy.

Bioenergy policies can be supply-side measures that increase biomass supply and demand-side instruments that create a market for bioenergy. Both are important. Table 4.1 provides an overview of the most common bioenergy policies worldwide. Several policies are also identified in an IRENA publication on bioenergy (IRENA, 2016a). According to the World Bank, by 2019, 99% of the world's countries had either established a comprehensive legal framework for renewable energy or had begun to do so.

**Table 4.1** Policies to foster bioenergy markets

| Policy | Description |
|---|---|
| **Government procurement of bioenergy** | Federal, provincial and municipal governments have vehicle fleets, buildings and other assets that can be operated with biofuels. Governments and their administration can serve as anchor clients that buy bioenergy at a premium to kick-start the industry. Government can also insert requirements into procurement rules that encourage contractors to use or install bioenergy for government-funded projects. |
| **Biofuel mandates and renewable portfolio standards** | To create a market for biofuels or renewable electricity, mandates can be used to oblige fuel retailers and electricity providers to source a defined percentage of their fuel from biobased sources. That percentage can be increased over time to allow for planning in line with industry growth. Separate percentages can also be defined for conventional versus lignocellulosic biofuels or for biobased electricity, including co-firing of biomass in coal power plants. In the United States, the biofuel mandate is combined with a certificate trading system where lignocellulosic fuels are given more value than first-generation or sugar-based biofuels. |
| **Low-carbon fuel standards** | Instead of fuel mandates, which are specific to the type of biofuel that is allowed to be used, low-carbon fuel standards are agnostic as to how the carbon intensity (emissions of fossil carbon dioxide per unit of fuel) is reduced. Biofuels then become one of several options for compliance, which reduces the level of certainty for investment. Yet, it also encourages the use of second-generation bioenergy products as these often have a very low carbon intensity and will therefore be worth more to distributors who need to reduce their average fuel carbon intensity. |

| | |
|---|---|
| **Production incentives** | On the supply side, governments can create an incentive scheme where producers are paid a subsidy for each unit of bioenergy produced (*e.g.* a litre of ethanol). This allows producers to sell their fuels at a lower cost. The amount of subsidy can be reduced over time as markets mature or as biofuels become less expensive to produce. The US Bioenergy Crop Assistance Program, although focused on purpose-growing energy crops, subsidises the cost of such biomass feedstock, including the development of related supply chains (FSA, 2023). India has created a programme to buy straw residues from farmers to be used in coal power plants, to reduce in-field burning (Reuters, 2017). |
| **Tax exemptions** | To reduce the price of biofuels, they can be exempted from excise or fuel taxes. This can make them cost-competitive with conventional fuels. |
| **Carbon taxes** | To support Paris climate goals, a carbon tax on fossil fuels can increase the cost competitiveness of biofuels, and tax revenue can be reinvested in new projects and related research. |
| **Subsidised pricing** | Gas grid operators can be obliged to purchase biomethane at higher prices than natural gas and the cost can then be charged to all ratepayers. For small percentages of biomethane fed into the grid, the extra charge per customer can then remain very small. The same principle is used with feed-in-tariffs, which set a price for renewable electricity made from biomass and other resources that reflects their typical production costs. |

**The example of Brazil:** Brazil is an international leader in the field of bioethanol production and use, being the world's second-largest producer of biofuels after the United States. Following the second major oil shock in 1979, a comprehensive programme was implemented, promoting the development of new plantations and a fleet of purely ethanol-fuelled vehicles. A series of tax and financial incentives was introduced. This resulted in ethanol production rising rapidly along with the number of vehicles running exclusively on ethanol. The government discontinued its support for hydrated ethanol around the end of the last century, leaving production, distribution and sales to the private sector. This led the transition from hydrous to anhydrous ethanol. Starting in 2005, Brazil enacted similar policies for biodiesel. After the Paris Accord in 2015, Brazil introduced the RenovaBIO Programme at the end of 2016. It is a policy shift from fuel mandates to a carbon intensity-based policy that financially rewards fuels with low carbon intensity over other fuels. It also expands the country's biofuel policies into gas markets, encouraging the injection of biomethane in the gas pipeline system.

Jurisdictions around the world have enacted legislation for renewable energy to diversify their energy resources, promote local energy production and encourage economic development. Three approaches to promoting renewable energy have evolved over recent decades:

- Renewable portfolio standards (RPS) or clean energy standards (CES) are quantity-based schemes in which the regulator requires a specific amount or proportion of gas to come from renewable or "clean" low-carbon sources. A carbon intensity standard is a variation of this approach.

- Feed-in tariffs (FITs) guarantee all eligible producers a fixed price per gigajoule of gas fed into the grid. The tariffs are part of standardised and simplified grid interconnection rules.

- Public tenders: A certain amount (GJ/yr) of renewable or low-carbon gas, or certain value (of investment) in renewable or low-carbon gas, is publicly tendered and sold to the lowest bidder or bidders with the highest volume.

Table 4.2 outlines the key features of each instrument. All of them have been tried and tested in the electricity sector over recent decades. Each has variations to accommodate different types of energy products or to apply similar concepts to sectors other than electricity, such as transport fuels.

**Table 4.2** Policy instruments for promoting renewable energy production

| | Renewable portfolio standard, clean energy standard or low-carbon fuel standard | Feed-in tariff or premium system | Public tenders or auctions |
|---|---|---|---|
| **Approach** | Quota for renewable or low-carbon gas or quota for maximum GHG intensity. | Set price for renewable or low-carbon gas fed into the grid or premium/bonus paid | Individual tenders for a certain type of renewable biomass energy. Reverse auction mechanism. |
| **Mechanism** | Volume-based. | Incentive-based, can be restricted by total target volume. | Either volume- or price-based. |
| **Technology** | Technology-neutral.<br>Only eligible technologies. | Technology-specific.<br>Carve-outs for specific technologies. | Technology-specific. |
| **Control of portfolio** | Investors and producers decide which pathway/ technology is used. | Government controls tariff for each pathway/ technology. | Tender specifies type and volume of energy, typically large projects only. |
| **Target control** | Penalty for not reaching target(s). | Markets and tariff decide uptake. Cap and floor for premiums. | Penalty for winning and then not implementing capacity. |
| **Certificate trading** | Possible. | Not possible. | Not possible. |
| **Investment security** | No investment security. | Stable cash flow insulates investors from revenue risks. | Binding investment limit. High risk for investors. |
| **Administrative effort** | Low | Medium | High |
| **Build-out / installed capacity** | Build-out rate dependent on target. | Robust short-term growth and high buildout if incentives adequate. | Many bids end up being too low and projects fail. |
| **Local development** | Certificate trading may not encourage local development. | Incentives for selective technologies can promote local and specific local development. | Frequently larger bidders from out of country. |
| **Research and development (R&D** | Lowest price technologies succeed. Little R&D. | Stimulates R&D input to reduce costs. | Lowest-price technologies succeed. Little R&D. |
| **Cost-effectiveness** | Least-cost instrument.<br>Competition between technologies.<br>Self-corrects.<br>More efficient at reducing GHG emissions and cost to ratepayers. | Lack of competition leads to higher costs than RPS.<br>Requires continual adjustment by government/ utility board.<br>Low transaction costs and low risk leads to low financing costs. | Strong push for low costs but some projects then fail due to often higher than expected costs.<br>High transaction costs. |

| | | | |
|---|---|---|---|
| **Impact on ratepayers** | Lower social risk than FIT. | Cost to ratepayer may be volatile. | Typically, lower than FIT. |
| **Key challenges** | Low buildout pace. | Social acceptance might decline with increased costs to ratepayer. | Top-down approach often does not meet with reality on the ground.<br>Monopolises production.<br>Political insecurity. |

**Source:** (Suchy *et al.*, 2022).

## Project support

To assist in the development of the bioenergy industry, governments can adopt market-based policies and also implement project-based support. This includes co-funding research, and pilot and demonstration projects through grants or low-interest loans. Loan guarantees to reduce the risk to private investors are also used. Table 4.3 lists several common measures to foster bioenergy industry development.

**Table 4.3** Project-based government support measures

| Policy | Description |
|---|---|
| **Grants** | Grants are often used for qualifying projects that align with government priorities. Between 25% and 75% of the capital cost of a project may typically be covered through a bioenergy funding programme. Earlier-stage projects carry more technological risks and therefore often need a higher percentage of government support to succeed. Grants may apply to all stages of technology development, including commercial deployment, but they are usually reduced in percentage as the technology matures. |
| **Loans** | Instead of grants, governments may opt to provide low-interest loans. These will usually be unsecured debt, leaving the lower-risk financing to the private sector. Loans are not effective for pilot and demonstration projects since the project needs to create a long-term revenue stream to then pay back the loan. |
| **Loan guarantees** | A government loan guarantee lowers the risk for private investors since they are reimbursed by government if the project fails. In many cases, the loan guarantee may not be called upon, meaning that only a percentage of the total amount covered by guarantees needs to be paid out to investors. |
| **Carbon credits** | Carbon credits or certificates are used in several climate change mitigation instruments, such as the Clean Development Mechanism. Sometimes a carbon credit system is also part of low-carbon fuel standards. Credits can also be sold on the private (voluntary) markets. Although their value is discounted when determining the bankability of a project, they can help finance a project and will shorten the payback period of projects. |
| **Flow-through tax credits** | Governments can allow for a given amount of tax-free investment to be directed towards priority industries. Private investors, including large companies and investment funds, may reduce their tax burden by investing in clean energy projects, including bioenergy. The ability to write off such investments will leverage additional capital for new projects. |
| **Green bonds** | Municipalities or provincial governments can issue green bonds to finance bioenergy projects. They will borrow from the market at preferred rates and can then invest that money into green infrastructure, including bioenergy production. Green bonds typically have low interest rates as the bond is secured by the government. |

| | |
|---|---|
| **Inter-connection rules** | Governments or utility boards can direct grid operators and utility companies to create fair grid access rules for third-party bioenergy producers. Complex, expensive and lengthy interconnection processes can seriously hamper bioenergy development. Streamlining this process by creating equitable rules for siting and connecting new projects can facilitate project development. |
| **Permitting** | Permitting can be cumbersome in terms of cost and time. Forward-looking governments prepare their own staff to permit projects using new technologies. Creating a one-window process where a single ministry is responsible for issuing operating permits and co-operates with other ministries internally to cover other aspects of permitting (environmental, social and administrative) can accelerate and facilitate project development. |
| **Feedstock subsidies** | Governments can subsidise certain feedstock types. Paying farmers for collecting, storing and delivering agricultural feedstock to nearby bioenergy facilities reduces the delivered cost for the facility and the resulting bioenergy costs. Such subsidies may be warranted at the beginning of industrial development, to develop supply chains or to recognise the benefits of using such feedstock, *e.g.* to prevent field burning. An example is the US Biomass Crop Assistance Program (BCAP). |

The creation of **bioenergy clusters** based on prior analysis of infrastructure and resource locations can kick-start bioenergy development in strategic locations, from which the industry can expand to other areas. Such an approach allows the required economies of scale to be reached more quickly, developing supply chains and establishing practices that can then be transferred to other regions. Such clusters can be located near resources and where infrastructure, including grain processors and loading stations, residue-producing industries and research organisations exist, to build on existing infrastructure and expertise. Government support could initially focus on these clusters, which may in turn facilitate permitting, encourage collaboration, enhance competition and foster R&D.

## 4.3 Legal and regulatory enablers

Environmental regulations can both limit and enhance the development of a bioenergy industry. For example, Côte d'Ivoire does not allow biodiesel to be produced from food crop oils, such as oil palm. This directs biodiesel production either to oils from unused residues or those using a gasification/pyrolysis pathway. Conversely, the country has no environmental regulations to compel livestock farmers or palm oil producers to treat their effluents. Much of their organic residue that could be used for bioenergy production is either released into the environment or landfilled. This suggests at least the following best practices:

- Regulate livestock and agro-industrial effluent to limit the allowable biological oxygen demand. This will force producers of effluent to take measures to pretreat it, usually with bioenergy systems. Regulations must be accompanied by inspections and enforcement to maximise the benefit of this policy.

- Limit the types of organics that may be landfilled. Excluding compostable and digestible organics from landfilling creates an incentive to use them as digester feedstock. It also means digester operators can charge a tipping fee to accept the material. Tipping fees are often an important element of the economics of anaerobic digesters and may allow the operation to pay for additional feedstock from field residues.

- Recognise the benefits of controlled combustion. Avoiding field burning by collecting residues for their use in bioenergy facilities with flue gas cleaning systems has air quality and health benefits. Governments can encourage such projects with grants and by making field burning illegal where suitable facilities exist that can use the residues.

**Monitoring sustainability**

Governments that wish to promote the bioenergy industry will want to ensure that the industry is growing while having a positive impact on the country's agricultural sector. To help with this, the Global Bioenergy Partnership (GBEP) has produced a set of 24 indicators for the assessment and monitoring of bioenergy sustainability at the national level. The GBEP indicators are intended to inform policy makers about the environmental, social and economic sustainability aspects of the bioenergy sector in their country and guide them towards policies that foster sustainable development. Indicators cover issues such as life cycle analysis, soil carbon levels, land-use changes and food pricing productivity to monitor the long-term effects of the bioenergy sector. The indicators have been tested in Colombia, Indonesia and other countries (FAO, 2014).

- Another possibility is imposing penalties for unused residues. Farmers or processors may be obliged to prove that their organic residues have been used by a bioenergy or composting facility or face financial penalties for unused amounts. This policy creates an incentive to provide the residues to users, but must be designed so as to not to have negative impacts on smallholder farmers. A recent example is the proposal by the Sabah state government, Malaysia, in its Sabah Energy Roadmap and Master Plan 2040, which aims to mandate a minimum requirement for making empty fruit bunches available for biomass power generation.

## 4.4 Political enablers and co-operation

### Private initiatives and public-private partnerships

The private sector can imitate policies that governments adopt. This includes setting internal targets for bioenergy use, moving vehicle fleets to biofuels or prioritising investment in the bioenergy industry. Banks can create their own programmes to finance bioenergy projects in line with government initiatives. For example, Banco do Brazil's Agro Energy Programme was created specifically to finance agricultural bioenergy projects, including biogas. It offers a lower interest rate of 2.5% for up to USD 50 000 (Pasqual *et al.*, 2017).

**Social benefit corporations** (see box) are for-profit corporations whose legally defined goals stipulate that they will have a positive impact on society, workers, the community and the environment in addition to making a profit. A benefit corporation's directors and officers operate the business with the same authority as in a traditional corporation, but they are required to consider the impact of their decisions not only on shareholders but also on society and the environment. Some biofuel projects in Africa and elsewhere have chosen this business model.

### Social benefit corporations

The Rwandan social benefit company *Inyenyeri* is a small, local pellet mill. It uses woody and agricultural feedstock brought by rural customers and gives them pellets in return, on a 1:4 weight basis. The pellets can be used in a special cookstove, which is leased to customers by the company at a nominal fee and financed by surplus pellet sales to urban customers.

Only small-diameter wood is accepted, to prevent deforestation. The pellets replace firewood and charcoal. For the company's urban customers, the cost of cooking with pellets is about 25% less than that of cooking with charcoal (www.inyenyeri.org).

The **bioenergy industry** itself also needs to adopt best practices to grow sustainably. Such practices include:

- Early engagement and collaboration with stakeholders, including smallholder farmers, feedstock producers, local government and other decision makers.
- Collaboration with farmers' co-operatives, universities and research organisations to assess bioenergy opportunities, quantify residue availability and optimise processes and supply chains.
- Clearly communicate industry needs, such as fair access to infrastructure and markets and the removal of fiscal and administrative barriers. At the same time, the benefits of developing the industry need to be conveyed, including job creation, environmental benefits and GHG reduction potential.

### An African bioenergy public-private partnership

Ethiopia's first commercial-scale biodiesel refinery, situated in Adama, was enabled by a public-private partnership (PPP). The project aims to reforest more than one million hectares of land to provide renewable feedstock, with annual production of 73 million litres of biodiesel The project will generate close to USD 100 million annually in revenue, create 10 000 jobs, lower fossil fuel use and reduce GHG emissions. Long-term plans are to build a total of ten such plants in the region. The projects are to be developed by API Renewable Energy PLC, a public-private partnership formed in 2009 to develop sustainable energy production and economic growth (API, 2018).

**Farmers and feedstock providers** also need to adopt best practices. Building on the Bioenergy and Food Security (BEFS) Analytical Framework, the FAO's BEFSCI project has developed a set of criteria, indicators, good practices and policy options for sustainable bioenergy production that foster rural development and food security (Rossi, 2012).The document refers to crop rotations, water management, biodiversity and other topics.

**Public-private partnerships** (PPPs) can be used to finance larger projects or projects that would not move ahead relying solely on the private sector. For example, the African Development Bank's PPP Strategic Framework and Africa PPP Development Fund support the scale-up of transport and energy solutions, information technology and health care (AfDB, 2022). PPPs require private-sector investment and may include government equity investment, but are generally seen as an umbrella term for several types of government support. AfDB uses all of its tools, such as debt, equity, risk mitigation instruments and guarantees or credit enhancement instruments, to enable PPPs. All PPPs require the private partner to take on a significant part of project risk, usually related to project performance and operation.

The types of infrastructure built through PPPs can include large bioenergy projects, such as stand-alone power plants, but also conventional infrastructure projects, including roads and train lines, which may benefit several industries at once. Ethiopia has opted to create a special-purpose vehicle to roll out bioenergy PPP projects (see previous box). PPPs are an important part of the ASEAN Strategy on Sustainable Biomass Energy for Agriculture Communities and Rural Development (ASEAN, 2021). The Malaysian government subsidises interest rates for bioenergy projects and provides loan guarantees for up to 60% of the loan amount, but does not make equity investments. Banks issue green bonds to source the capital for such projects (MBIC, 2021). Many tools and resources are provided by the World Bank to assist governments and corporations in setting up bioenergy PPPs (World Bank, n.d.).

## Collaborative approaches

The development of a successful bioenergy industry requires collaboration between the main parties, that is farmers and their associations, the bioenergy industry, bioenergy users, government and academia.

Several measures that have been used to enhance industry development include:

- **Centres of excellence:** A centre of excellence can be a facility or organisation that provides leadership, research and innovation, support or training for a specific topic (Halliwell, 2013). This is achieved by institutional profiling and generating a group of researchers. Centres of excellence in bioenergy can be established nationally or as a collaborative approach between several governments with shared interests. They can operate as autonomous research centres or as networks and can be business-led or purely academic. As an illustration, the World Bank funded the African Centre of Excellence, CEA VALOPRO, in Côte d'Ivoire. The centre focuses on developing the bioeconomy and includes the production of bioenergy as part of its mission.

- **Bioindustry clusters:** Local or provincial governments may want to encourage the establishment of bioenergy clusters (see box for an example from Ontario, Canada, below). These are industry clusters that bring together several companies with similar goals in the same location. This can be achieved by reserving space or land or by developing promotional schemes to attract relevant industries and related R&D. These clusters could be built around a university or alongside existing bioenergy companies in the same city or country.

- **Training and capacity-building:** Government can work with other stakeholders, especially industry and academia, to create training, academic and technical programmes to train the workforce needed to build the bioenergy industry. This workforce includes engineers, agricultural and logistical experts, and technicians like millwrights and machine operators. Programmes could also be developed to assist with business development skills and access to financing for project developers.

- **Awareness raising:** Government and industrial associations can play a role in promoting the bioenergy industry, informing local stakeholders about the opportunities. and encouraging bioenergy development. This can be done by organising workshops and presentations, printing brochures, participating in local and regional events such as trade shows, and creating and maintaining websites. Governments can also provide leadership by developing bioenergy strategies and by assessing and quantifying feedstock availability.

- **Intragovernmental co-operation:** Whereas government agencies and ministries often work in a compartmentalised way, bioenergy is a cross-ministerial issue that requires collaboration between energy, agriculture, forestry, transport and other ministries. For example, the US Biomass Research & Development Board co-ordinated R&D activities relating to the bioenergy industry in the United States for two decades until 2020. It used quarterly meetings, assembling experts from the departments of energy, agriculture, transport, interior, defence and environmental protection to co-ordinate planning and policy at the federal level. Today, the Fuels for Future Advisory Board has assumed similar functions in the United States.

## International collaboration

The **IEA Bioenergy Technology Collaboration Programme**, initiated in 1978, has 23 contracting parties, including Brazil and South Africa. Its work focuses on the main R&D challenges associated with bioenergy and is organised under ten active "tasks". Several projects are organised to deal with cross-cutting issues or to respond to particular issues of interest to participant members. The programme produces a significant number of authoritative publications each year, as well as organising workshops and conferences (www.ieabioenergy.com/).

The **Biofuture Platform** is a 22-country effort to promote an advanced low-carbon bioeconomy that is sustainable, innovative and scalable. The platform is a government-led, multi-stakeholder initiative designed to promote international co-ordination on advanced low-carbon fuels and bioeconomy development. Members include Mozambique and Indonesia. It complements the work of existing international initiatives such as IEA Bioenergy and IRENA and to formulate ways to best address existing gaps (https://biofutureplatform.org/)

**The Global Bioenergy Partnership (GBEP)** was founded in 2006, with its secretariat currently housed at the FAO Headquarters in Rome. Over the past 15 years, the organisation has experienced substantial growth, with a membership that now exceeds 80 members and a broader range of initiatives taking place in various countries. GBEP serves as a platform that brings together stakeholders from the public, private and civil society sectors to advance bioenergy for the cause of sustainable development. The partnership concentrates its efforts on three key strategic domains: sustainable development, climate change, and food and energy security (www.fao.org/in-action/global-bioenergy-partnership/en).

## Bio-industry development in Ontario, Canada

Ontario's bio-industry cluster has already begun to provide opportunities to farmers through a Cellulosic Sugar Producers Co-operative, which was created through a partnership with Bioindustrial Innovation Canada and companies Comet Biorefining and BioAmber. This initiative was supported by the Ontario Ministry of Agriculture as an Agri-Science Cluster Project.

The co-operative looks to collect over 50 000 t of corn stover biomass annually from approximately 280 000 ha, yielding over 10 t/ha in southwestern Ontario. Approximately 26 500 t of wheat straw will also be collected as feedstock for Comet Biorefining (OFA, 2023).

The Ontario Ministry of Agriculture also assists local companies to connect with international companies in the bioproducts field to form strategic alliances and maps bioindustry companies in the province (OMAFRA, 2022).

At the federal level, the Biomass Canada Research Cluster is a collaboration of several universities that aims to improve the bio-based economy by developing and using cutting-edge technologies and market opportunities for biomass, bioenergy and bioproducts, with a special focus on agricultural residues. It has funding for five years and will look at feedstock recovery, economics and knowledge transfer to the farming community (Smith, 2019).

## 4.5 Best practices for biogas

Different principles apply to biochemical bioenergy processes than for thermochemical conversion of biomass. Biogas uses liquid and wet or "green" biomass as a feedstock. Due to the high moisture content, its energy density is very low and does not permit transporting such feedstock over long distances. Usually, a radius of 25 km is the limit for identifying feedstock sources. Digesters can be sized small, sometimes to fit the output of a single farm or the largest farm in the area.[9] Best practices for biogas development include:

- Siting the biogas plant close to the user, *e.g.* a gas pipeline and industrial user or the electricity grid.
- Locating the plant next to an anchor feedstock provider, such as a large livestock facility or a palm oil producer.
- Regulations that allow for the construction of digesters in rural regions and close to livestock operations to facilitate digester construction, noting that this may require zoning changes.
- Regulators allowing the use of waste, *i.e.* organic material that has value as digester feedstock, without imposing onerous waste management practices that would make the transport and sale of such feedstock more difficult. For example, urban organic waste is a suitable feedstock for digesters situated outside urban regions.
- Regulations that discourage the landfilling of organic waste through prohibitions, incentives to source-separate organic waste or through increased landfilling costs can direct these waste streams to digester plants and allow processors to charge a tipping fee.
- Regulators proscribing the treatment of industrial wastewater, such as POME,[10] that is suitable for biogas production, in open ponds or its uncontrolled release, to encourage the use of digesters as an effluent treatment option. Palm oil buyers that insist on sustainable practices with respect to the treatment of POME will help realise this potential.
- Requiring effluent treatment as a condition of new operating permits for livestock farming, palm oil processing, etc., and imposing the same when existing operating permits come up for renewal.
- Regulators facilitating the connection of biogas plants to the gas grid or the electricity grid by requiring the grid operators to create fair and equitable access rules for new facilities. Policies like feed-in tariffs or renewable energy mandates will create the market to build this industry.

*[9] Small micro-digesters that produce gas for cooking are not the subject of this section but are covered later in this report.*

*[10] Palm oil milling effluent – a liquid rich in organic load that is a good digester feedstock.*

- Mixing different types of residues to increase both biogas production and the quality of the digestate and compost produced. Emphasis needs to be placed on reaching an optimum C-N ratio of between 1:20 and 1:30 in the feedstock. Using livestock manure alone does not result in good economics. In the planning stage, the project developer needs to make sure that both manure with a high nitrogen content and plant-based feedstock with a high carbon content are available.

- Noting that not all moist residues are suitable for digesters – for example, citrus waste is antiseptic and can reduce gas yields by inhibiting microbial activity. Prior testing is required to optimise gas production.

- Recognising that odour control is important whenever digesters are located close to inhabited areas. Compost piles or windrows need to be well aerated, *e.g.* by turning rows frequently to improve porosity and to redistribute cooler and hotter portions of the pile. Odour and moisture control may require digestate to be covered or stored and stabilised inside a building, at higher cost.

- Applying anaerobic digestion as a circular economy concept: solid digestate can be used on farmland to improve soil quality and liquid digestate serves as natural fertiliser. Ongoing quality control of the compost produced is a good practice that helps with the acceptance of this approach.

- Recognising that liquid digestate has a high nitrogen content and can be sold to farmers nearby. The practice of spreading liquid digestate is not yet common in many countries and requires prior study to determine appropriate timing and quantities for application, as well as the establishment or adaptation of existing nutrient management plans.

- Direct composting and, in the future, hydrothermal liquefaction (HTL) of moist agricultural residues as an alternative to anaerobic digestion, acknowledging that composting does not produce energy and HTL does not produce compost. To maximise energy production, suitable residues can be used in digesters (or for HTL). This requires a ranking of residues to allocate them to the best uses.

- Treating animal manure and other effluents, such as POME, to deliver significant GHG emission reductions – even net-negative carbon intensities – by avoiding their storage in open ponds with high methane emissions. This helps reach national GHG emission reduction goals and also increases the amount of carbon credits generated, as well as reducing negative impacts on groundwater and surface water.

- Government grants for farmers and other parties to install digesters as a tool to establish the biogas industry. Incentives should be combined with R&D programmes that facilitate the testing of feedstocks and the use of the digestate.

**Biogas development in Brazil**

Brazil's Low-Carbon Agriculture Plan provides technical assistance to promote the improvement of rural infrastructure. Credit is offered to biogas producers from several tax-financed funds. The GIZ Energy Programme (Programa Energia), implemented with the assistance of the German Federal Ministry of Economic Cooperation and Development, aims to increase the sustainable use of biogas in Brazil, the analysis of experience and know-how transfer between German and Brazilian partners.

Several institutions have been created to provide permanent support to biogas production in Brazil. These include the International Centre on Renewable Energy – Biogas (CIBiogás) and the Brazilian Association of Biogas and Biomethane. The latter intends to be an interface between civil society, the federal and state governments, municipalities and agencies responsible for planning Brazilian energy.

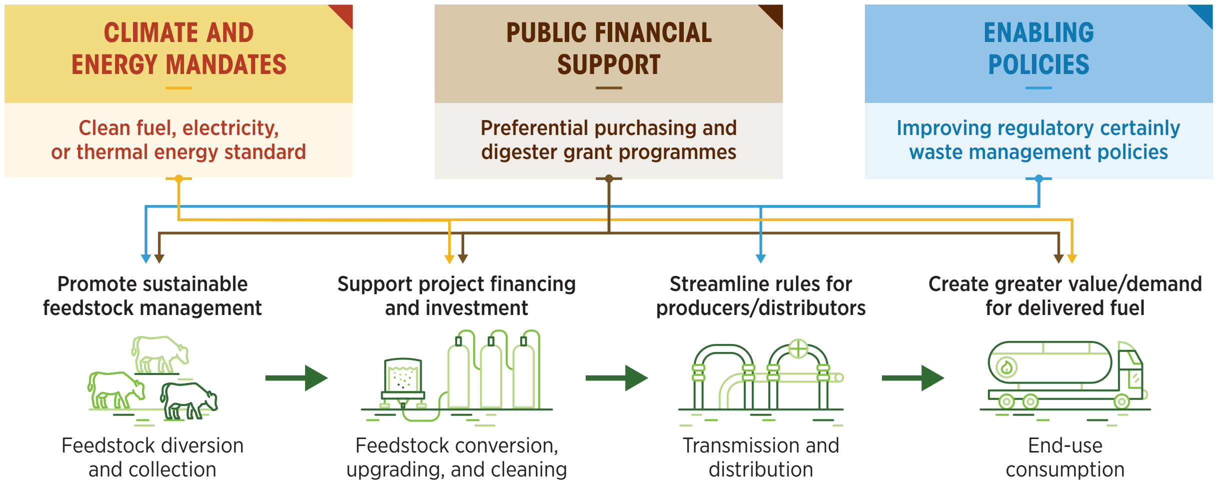
CIBiogás aims to be a reference point for the biogas industry. It aims to provide demonstration units, promote technology development and disseminate expertise in renewable energy. The National Programme on Biogas and Biomethane aims to support institutional development and use of biogas and biomethane and stimulate their application in the energy matrix (IEA Bioenergy, 2017)

Brazil's RenovaBio Programme puts the focus on biomethane production from biogas, setting a 5% target for biomethane in the country's natural gas supplies, supported by a carbon credit system. The *Federal Strategy of Incentive to the Sustainable Use of Biogas and Biomethane*, launched in March 2022, enhances this by creating methane emission reduction credits to support biogas production (Bezerra *et al.*, 2022).

Digesters can be used to achieve several public policy objectives, including circular economy goals, GHG emission reductions and reducing the pollution of waterways. The production of digestate helps reduce dependency on often imported artificial fertiliser and the energy produced can reduce fossil fuel imports. In addition, digesters can reduce poverty by providing new, stable income sources for farmers – both those who operate the digesters and those who sell feedstock to the operator. Small-scale (household-size) digesters can also help reduce deforestation as the biogas reduces demand for charcoal made from wood. Finally, digesters can help with rural electrification as they stabilise the local grid.

The promotion of biomethane and other renewable and low-carbon gases takes place across a broad spectrum of policy areas, ranging from agricultural/forestry, waste, energy and climate to environmental. As illustrated in Figure 4.1, the biomethane value chain can be affected and enhanced at several stages, including facilitating feedstock acquisition, creating a demand-pull using incentives or mandates and a regulatory environment that supports biomethane deployment.

**Figure 4.1** Policies promoting the development of biomethane




**Source:** (Cyrs *et al.*, 2020).

## 4.6 Summary of best practices

An overview of best practices is given in the matrix below (Table 4.4) for all types of agricultural biomass. These address the six main barriers identified in Chapter 3; several measures are not unique to any one barrier but may address several barriers, which leads to some repetition in this table.

**Table 4.4** Best practices for bioenergy deployment

| Technical and infrastructure | Legal and regulatory |
|---|---|
| • Ensure government support for pilot and demonstration projects<br>• Develop and test feedstock supply chains<br>• Create training courses through colleges and associations<br>• Consider public-private partnerships to create new infrastructure<br>• Create streamlined electrical grid interconnection rules | • Regulate organic effluents from livestock production and industry<br>• Allow co-processing of organic waste from farms and other sources<br>• Implement regulations to foster markets for bioenergy products<br>• Prohibit or restrict landfilling of organics<br>• Introduce one-window permitting process<br>• Allow rezoning for agricultural digesters |

| Financial and economic | Political and institutional |
|---|---|
| • Consider public-private partnerships<br>• Offer grants, low-interest loans and loan guarantees for bioenergy projects<br>• Introduce sales tax exemptions<br>• Use carbon taxes<br>• Consider flow-through shares<br>• Reduce or eliminate fossil fuel subsidies<br>• Introduce targeted financing programmes via banks | • Create research centres of excellence focused on bioenergy<br>• Enhance interministerial co-operation on bioenergy policies and programmes<br>• Create long-term, stable policies such as biofuel blending mandates<br>• Develop a bioenergy strategy with stakeholder co-operation<br>• Create mechanisms to reward GHG emission reductions from biogas and other bioenergy projects<br>• Embed bioenergy in a circular economy policy concept |
| **Information and public awareness** | **Supply chain** |
| • Provide education on organic waste separation.<br>• Promote bioenergy and residue collection among farmers, backed by research on nutrient balances and soil carbon stocks<br>• Offer training on project development and operation<br>• Use pilot projects and incentives to demonstrate alternative energy options, such as small-scale biogas or biochar use for cooking<br>• Educate about health and environmental risks related to unsustainable wood use | • Develop nutrient management plans and harvest protocols to account for compost use and residue removals<br>• Optimise transportation routes and schedules, including the use of specialist software and GPS locations<br>• Integrate field residue recovery with compost or other deliveries to close nutrient cycle<br>• Employ baling or densification technologies.<br>• Develop a feedstock grading system |

**Key takeaways:**

1. Bioenergy development must be underpinned by a comprehensive policy approach and requires a suitable regulatory framework.
2. Key aspects of a successful bioenergy strategy support the following areas:
   - fostering market development
   - providing project development support
   - removing legal and administrative barriers
   - fostering collaboration within government and between stakeholders
   - focusing on supply chain development, possibly starting with selected industry clusters, from which further development can expand
   - promoting the value and benefits of the bioenergy industry
   - developing the industry responsibly, securing stakeholder consent and based on sustainable practices.

# 5 CASE STUDIES: SUBREGIONAL CLUSTERS

This chapter further splits South America, Southeast Asia and sub-Saharan Africa into subregional clusters, *i.e.* smaller groups of countries with common characteristics, such as similar economic development, climatic conditions or cultivated crops, located within the same geographical area.

Each region consists of several clusters. The study selects one cluster in each region for a more detailed analysis, based on the criterion that the respective clusters have good bioenergy potential but have yet to develop their potential. These countries would benefit from applying best practices from countries in the region that have already created a bioenergy industry.

The three clusters selected for in-depth case studies are:

- Southeast Asia: Non-palm oil producing countries, *i.e.* Cambodia, Lao PDR, Myanmar, the Philippines and Viet Nam
- Sub-Saharan Africa: 14 selected countrie[11]s situated along the tropical west coast of Africa
- South America: Mid-developed Amazonian countries, *i.e.* Bolivia, Ecuador and Peru.

*[11] Benin, Cameroon, Congo, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Côte d'Ivoire, Liberia, Nigeria, Sierra Leone, Togo.*

Local experts contributed to this chapter via online workshops in early 2023. For each cluster, this chapter presents the following:

- **Overview of bioenergy potential**: This aims to provide a realistic view of the potential for bioenergy, looking at the top ten crops for these three clusters, quantifying the available amounts of post-harvest field residues, processing residues and livestock waste. The database determines the technical potential from the theoretical potential, taking recoverability and existing uses of residues into account. The study does not specify a residue's economic potential, which depends on local conditions and is beyond the scope of this report.

- **Enabling institutions, envisaged markets, gap analysis, and strategies to create momentum for bioenergy**: This covers the entire supply chain from feedstock to processing technologies and markets. These strategies have common elements, as some clusters have similar barriers and enablers. Table 5.1 Provides an overview of the proposed strategies.

**Table 5.1** Overview of supply-side, technology and demand-side measures to support bioenergy

| Supply-side measures<br>FEEDSTOCK | Technology measures<br>TECHNOLOGY | Demand-side measures<br>MARKETS |
|---|---|---|
| Policy and regulatory changes to facilitate agricultural residue recovery and use | Adapting technologies to local conditions | Market development measures, including a regulatory framework favouring renewables, incentives and market pull policies |
| Supply chain development and mapping | Capacity development | Carbon credit, renewable portfolio standards or fuel blending requirements |
| Infrastructure (transport) improvements | Dissemination of successful initiatives | Infrastructure (electrical grid, gas pipeline network, *etc.*) |


TOM...foto © Shutterstock.com

## 5.1 Southeast Asian cluster: Non-palm oil producing countries

### Introduction

The study selected **countries with small or no palm oil production,** *i.e.* Cambodia, Lao PDR, Myanmar, the Philippines and Viet Nam, for analysis and further elaboration. These countries are part of The Association of Southeast Asian Nations (ASEAN) and therefore part of the ASEAN Strategy on Sustainable Biomass Energy from Agriculture. While the countries have defined renewable energy targets in national energy strategies, specific and comprehensive national bioenergy strategies are still needed to translate these targets into concrete action, such as expanding the bioenergy sector and considering national priorities and locally available resources.

Notably, a particular environmental challenge in the region is open field burning, mainly of rice straw, maize stalks and field residues from sugar cane and pineapple plantations. Post-harvest field burning can lead to uncontrolled forest fires (NST, 2019). Rice straw can be ploughed in after harvest, but decomposes slowly, so many farmers burn the straw instead. This practice regularly causes severe air pollution in the region. Although open burning is illegal in most of Southeast Asia, governments rarely enforce the law. Farmers need to replant quickly, making residue management a challenge, especially if the monsoon season is longer than usual.

### Bioenergy potential

Southeast Asia has a range of field residues that are often burned and could be converted to bioenergy, reducing field burning and the associated air quality impacts. The cluster of non-palm oil producing countries has the following primary feedstocks:

- **Rice:** Southeast Asia accounts for 26% of global rice production (Yuan *et al.*, 2022). However, there is still no systematic use of the residues. Farmers often burn rice straw in the field, potentially creating serious air pollution problems. Some rice mills use their rice husks for heat and electricity production; others sell husks to local industries, such as cement factories.

- **Sugar cane:** Some Philippine power plants use bagasse to generate electricity. Some use molasses to produce biofuel, even though there are some competitive uses.

- **Natural rubber:** In the coming 10 to 20 years, many plantations will reach the end of their commercial life cycle. If replanting were to take place, the old trees may offer substantial amounts of woody biomass.

- **Coconuts:** Coconuts have a relatively high mass and energy density (21 megajoule/kilogram [MJ/kg]) compared to other types of agricultural residues. Currently, some coconut shells are used partially by the coconut processing industry as fuel in boilers. There are also competitive uses, such as activated charcoal for the pharmaceutical and cosmetic industries. There may still be untapped potential, such as conversion into charcoal briquettes, mainly limited by the technical difficulties of industrial upscaling.

- **Residues from coffee plantations and processing:** These are plentiful in Viet Nam, the second-largest global coffee producer after Brazil. Currently, coffee waste management systems in Viet Nam are still lacking. Studies show that untreated waste from the industry could threaten surface waters. Coffee waste, husks and especially pulps (the residue derived from wet processing) can be potentially used for biogas production (Thriveni *et al.*, 2017). Coffee husk pellet production is still at an early stage (Wood Pellet Mill, 2023)

- **Cassava:** In comes cases, cassava peels from starch production are used as feedstock for biogas or biofuels (Sivamani *et al.*, 2018).

- **Maize:** Maize cob burning is currently the main energy application. It is widely used in boilers in small, local industries and by small farmers to supplement fuelwood for cooking.

- **Livestock:** There is also great potential to use livestock waste as a resource. Diets in Southeast Asia are moving towards increased meat and dairy consumption, and Viet Nam is seeing an unprecedented boom in animal husbandry. Anaerobic digesters turning manure into electricity is a potential option to stabilise the grid or power local microgrids. Some countries have implemented national biogas programmes to promote small-scale biodigesters for smallholder farmers, and additional potential remains.

Table 5.2 provides a snapshot of the technical potential for bioenergy generation from various agricultural residues. Among the notable contributors are rice straw, with a substantial potential of 1 714 PJ/yr, followed by coconut tree trunks and leaves at 387 PJ/yr. Other significant sources include broiler litter (358 PJ/yr), coffee pruning and stump waste (281 PJ/yr), and non-dairy cattle manure (272 PJ/yr). These residues collectively represent a substantial bioenergy resource, totaling 3 821 PJ/yr, highlighting the significant potential for sustainable energy production in the agricultural sector.

**Table 5.2** Top ten residues in the non-oil palm producing subregional cluster and corresponding technical potential

| Type of residues | Technical potential (PJ/yr) |
|---|---|
| Rice straw | 1 714 |
| Coconut tree trunks and leaves | 387 |
| Broiler litter | 358 |
| Coffee pruning and stump waste | 281 |
| Non-dairy cattle manure | 272 |
| Buffalo manure | 248 |
| Market swine manure | 168 |
| Rice hull | 160 |
| Layer hen litter | 134 |
| Corn stover/stalk | 99 |
| **TOTAL** | **3 821** |

## Envisaged markets

The subregion under review is characterised by rapid and dynamic development, with a significant increase in electricity consumption. In particular, Viet Nam has ambitious plans to quadruple its power generation capacity from 0.5 gigawatts (GW) in 2020 to a remarkable 2 GW by 2030. In contrast, the overall infrastructure in Myanmar, Cambodia and Lao PDR lags behind, highlighting the need for significant development efforts.

To encourage sustainable energy practices, most governments have introduced supportive policies, including feed-in tariffs for electricity generated from renewable sources, including biomass. Both Viet Nam and the Philippines have set commendable targets for biomass energy, reflecting their commitment to harnessing this renewable resource. Progress has also been made in the private sector. For example, large international textile manufacturers have created a small voluntary market for renewable energy. These companies plan to replace fossil fuels with biomass, which could force smaller companies to follow suit.

Although developed economies are currently moving rapidly towards electrification of transport, this transition may take longer in the three regions studied, offering opportunities for liquid biofuels to contribute. Several countries in Southeast Asia have mandated a minimum percentage of biofuels, mainly ethanol and biodiesel, but these are not currently made from agricultural residues.

The most significant applications for bioenergy in the subregion are:

- Large-scale production of electricity from biomass in possible in response to rapidly growing power demand.
- Lignocellulosic feedstock may be potentially used for advanced biofuels and SAF.
- Combustion of agricultural residues can be used to produce heat and steam in various industries – garment, cement, rice mills, palm oil and sugar cane – to replace coal and wood sourced from overharvested forests.
- Electricity produced by gasifiers and biogas reactors is an opportunity for industry and rural microgrids.
- Charcoal produced from agricultural residues can replace charcoal made from wood.
- Export of agricultural pellets and charcoal can be attractive.

The case study on the use of coconut shells as a feedstock for charcoal production illustrates the opportunities and challenges of using agricultural feedstocks as a primary source. Charcoal from coconut residues is one of many opportunities in the region where bioenergy could simultaneously solve a residue management challenge, create new economic opportunities and reduce deforestation rates.

The subregion might consider the pathways identified in Table 5.3, which summarises the types of energy that prevalent agricultural residues might be converted to.

**Table 5.3** Feedstocks, technologies and markets for bioenergy in non-palm oil producing countries of Southeast Asia

| Feedstock | Technology | Market |
|---|---|---|
| • Coconut shell | • Pyrolysis | • Local cooking fuel<br>• Export to Europe or North America |
| • Coconut husk<br>• Plantation waste<br>• Rice straw<br>• Replanting of coconut and rubber trees<br>• Rice hulls<br>• Maize cobs | • Combustion | • Industrial boilers |
| • Wood residues | • Pelletisation | • Fuel for power plants (exports) |
| • Corn cobs<br>• Rice straw<br>• Sugarcane stalks<br>• Bagasse<br>• Coconut husk<br>• Rice hulls | • Combustion or small-scale gasification* | • Power generation |
| • Livestock waste<br>• Coffee pulp<br>• Cassava waste | Anaerobic treatment | • Biogas for power generation |

* Produces a char residue that can, in turn, can be used to produce cooking fuel.

Finally, there are export markets in the Asia Pacific region and beyond. South Korea and Japan have sourced solid fuels such as wood chips or pellets, palm kernel shells and biochar from the region. Globally, long-haul aviation is expected to continue to rely on liquid fuels, which can be produced from agricultural residues found in the selected countries (see box on page 74).

## Enabling institutions

Each cluster country has leading institutions that can contribute to bioenergy development – see Table 5.4. Co-operation between these institutions and between national governments, as well as North-South and South-South co-operation and information exchange, is necessary to advance the bioenergy industry.

### Producing SAF in Southeast Asia – An industry perspective

One opportunity for using agricultural residue is to address a difficult-to-decarbonise sector – aviation – by producing sustainable aviation fuel (SAF). Neste, a Finnish biofuels company with a strong presence in Southeast Asia, commented on several questions in this study's context. Neste only uses residue, so no palm or other plant oils, to make SAF.

Given that the current IATA (International Air Transport Association) target for SAF of 5% by 2030 is not binding, there is no prospect of a stable market that would lead to industry investment in second-generation biofuel production. France, Sweden and Norway have set national SAF mandates, but apart from that only some airports have taken measures, such as Heathrow offering to subsidise 50% of the cost of using SAF. Changi Airport in Singapore could help create a limited market, but ASEAN governments ultimately have the most control over large-scale demand for SAF.

Neste is currently looking at forest residue to produce lignocellulosic fuels for feedstock. They consider infrastructure, regulatory push and pull, and feedstock availability to be crucial in making investment decisions. The company has already assessed feedstock availability in Southeast Asia to gauge the potential for future projects.

Technology is seen as a barrier since most second-generation SAF production pathways remain precommercial. Yet, the company considers feedstock costs, resulting fuel costs and a lack of regulatory measures as more important barriers than technology. Such regulations should implement blending mandates and sustainability standards to enable supply chain development and production. Sustainability standards should use global benchmarks, such as ICAO CORSIA or the Renewable Energy Directive of the European Union.

**Table 5.4** Institutions relevant to developing a bioenergy strategy in Southeast Asia

| Institution | Comments |
|---|---|
| **ASEAN** | Co-operation between national governments and exchange of best regulatory practices. Implementation of the regional 2021 Strategy on Sustainable Biomass Energy from Agriculture. |
| **Asian Centre for Energy (ACE)** | ASEAN ACE is an intergovernmental organisation within the ASEAN structure representing the 10 ASEAN Member States' interests in the energy sector. The centre trains people, and provides annual reports and energy statistics for the region and strives to integrate energy policy. |
| **National ministries of energy** | Can lead with the application and adjustment of incentives, feed-in tariffs and other energy policies and regulations to support bioenergy development in priority areas. |
| **National ministries of agriculture** | Can help implement best management practices to optimise field residue collection and work with the academic sector to determine sustainable removal rates and implement a circular economy approach. |
| **National ministries of industry** | Can help create a vision for the bioenergy industry, work with related sectors to develop strategies, address barriers and support tax breaks and similar measures. |
| **Asian Development Bank** | The bank provides project (private) funding and loans to governments. Its knowledge and technical assistance programme supports the transition to a cleaner energy future through its "Energy Transition Mechanism". |

| | |
|---|---|
| **National and private banks** | Can create specific agricultural bioenergy programmes and familiarise themselves with the sector to better understand risks and opportunities. |
| **Private Financing Advisory Network** | A global network with regional hubs of climate and clean energy financing experts offers free business coaching and investment facilitation to entrepreneurs developing climate and clean energy projects in emerging markets. |
| **National bioenergy associations** | Industry associations, such as the Philippine Biofuels Association (PBA) and the Biomass Industry Network in the Philippines (BINP) |
| **Research institutes** | Agriculture or energy departments in national universities or specialised research institutes, whether national or international. |

## Gap analysis

During the online workshop held on 16 February 2023, the participating local experts identified the cost and competitiveness of bioenergy as the main barrier, followed by legal and regulatory barriers, and then technological readiness. Notably, no respondent identified administrative barriers as a barrier. In a follow-up survey after the workshop, respondents identified feedstock management and supply chains as the main problem. At the same time, they favoured the creation of government-mandated bioenergy markets as a means of facilitating the development of the bioenergy industry, followed by supply chain development. The lack of skilled labour is less of a barrier.

In general, the subregion is familiar with bioenergy, but its modern forms still need to be developed in the cluster countries. Governments and other stakeholders can address these barriers in a number of ways. In light of the above pathways and the workshop contributions, national governments and industry representatives may need to address the following gaps, some of which were identified by a renowned textile manufacturer during the consultation workshop in February 2023, in order to facilitate the development of the bioenergy industry:

- All cluster countries still need to develop a regulatory framework for bioenergy. Such a framework must address national energy priorities and create attractive markets that will provide long-term conditions enabling investment and offering business opportunities.

- The industry is hesitant to use bioenergy because it requires new investments in suitable boilers and more space for biomass storage. More incentives for such investment and developing agricultural residue supply chains must evolve. Sales co-operatives, combined with concepts around field storage, staggered harvesting and on-time deliveries of boiler fuel, may provide buyers with access to several biomass producers, guaranteeing a year-round biomass supply.

- A lack of certification and proof-of-origin documentation makes the industry hesitant to use biomass for their operations. If the public perceives any of the biomass sourced to be unsustainable or related to deforestation, this might damage the industry's reputation, which presents a risk.

- There needs to be more enforcement of environmental laws. Illegal logging and field burning compete with bioenergy opportunities, making industry development more difficult.

- Workshop participants also confirmed that access to financing is not readily available for bioenergy projects and that regulatory and legal barriers exist. National bioenergy strategies and related actions can be a first step to removing these barriers and developing the bioenergy industry.

## Recommendations

The cluster countries might consider implementing the following measures:

**Feed-in tariffs:** In Southeast Asia, Thailand, the Philippines, Indonesia and Viet Nam have feed-in tariffs that regulate payments to third-party renewable power producers feeding into the public grid. Although Thailand is not one of the selected countries in this cluster, its experience can be shared. The country offers different tariffs for biogas and non-biogas electricity generation. The tariffs encourage the collection of field residues that farmers would otherwise burn, which can now be sold as fuel for nearby power plants. The scheme allows existing bagasse-fired cogeneration plants to operate year-round by combining bagasse with other field residues (ViR, 2020). This strategy reduces air pollution because the controlled burning of biomass in power plants reduces air emissions compared to open burning. Other benefits include job creation, better electrification, hedging against rising electricity prices and potentially stabilising the power grid by generating electricity closer to users. Tariffs can be varied to cover different situations, *e.g.* a lower tariff for sugar cane or power generation industries that can co-incinerate agricultural residues compared to small gasifiers or new power generation projects based on agricultural residues.

Removal of crop residues may not be the best solution in all situations, and there are other options for dealing with crop residues. Farmers' associations, government guidelines or even vocational schools should advise farmers on residue management options. Academia and research institutions need to contribute to a sustainable approach to crop residue harvesting by advising on appropriate harvest levels and helping to implement best practices to maintain soil fertility.

An approach that takes account of farmers' circumstances and purchasing power is essential. While fines can discourage open burning, they can also penalise farmers without allowing them to turn their residue management challenges into opportunities. Solutions include farmer co-operatives buying or sharing harvesting machinery, thereby reducing the financial burden on the individual farmer. Education will be an essential part of any such programme to change current practices, and subsidies may be needed to help pay for new harvesting equipment.

## RECOMMENDATION 1

—

**Governments could use a feed-in tariff system or equivalent policy to divert field residues destined for open burning as fuel to power plants.**

**Enforcement:** Each cluster country has major surplus residues that could be developed. Stricter enforcement of laws against open burning will help create bioenergy opportunities. To phase out these undesirable practices, alternatives need to be in place. India has created a market for rice straw in the power sector, and some cluster countries have used feed-in tariffs for biomass-generated electricity (see box). A co-operative approach takes into account the needs of farmers, offering subsidies for harvesting equipment, collective purchasing and sharing of expensive harvesting equipment. Vocational training will help determine sustainable harvest levels and optimise supply chains.

### Reducing field burning in India

In India, authorities are now distributing fungi capsules for farmers to spread on the paddy to accelerate decomposition through fungal activity to degrade the material in 25 days, hoping to make stubble burning unnecessary to prepare for the next crop (usually wheat) (Lalwani, 2021).

They have also purchased harvesting engines that are made available to farmers to bundle the rice straw as fuel for nearby power plants. The government has directed power plants to use rice straw for 10% of their fuel input. India incentivises the industry to install biomass boilers that can burn rice straw. The government provides land to store the straw bales, which are generated in large quantities once per year for up to 55 days (Lalwani, 2021).

The Indian Energy and Resources Institute recommends (Datta *et al.*, 2020):

- Leaving 30-40% of crop residues with a lower lignin content (< 20% lignin) on the cropland after harvest and managing it with in situ crop residue management.
- Developing or adapting crop harvesting machinery that leaves 30-40% of crop residues on the field while bailing the rest.
- Mandating existing power plants to use 5-10% of the rice residue as their fuel input.
- Creating the infrastructure for biomass depots to store bailed crop residue.
- Mandating a state or national organisation to aggregate crop residues.
- Creating a particular credit line/scheme for financing farm equipment and high working capital for private sector participation.

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## RECOMMENDATION 2

—

**Enforcement of environmental regulations on field burning could help move the bioenergy sector forward. Education and financial support will be needed to change field residue management practices.**

**Improve supply chains:** To encourage the industry to use more agricultural residues instead of wood from forests, governments could consider tax credits for the purchase of biomass boilers or similar incentives. The agricultural industry needs to work together to provide a year-round supply of biomass. This may involve the regrouping of farms and the management of harvests to spread the supply of residues over a longer period more suited to the fuel needs of industry, or the combination of different types of crop residues to provide a year-round supply from different crops. Each subregion could develop approaches to the on-farm storage of already harvested residues, extending the timeframe in which agricultural waste is available, rather than forcing users to store large quantities of biomass fuel on site.

## RECOMMENDATION 3

—

**Boiler fuel needs to be provided year-round. Government and industry can implement measures to adopt bioenergy more easily and cost-effectively by incentivising the purchase of biomass boilers and creating supply chains that can guarantee fuel supplies throughout the year.**

**Proof-of-origin tracking:** Every industry, especially those operating in a voluntary market, must demonstrate that their bioenergy is sustainable. Proving sustainability is relevant for cooking fuels, industrial boiler fuels and power plants. Developing a bioenergy industry must avoid creating new environmental burdens or encouraging the use of unsustainably sourced biomass. A tracking system that links each agricultural biofuel delivery to a defined point of origin will support these efforts. Sustainability certification makes supply chain management rules necessary. The Sustainable Agricultural Network (SAN), Better Sugarcane Initiative, the Roundtable on Sustainable Palm Oil and the Roundtable on Responsible Soy are initiatives that focus specifically on feedstock sustainability.

The new EU law on deforestation-free products forces companies to ensure that biomass sold in the European Union does not come from deforested land anywhere in the world (European Parliament, 2022). The agricultural industry must adopt best practices in this respect and buyers should insist on such documentation for any biofuel that bears the risk of being unsustainably sourced. Related activities include the creation of certification or documentation schemes adapted to the region. For example, there is currently no such scheme applicable to biochar. Industry and bioenergy associations must promote this approach among their members and insist that sustainability certification and tracking are central to creating the industry.

## RECOMMENDATION 4

—

**Developing or adopting proof of origin and sustainability certification schemes at regional and international level. Proof-of-origin tracking of agricultural residues would facilitate their use in industry.**

**General:** Several recommendations would apply to the entire agricultural sector, regardless of geographical region or circumstances. These elements are frequently "no-regret" measures that will help establish the bioenergy industry on a sustainable footing and create a culture of using agricultural waste rather than ignoring the opportunities it presents. Some of these measures are discussed in Chapter 4 and include:

- Develop a bioenergy strategy, as pointed out at the beginning of this chapter. The design should be based on national priorities, considering the existing ASEAN strategy, but will also identify specific barriers and target markets for each country.
- Conduct agricultural residue assessments and mapping to facilitate the identification of opportunities for project development.
- Provide public funding for pilot and demonstration projects.
- Support small, family-sized digesters, as done with the Viet Nam Biogas Programme, that reduce demand for unsustainable cooking fuel and manage animal waste.
- Identify and implement best practices around harvesting, transport, storage and biomass residue use to reduce health hazards and maximise economic and social benefits.
- Pursue international co-operation, including South-South co-operation, between sub-Saharan Africa, Southeast Asia and South America to learn from success stories and disseminate knowledge around bioenergy development.
- Introduce tax incentives for "green" fuels and infrastructure to facilitate market adoption.
- Encourage target-setting, government leadership and education to reinforce bioenergy opportunities and acknowledge their benefits.

The ASEAN strategy calls for creating a network of R&D centres and educational training. Such a network and related centres of excellence could lead the effort to adopt sustainable technologies and practices for bioenergy, including exploring the use of field residue for pyrolysis and returning char residue to the field to reduce fertiliser needs and improve soil properties and yields.

## 5.2 Sub-Saharan Africa country cluster: Western Africa

### Introduction

The study selected **Western African countries** for analysis and further elaboration. These countries have a tropical climate and huge unexploited agricultural residue potential. Yet, they also experience economic challenges, underdeveloped infrastructure and lower agricultural yields than other world regions.

Western Africa's agriculture is characterised by diverse crops, with none of them dominating as soybeans do in South America and palm oil cultivation does in Southeast Asia. Crops like cassava and cacao are ubiquitous and are more common here than in other regions. A large share of smallholder farms requires a different approach to collecting residue than an agricultural sector comprising large plantations. Farmer co-operatives and aggregators are necessary to secure large amounts of residue for bioenergy projects contractually. At the regional level, organisations such as the Economic Community of West African States (ECOWAS) help with political co-operation and exchange regulatory approaches. The organisation and its members have yet to facilitate bioenergy development and agricultural supply chain development at the regional and national levels. Still, some bioenergy projects are coming to the fore, creating examples for replication in the region.

### Bioenergy potential

The Western African cluster of countries has the following primary feedstock: field residue from cocoa harvest, pruning and replacing ageing plantations, field and process residue from palm oil, and field residue from cashew and rubber replanting. Cassava is an important crop, offering cassava peels and processing wastewater as feedstock. Residue streams from rice, maize, plantain banana, coffee, coconut, banana and sugarcane are also available. Livestock waste is abundant and underused.

The most promising crops are tree crops with yearly harvests and replacement cycles every few decades, namely cocoa, palm, cashew and rubber. These crops produce woody biomass for combustion to produce electricity and cooking energy. They come as husks and shells, and trunks and branches when unproductive trees are replaced. The low percentage of local processing of these crops, except for oil palm fruits, means that the technical bioenergy potential depends on the capacity to collect field residues over the entire year. See Table 5.5 for the technical potential of the top ten residues.

**Table 5.5** Top ten residues in the Western Africa subregional cluster and corresponding technical potential

| Type of residues | Technical potential (PJ/yr) |
|---|---|
| Oil palm trunks and fronds | 271 |
| Cassava pulp | 206 |
| Non-dairy cattle manure | 186 |
| Cassava wastewater | 103 |
| Yam stems | 76 |
| Goat manure | 68 |
| Rice straw | 52 |
| Corn stover/stalk | 49 |
| Groundnut haulms | 42 |
| Market swine manure | 39 |
| **TOTAL** | **1 092** |

## Envisaged markets

Below are the top three responses to the survey question on markets for bioenergy in this cluster:

- small-scale biogas production for cooking, thermal use or electricity
- charcoal for agriculture (biochar) or for cooking
- electrical micro-grids.

Western Africa's growing population requires additional energy production, especially electricity. Electrification remains low, varying between 25% and 70% among the countries. Where power is available it is frequently sporadic or unreliable. Power production from agricultural residue can cover some of the "new" demand, improving grid stability by adding more decentralised power sources. Several large industries – especially palm oil – can become net energy producers should they use their POME effluent for biogas production. The industry's field and processing residue can fuel gasifiers or steam boilers to generate power (and heat).

In the top biomass-producing countries, biomass energy may be expanded from about 100% to over 300% of additional capacity to the current installed electricity capacity. The primary pathway for extracting energy from these biomass sources is chipping and subsequent combustion for thermal energy and electricity, both for on-grid and off-grid use. A by-product of this pathway is mineral ash that can be processed into fertiliser. The regulatory environment in Western African countries does not yet permit commercial off-grid bioenergy electricity production. As a result, a main challenge for all project developers is obtaining a power purchase agreement from the energy distribution monopoly.

The area's growing population requires increasing quantities of cooking fuel currently being supplied as firewood, charcoal and butane. Using agricultural residues, such as coconut shells, palm kernels or cashew shells, to make charcoal or combustible briquettes will help reduce pressure on forests and provide improved cooking fuel. Another pathway that shows potential for these biomass sources is pyrolysis to produce syngas, biocrude and biochar as by-products. This pathway, which allows for the production of cooking fuel, would require facilitating access by households to clean cooking stoves to use the char most effectively.

Additional biogas opportunities include small-scale applications (family-size digesters) and some larger livestock producers as primary feedstock providers for large-scale digesters. Biomass sources with high potential are wastewater streams such as pig manure, cassava wastewater and palm oil mill effluent. These liquid streams contain a high concentration of organic matter and are suitable for biogas production. The secondary product of this pathway is organic fertiliser in the form of compost and digestate, and this co-product is a high-value product for Western Africa. The main issues are regulatory since these biomass sources originate at central processing or livestock breeding locations. Incentives for properly managing manure and processing wastewater, with penalties for not doing so, and financial support would unleash economic opportunities. Also, applying any butane gas and liquefied petroleum gas subsidies equally to biogas and biomethane would create a level playing field.

Liquid biofuels are another potential pathway. Ghana has set a goal for liquid biofuels to account for 20% of the market in the transport sector and ECOWAS has set gradual goals for several cluster countries. Biofuels are, however, not made from agricultural residue at this point. This potential could be explored further, including using rubber tree seeds for biodiesel production or lignocellulosic biofuels once related technologies become more commercialised.

Table 5.6 summarises the most promising pathways that meet the priorities identified for the cluster. Decisive government policy and a concerted effort from local, national and regional actors will realise these opportunities.

**Table 5.6** Feedstocks, technologies and markets for bioenergy in Western Africa

| Feedstock | Technology | Market |
|---|---|---|
| • Coconut shell<br>• Palm kernel shells<br>• Cashew nut shells<br>• Rubber seed shells | • Torrefaction | • Local cooking fuel |
| • Biomass pellets from woody residue<br>• Empty palm fruit bunches<br>• Palm fibre<br>• Rice husks<br>• Maize cobs | • Combustion | • Industrial boilers |
| • Cocoa pods<br>• Palm kernel shells<br>• Corn cobs<br>• Rice straw<br>• Sugarcane stalks<br>• Bagasse<br>• Plantation waste<br>• Coconut husk and shells<br>• Rice husks | • Combustion or small-scale gasification* | • Power generation |
| • Livestock waste<br>• Coffee pulp<br>• POME<br>• Cassava peels and wastewater<br>• Fruit processing waste | • Anaerobic treatment | • Biogas for power generation |

* Produces a char residue that can, in turn, can be used to produce cooking fuel.

## Enabling institutions

Some leading Western African institutions that may contribute to developing the bio-economy are listed below. Co-operation among these institutions and national governments, as well as North-South and South-South collaboration and information sharing, are necessary to advance the bioenergy industry. Policy makers working with these organisations are more likely to create strategies, programmes and regulations that are successful.

**Table 5.7** Institutions relevant to developing a bioenergy strategy in sub-Saharan Africa

| Institution | Comments |
|---|---|
| **ECOWAS and ECREEE** | Co-operation between national governments and exchange of best regulatory practices. The Economic Community of West African States (ECOWAS) operates the Regional Centre for Renewable Energy and Energy Efficiency (ECREEE). |
| **OECD** | The OECD's Sahel and West Africa Club focuses on various policy initiatives, including renewable energy policy. The organisation seeks to improve regional governance to enable the transition to further the economic and social well-being in the region. |
| **National ministries of energy** | Can lead with the application and adjustment of incentives, feed-in tariffs and other energy policies and regulations to support bioenergy development in priority areas. |
| **National ministries of agriculture** | Can help implement best management practices to optimise field residue collection, work with the academic sector to determine sustainable removal rates and implement a circular economy approach. |
| **National ministries of industry** | Can help create a vision for the bioenergy industry, work with related sectors to develop strategies and address barriers and work in favour of tax breaks and other measures to support the industry. |
| **Chambers of commerce** | Can help with voicing the needs of private sector actors such as project developers and equipment suppliers. |
| **African Development Bank** | The bank provides project (private) funding and loans to governments and project finance. |
| **World Bank Group and development finance entities** | These entities provide financing at the early stage to move the project through its development stages. In doing so, they play a vital role in the early stage of developing a new bioenergy sector. |
| **National and private banks** | Can create specific agricultural bioenergy programmes and familiarise themselves with the sector to better understand risks and opportunities. |
| **Private Financing Advisory Network** | A global network with regional hubs of climate and clean energy financing experts offering free business coaching and investment facilitation to entrepreneurs developing climate and clean energy projects in emerging markets. |
| **National bioenergy associations** | Industry associations, such as the Renewable Energy Association of Nigeria. |
| **Agricultural associations and regulators** | Industry associations representing the livestock and crop production industries are often segmented by product type or crop. They can communicate with their industry members, respond to market demand for residue and disseminate information and best practices. They are also well-equipped to work on sustainability certification. Similarly, national regulators of crop production, such as cacao or cashew, can assist in implementing best practices and market development. |
| **Research institutes** | Organisations involved in R&D can be agriculture or energy departments in national universities or specialised research institutes, whether national (*e.g.* Institut National Polytechnique Félix Houphouët-Boigny in Côte d'Ivoire) or international. |

## Gap analysis

During the online workshop held on 15 February 2023, participants identified access to financing for bioenergy projects as a primary barrier, followed by technology readiness and feedstock quality and availability. Administrative hurdles and cultural preferences were given less emphasis as barriers. In a follow-up survey, respondents identified a low level of industrialisation and low purchasing power as the main barriers. They also preferred creating government-mandated bioenergy markets as the primary tool to facilitate bioenergy industry development, followed by levelling the playing field between subsidies for fossil fuels versus biofuels. The workshop participants identified limited access to financing and project funding as significant barriers. Participants perceived enforcing environmental laws as less critical but training the workforce for the bioenergy industry was deemed necessary.

The case study on power generation using biogas produced from agricultural residue in South Africa highlights the opportunities that agricultural residues create and the project's challenges with the local electrical grid. The project has no grid connection and is selling electricity directly to a large industrial consumer that needs a reliable electricity supply and prefers low-carbon electricity. The generator reduces its client's power consumption from the grid, provides backup power during blackouts and helps stabilise the local grid by reducing industrial power use. Another case study presented during the workshop introduced the Biovea project (https://biovea-energie.com/), which benefits from a power sales contract with Côte d'Ivoire's grid operator. The project will use agricultural residue in a combustion process to power turbines in a 43 megawatt (MW) biomass power plant. This facility will help the country produce low-carbon electricity to alleviate the increasing demand for electricity caused by a growing population and increased industrialisation. These projects represent good examples for project developers and regulators to follow.

In general, Western Africa has mainly used woody biomass to make charcoal, often with inefficient methods that have led to high demand for wood and caused deforestation. Several projects using agricultural residue are now under development, for example in Côte d'Ivoire. The circular economy concept is taking shape through private efforts to promote composting of field and processing residue. These developments show that the region's vast potential may support its growth in terms of population and industrialisation. In light of the pathways mentioned above and from workshop contributions, national governments and industry representatives need to address the following gaps to facilitate bioenergy industry development:

- National policy frameworks and GHG emission reduction plans need to give due consideration to bioenergy. Assessing and incorporating bioenergy potential into national energy planning and policy is necessary.

- Western African countries still have to develop a regulatory framework for bioenergy for cooking energy and electrical power. However, ECOWAS has proposed targets and feed-in tariff systems to promote bioenergy. Only a few national governments have implemented these recommendations. Some have mandated national targets for power generation and liquid biomass fuels, which limits markets of bioenergy for cooking and makes project development more difficult.

- Related to the above, the rules for independent power producers to sell electricity to the grid operator and connect to the power grid vary significantly between countries, favouring larger projects proposing more than 20 MW of power. In many areas, the grid infrastructure may not technically allow new power producers to come online, as this would create instabilities in the grid.

- Environmental laws or regulations on industrial effluent treatment need to be enforced. Illegal logging and the freedom to dispose of untreated wastewater compete with bioenergy opportunities, making industry development more difficult.

- Poor roads and inadequate infrastructure hamper access to agricultural field residue. Reducing the cost of residue harvesting and preprocessing for transport to the project location is essential – and a significant risk for project developers. Frequently, financing institutions ask for feedstock supply agreements but these are rarely available or banks question the supplier's balance sheet.

- For various reasons, the agricultural sector only sometimes applies best practices. Farmers do not always return post-harvest or processing residue to the field as compost or digestate, an approach that provides minerals, improves soil quality and ultimately enhances yields. The government may create incentives for farmers to adopt best practices and renew ageing plantations while making good use of the resulting woody biomass. Mechanisms for this include tax-based subsidies or levies on related crop products that are then returned to farmers to help pay for timely replanting, thus maximising yields and social benefits and producing energy from residues.

- Workshop participants also confirmed that access to financing is not readily available for bioenergy projects. Companies and organisations with large balance sheets or public-private partnerships must capitalise on opportunities to develop the bioenergy sector.

## Recommendations

Many decision makers in cluster countries believe that bioenergy cannot significantly contribute to meeting current and future energy needs. Recent or historical gas field discoveries in countries such as Côte d'Ivoire, Ghana and Nigeria, as part of the Gulf of Guinea gas and oil fields, compound this challenge. Demonstration and commercial-sized projects, such as those currently underway in Côte d'Ivoire, can demonstrate the potential that agricultural bioenergy holds. Power plants should ideally sell their electricity to large industrial customers rather than to the public grid. Operating as an independent power producer that feeds into a public grid is only viable in locations with stable grids.

Workshop participants stressed that accessing agricultural residues is difficult, mainly because of poor infrastructure. For national governments, bioenergy development could become part of their infrastructure planning, prioritising regions where improved infrastructure could serve the development of energy and industrial infrastructure. Agricultural residue needs to be recognised for its energy potential and positive environmental and social benefits that contribute to reducing poverty, improving access to electricity and reducing environmental problems such as eutrophication and deforestation. More concretely, based on the input from workshop participants and local experts in cluster countries, the following measures were identified as helpful for bioenergy development in the region:

**Fostering market development:** Côte d'Ivoire has created rules for biomass power producers to gain grid access and sell their electricity to the grid operator. ECOWAS also recommends introducing feed-in tariffs to encourage renewable power producers. Without clear rules for the market value of electricity from agricultural biomass and fair economic and technical regulations for grid connection, project developers need to find opportunities to sell their power directly to users, which limits the sector's development. The lack of remuneration seems to have discouraged cane sugar mills from producing more electricity with bagasse, a resource which could be harnessed quickly and cheaply to produce more electricity.

### RECOMMENDATION 1

—

**Governments could direct grid operators to develop fair grid access rules for independent power producers, and introduce proven regulatory approaches, *e.g.* feed-in tariffs or renewable portfolio standards.**

**Environmental regulations:** Agricultural residues are an opportunity for bioenergy production if the industry is forced to treat its waste, including wastewater. It may then be more economic to use the waste as a resource for bioenergy. Sustainable biochar from agricultural residue competes with products such as illegally cut wood.

### RECOMMENDATION 2

—

**Governments can support the bioenergy sector by creating and enforcing regulations against deforestation and the direct release of untreated wastewater from palm oil processing, industrial livestock farms and similar sources.**

**Improve supply chains:** A constant supply of agricultural residues is required to enable bioenergy project development. Continuous feedstock supplies may be easy with livestock farming, but it is more challenging with crop residue, which may only be seasonally available. Industry associations, governments and academia could develop logistical concepts considering staggered harvesting, collection and suitable storage and transport. Regrouping several farms into residue co-operatives or similar approaches may help secure year-round feedstock supplies for the industry as a basis for new bioenergy projects. Similarly, farmers should be encouraged to adopt best practices and renew ageing plantations regularly while producing high-quality biomass residue for energy production.

### RECOMMENDATION 3

—

**Farmers, agricultural associations and regulators can collaborate to develop residue supply chains suitable for bioenergy project development. Best practices in agriculture help to increase yields and renew ageing plantations.**

**Project financing:** A significant barrier identified by workshop participants was access to financing and a need for project funding to support private initiatives. Specific funding programmes can assist bioenergy project development in priority areas, such as using agro-industrial effluents, generating electricity with agricultural residue or producing sustainable cooking fuels. A two-pronged approach is necessary. Government funding and tax incentives, such as accelerated depreciation or tax exemptions on equipment and biochar sales can direct project development to where bioenergy strategies have identified a critical national interest. The banking sector must also educate itself about bioenergy risks and benefits. Agricultural bioenergy projects are complex, possibly requiring many feedstock providers, using technologies that are not yet well established in the region, and addressing new markets. Financiers will be reluctant to provide money for bioenergy projects or will impose terms that are difficult to meet for project developers. Government and industry need to work with the financing sector to prioritise bioenergy. Similarly, public-private partnerships, loan guarantees or other such mechanisms leverage private financing and enable the financing of agricultural bioenergy projects.

### RECOMMENDATION 4

—

**Develop agricultural bioenergy-specific government loan and grant programmes in priority areas. Work with the private sector to de-risk and facilitate the financing of bioenergy projects, including loan guarantees, public-private partnerships, tax exemptions or reductions, education and subsidies to level the playing field between bioenergy and fossil fuels, especially during the early years of bioenergy development.**

**General:** Several recommendations apply to the entire agricultural sector, regardless of geographical region or circumstances. These elements are frequently "no-regret" measures that will help establish the bioenergy industry on a sustainable footing and create a culture of using agricultural waste rather than ignoring the opportunities it presents. Some of these measures are discussed in Chapter 4 and include:

- Developing a bioenergy strategy, as pointed out at the beginning of this chapter. The design should be based on national priorities, consider existing national and ECOWAS targets, and identify specific barriers and target markets for each country.

- Developing instruments to reduce biomass supply risks for project developers, particularly for pioneering projects defining the sector.

- Assessing and mapping agricultural residues to facilitate the identification of opportunities for project development.

- Supporting small, family-size digesters through targeted biogas programmes that reduce demand for unsustainable cooking fuel and manage animal waste.
- Identify and implement best practices around harvesting, transport, storage and biomass residue use to reduce health hazards and maximise economic and social benefits.
- Encourage international co-operation, including South-South co-operation between sub-Saharan Africa, Southeast Asia and South America, to learn from success stories and disseminate knowledge around bioenergy development.
- Tax incentives for "green" fuels and infrastructure to facilitate market adoption.
- Target-setting and government leadership and education to reinforce the bioenergy opportunity and acknowledge its benefits.

## 5.3 South American cluster: Mid-developed Amazonian countries

### Introduction

The study selected **Bolivia, Ecuador** and **Peru** for analysis and further elaboration. These countries are situated within the tropical zone and have crops similar to Brazil and Colombia, considered regional leaders in agricultural residue use for bioenergy. Agriculture is the largest employer in these regions and improving farming practices and income directly benefits society. Smallholder farmers operate many farms. Some cluster countries have promoted bioenergy already, such as the Ecuadorian National Biogas Programme or the PROBIOCOM programme in Peru, which supports small-scale digesters. All three cluster countries have liquid biofuel mandates or targets for bioethanol, and partly for biodiesel.

***"There is a road already travelled by the sugar mills. Other sectors will follow suit once economic and regulatory signals are visible."***

**Response to a survey question asking how the bioenergy sector is likely to develop in the next five to ten years.**

Julio Ricco © Shutterstock.com

## Bioenergy potential

The geographical and climatic conditions of the Amazonian countries are conducive to farming all year round and with excellent yields. Organising and strengthening the agricultural sector within a circular economy approach can yield multiple benefits, improving trade balances and rural income. Residue types available for bioenergy production in the cluster (Bolivia, Ecuador and Peru) include those below. See also Table 5.8 for estimated figures.

**Feedstock mainly for power generation, cogeneration and lignocellulosic biofuels:**

- Sugar cane stalk
- Corn stover
- Banana residue (Ecuador, Peru)
- Cocoa residue (Ecuador)
- Coffee residue (Peru)
- Pruning and stumping residue from oil palm, PKS and empty fruit bunches (Ecuador, Peru)
- Rice straw
- Sorghum straw (Bolivia)

**Feedstock for anaerobic digesters**

- Soybean oilcake (Bolivia)
- Coffee pulp
- POME (Peru, Ecuador)
- Manure
- Fish and seafood residue (Ecuador)

**Table 5.8** Top ten residues in the Mid-developed Amazonian countries subregional cluster and corresponding technical potential

| Type of residues | Technical potential (PJ/yr) |
|---|---|
| Broiler litter | 284 |
| Dairy cow manure | 37 |
| Layer hen litter | 32 |
| Rice straw | 31 |
| Soybean straw, soybean forage | 26 |
| Market swine manure | 18 |
| Sugar cane stalk | 17 |
| Vinegar/syrup | 10 |
| Sorghum straw/stalks | 10 |
| Plantain stems and leaves | 5 |
| **TOTAL** | **470** |

## Envisaged markets

The biofuels market in the three countries remains strong, but has focused on conventional biofuels made from energy crops, such as maize and oilseed. Domestic production of biofuels is insufficient to reach the blending targets, leading to imports. At the time of writing this report, no incentive structure for liquid biofuels to use second-generation (lignocellulosic) biofuels was yet in place. Fossil fuel subsidies make it difficult for biofuels to be price competitive. Likewise, subsidised grain and biofuel imports create unfair competition for the local agricultural sector. These are the main financial barriers to producing and commercialising liquid biofuels.

Other markets include cogeneration, industrial heat and small-scale power production (gasifiers). The latter can substitute diesel generators in remote grids. Export markets for biofuels (liquid or solid) are currently not envisaged. Exporting palm oil field residue and PKS may be possible, but these residues can also be used locally to reduce dependence on fossil fuels and related subsidies. Current policies, such as auctions for power generation and existing biofuel targets, are insufficient to incentivise the development of the bioenergy sector. Industry associations have studied the potential for biogas for over a decade, yet little has been implemented, despite concerted planning and dedicated budgets. Innovative policies that continue over time, independent of government changes, are necessary to enable bioenergy development in cluster countries.

The sugarcane industry in Brazil and Colombia demonstrates the opportunities to produce new bioenergy products, such as biomethane or hydrogen, using the industry's residues. Using existing infrastructure for bioenergy is essential as it does not require investment in new industrial facilities and using residue from outside the sugarcane supply chain can increase bioenergy outputs from these facilities.

There are no incentives for the production of cooking fuels from solid agricultural residues. Current programmes all focus on biogas. Existing small-scale digester programmes have had limited success and should be adapted to be more effective. Power generation is an important market for larger bioenergy projects, and the three countries are developing this market. The oil palm industry can serve as an anchor site to use its residues, including POME effluent, to produce biogas for power generation. Large livestock producers can also serve as anchor sites for large digesters. In addition, biomass can be used to meet industrial heat demand. Prunings and tree trunks from replanting, rice straw, palm kernel shells and empty fruit bunches from the palm oil industry could be used as fuel.

Bolivia, Ecuador and Peru might consider the pathways identified in Table 5.9, which summarises the available agricultural residues, technologies and markets they might serve. Decisive government policy and a concerted effort from local, national and regional actors will help these opportunities materialise.

**Table 5.9** Feedstock, technologies and markets for bioenergy in Bolivia, Ecuador and Peru

| Feedstock | Technology | Market |
|---|---|---|
| • Bagasse<br>• Plantation waste<br>• Cocoa pods<br>• Rice straw<br>• Soybean straw<br>• Rice hulls<br>• Maize cobs | • Combustion or gasification | • Industrial heat and cogeneration<br>• Second-generation biofuels |
| • Corn cobs<br>• Cocoa pods<br>• Rice straw<br>• Soybean straw<br>• Sugarcane stalks<br>• Plantation waste<br>• Rice hulls | • Combustion | • Power generation, on-grid |
| • Plantation waste<br>• Rice straw<br>• Maize cobs<br>• Bean straw | • Gasification (small-scale) | • Power generation, behind-the-meter and remote diesel grids |
| • PKS<br>• Plantation wood | • Pyrolysis or briquetting | • Solid cooking fuel to replace firewood |
| • Manure<br>• Coffee pulp<br>• POME<br>• Vinasse from sugarcane | • Anaerobic treatment | • Biogas for power generation<br>• Biogas for cooking<br>• Vehicle fuel (biomethane) |

## Enabling institutions

Several leading institutions in this subregion can contribute to developing the bioeconomy. Co-operation between these institutions and among national governments, as well as North-South and South-South collaboration and information sharing, are necessary to advance the bioenergy industry. The following stakeholders (Table 5.10) should be consulted when creating strategies, programmes and policies for bioenergy.

**Table 5.10** Institutions relevant to developing a bioenergy strategy in South America

| Institution | Comments |
|---|---|
| **OLADE** | The Latin American Energy Organization (OLADE) is an intergovernmental public body for co-operation, co-ordination and technical advice working to promote the integration, conservation, rational use, commercialisation and defence of the region's energy resources. |
| **CAN** | The Andean Community (Comunidad Andina – CAN) has various bodies and institutions that make up the Andean Integration System (SAI). Its objective is to achieve balanced and autonomous development through Andean integration, extending towards South American and Latin American integration. It focuses on managing energy integration, agricultural development and the use of biofertilisers. |
| **National ministries of energy** | Can lead with the application and adjustment of incentives, feed-in tariffs and other energy policies and regulations to support bioenergy development in priority areas. |
| **National ministries of agriculture** | Can help implement best management practices to optimise field residue collection, work with the academic sector to determine sustainable removal rates and implement a circular economy approach. Direct land use and operate programmes to develop rural areas and new business activities. |
| **National ministries of industry or finance** | Can help create a vision for the bioenergy industry, work with related industries to develop strategies and address barriers and work in favour of tax breaks and other measures to support the industry. |
| **Ministries of the environment and natural resources** | Direct and regulate sustainable resource use, climate strategies and effluent and emissions management. |
| **Development Bank of Latin America** | The bank provides project (private) funding and loans to governments. Its green bond programme supports reaching the Paris climate goals through investment in renewable energy, clean transport, waste management and sustainable land use. Its energy programme is helping the energy transition in Latin America. |
| **IDB** | The Inter-American Development Bank (IDB) is active in both the agricultural and energy sectors, focusing on improving food security, combating the effects of climate change and sustainably harnessing natural resources. The energy programme focuses on cogeneration from biomass, among others. |
| **National and private banks** | Can create specific agricultural bioenergy programmes and familiarise themselves with the sector to better understand risks and opportunities. |
| **FIAS** | Institutions like the Ecuadorian Sustainable Environmental Investment Fund (FIAS) can leverage project funding, especially for public-private partnership projects. |
| **Private Financing Advisory Network** | A global network with regional hubs of climate and clean energy financing experts that offers free business coaching and investment facilitation to entrepreneurs developing climate and clean energy projects in emerging markets. |
| **National bioenergy associations** | Industry associations, such as the Ecuadorian Biofuels Association (APALE), Peruvian Association of Agricultural and Fish Producers (APPAGRO), and the Sugarcane Union of Guariba (Bolivia). |
| **ENERGY HUB** | The HUB encompasses the collaboration between Sustainable Energy For All, ariae.org, IDB, ECLAC, OLADE and IRENA and a network of universities. It seeks to integrate and disseminate energy-related information in the region and accelerate knowledge generation by facilitating regional research by generating discussion around solutions and sharing lessons learnt. |

| | |
|---|---|
| **LEDS-LAC** | The organisation is an international platform for co-operation between government employees, academia and industry. They maintain a bioenergy group that exchanges best practices and knowledge around bioenergy. |
| **Bioenergy Desk** | The Bioenergy Desk (Mesa Técnica Interinstitucional de Bioenergía), created in Ecuador with UNDP support, is a collaboration between energy and natural resource ministries, other ministries and institutes and the national power corporation to further bioenergy development. |
| **Research institutes** | Agriculture or energy departments in national universities or specialised research institutes can support bioenergy development with scientific studies. |

## Gap analysis

Through an online workshop, local experts contributed towards the knowledge collected for this report, suggesting markets, critical resources to be used, and the most significant barriers and ways to remove them. During the workshop held on 14 February 2023, participants identified technological readiness, feedstock costs and the competitiveness of bioenergy as the main barriers.

Legal and regulatory issues are also of concern and the participants did not select administrative hurdles or infrastructure-related issues as barriers. During a follow-up survey after the workshop, participants identified feedstock management and supply chains as the main barrier, followed by the high cost of capital and an inadequate legal and regulatory framework for bioenergy (Figure 5.1). Respondents identified phasing out fossil fuel subsidies and levelling the playing field for renewable energy as the primary enabling measures, followed by more accessible financing and government-mandated markets (Figure 5.2).

**Figure 5.1** Responses to a survey regarding barriers to bioenergy development in South America conducted after an IRENA seminar

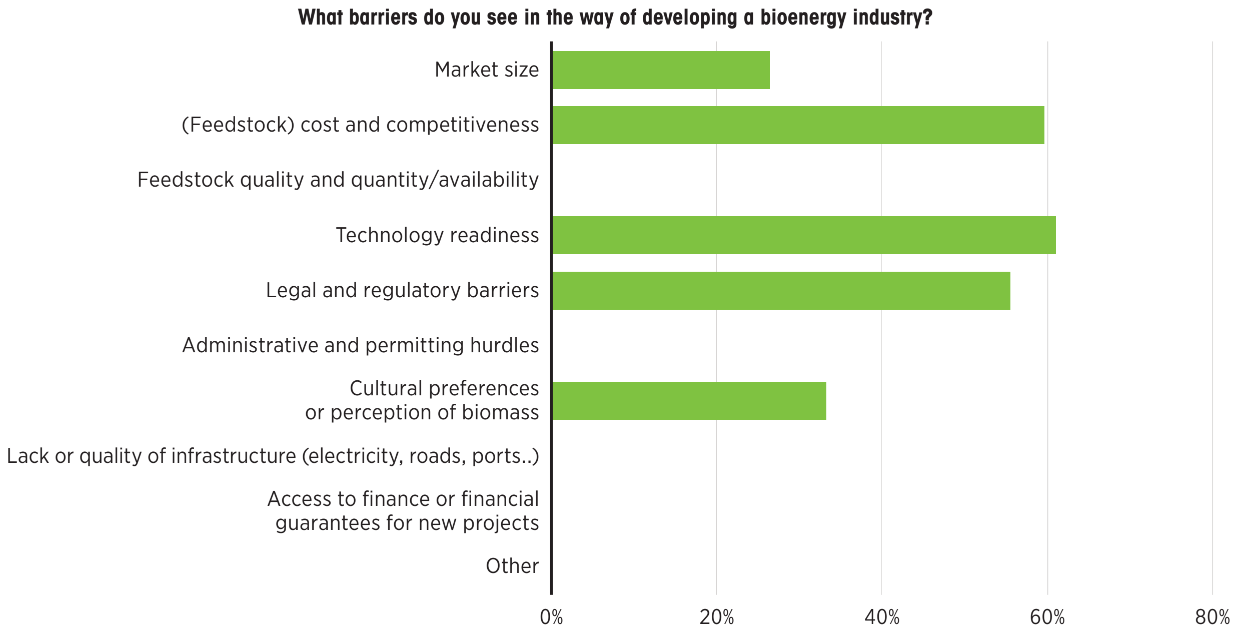
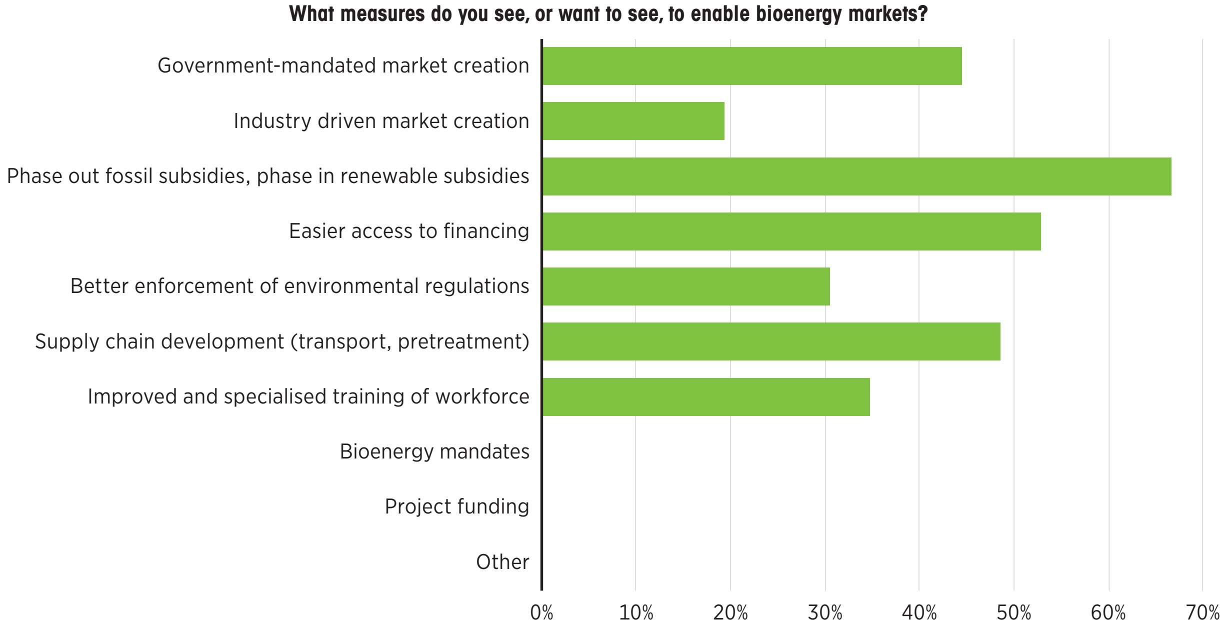


**Figure 5.2** Responses to a survey regarding enablers of bioenergy development in South America conducted after an IRENA seminar in 2023




Bioenergy still needs to be part of the regional core strategies to reduce GHG emissions and secure a sustainable energy transition. Increased investment in bioenergy will benefit the agricultural sector, a principal employer in the region. In light of the pathways mentioned above and from workshop contributions, national governments and industry representatives need to address the following gaps to facilitate bioenergy industry development:

- The regulatory framework for bioenergy is incomplete and mainly addresses first-generation biofuels. Long-term government mandates can create attractive markets in the electricity and industrial heat sectors, enabling investment and offering business opportunities. Yet bioenergy policies in the three cluster countries are sometimes short-lived and change when the government changes. Generally, energy planning and policy need to give more emphasis to bioenergy.

- Governments frequently acquire private power generation through auctions. Developers sometimes offer very low bids, too low to be commercially viable. The developers then abandon projects, even if provided with contracts. Also, bioenergy projects are more complicated to develop than solar or wind projects and the electricity produced usually costs more. Unless social and other benefits of bioenergy are part of the auctions, either by increasing prices or by conducting separate auctions for biomass-to-electricity projects, bioenergy remains disadvantaged and projects are unlikely to be selected in an auction system.

- Fossil fuels are government subsidised, creating a disadvantage for biofuels, which do not receive such subsidies. Also, subsidised biofuels (and some grains) imported from countries like the United States put local producers at a disadvantage when no tariffs are in place to protect local, unsubsidised producers.

- There needs to be adequate technology, especially for large digesters. Imported technology can be expensive and designs adapted to local needs and capacities are required.

- Workshop participants also confirmed that access to financing is not readily available for bioenergy projects and regulatory and legal barriers exist. National bioenergy strategies and related actions should address these issues to foster bioenergy industrial development in each country. Training courses or technical guidelines could help project developers preparing bankable proposals.

**GHG emissions from agricultural by-products**

Plants convert $CO_2$ from the atmosphere into biomass. Carbon stored in biomass is called biogenic carbon. Some of this carbon stays above ground and some in the ground. When plants die, decomposition starts. As plant material decays, the stored carbon is released as $CO_2$ back into the atmosphere. If the amount of carbon released in biomass plantations and forests equals the amount of carbon sequestered, then the biomass carbon cycle is in balance. There are also circumstances where some of the carbon is stored in the ground. The amount of carbon stored is enormous, for example, in the case of peatland.

When biomass is combusted, biogenic carbon is released into the atmosphere. If the total biogenic carbon released during biomass decay and/or combustion is sequestered, the system continues to be in balance. As a result, the amount of $CO_2$ in the atmosphere does not increase. This is fundamentally different from $CO_2$ emissions from the combustion of fossil fuels, for which no mechanism exists to recycle the carbon in the short term; therefore, their combustion increases the volume of $CO_2$ emissions in the atmosphere.

When short-rotation energy crops or agricultural residues are used as fuel, they result in a balanced carbon cycle because they grow/renew themselves annually. In comparison, the rapid expansion of palm oil plantations in Indonesia and Malaysia, for example, has led to deforestation and peat loss. Plantations on carbon-rich peat soils in the region resulted in drainage. The subsequent oxidation of peat and natural or anthropogenic fires result in substantial $CO_2$ emissions. Peat digging also has a negative effect, which results in an increase in $CO_2$ emissions in the atmosphere.

The impact bioenergy may have on the life cycle GHG emissions depends on several factors, including, but not limited to the pathway and technology used and the fuel or energy bioenergy substitutes. A case-by-case analysis is needed for a proper assessment.

**Source:** (IRENA, 2014).

## Recommendations

The cluster countries could consider implementing the following measures:

**Electricity markets:** The auction system used in cluster countries to contract for new power generation capacity needs to be reformed or replaced with other mechanisms, such as feed-in tariffs, renewable portfolio standards or purchase obligations, as implemented in India. Alternatively, the government could hold separate auctions to source bioenergy from agricultural residues. Benefits, such as rural income creation, nutrient management, effluent treatment, a circular economy, improved disease control, fewer power imports and energy security, are hard to monetise but might still be considered. Many countries have succeeded with feed-in tariffs for renewable energy. The tariffs reflect the actual costs of generating electricity from a specific source or pathway. They decline as costs decline. From an administrative point of view, feed-in tariffs are a simple mechanism that allow even smaller producers to participate in the market and increase their annual revenue. Yet another possibility is carbon taxes, as applied in Colombia, which creates an advantage for low-carbon electricity made from bioenergy and other sources and would increase the cost of electricity produced from fossil fuels.

Fair and transparent grid connection rules must complement a bio-electricity mandate so project developers can anticipate the costs and delays linked to related studies and procedures. At the same time, academics and regulators could support and direct farmers to adopt best management practices for maintaining soil fertility. A circular economy concept returns ash, digestate or carbon to the field, leaving enough residue to maintain soil carbon levels.

### RECOMMENDATION 1

—

**Implement policies that foster markets for electricity made from agricultural residues. Auctions can be designed to recognise the added benefits of bioenergy, or alternative policies such as feed-in tariffs or renewable portfolio standards can be considered.**

**Using existing infrastructure:** The sugarcane and palm oil industries are already producing bioenergy from residue created within their supply chains. Feeding additional agricultural residue, possibly from off-farm sources, into these production facilities would increase their output or extend the operation year-round with little or no investment. The industry can also expand the range of bioenergy products by using additional residue and adding new technologies, such as converting biogas to biomethane or hydrogen, or even producing second-generation liquid biofuels or biomethane.

## RECOMMENDATION 2

—

**Increase energy production in the sugarcane and palm oil industries using third-party residues. Consider additional bioenergy production, such as biomethane from currently unused residue streams, possibly through the adoption of new technologies.**

**Increase residue harvesting:** Farmers may not want to sell their field residue due to concerns that removing nutrients will deplete soil fertility. Universities need to be engaged in long-term research programmes to examine the use of digestate from biogas production or the integration of biochar into fields, gauging the resulting need for fertiliser and how this affects soil quality and nutrients in the long run. This research will help inform and protect farmers who want to create extra revenue from residue sales. It may lead to increased residue removal rates above the currently accepted 50% limit where a circular economy approach optimises agricultural practices while creating new sources of income.

## RECOMMENDATION 3

—

**Undertake long-term studies to determine the impact of increased field residue removal on nutrient balances when digestate or biochar is used to close the nutrient cycle. Develop crop-specific best practices and recommendations.**

**Adequate technologies:** The workshop participants identified technological readiness as a barrier to bioenergy development. One example is the need for low-cost digesters beyond small-scale family digesters. Imported technologies are frequently costly, using stainless steel vessels and cogeneration concepts. Using lower-cost materials and designs geared towards electricity production or biomethane for transport would better fit large livestock farms and the palm oil industry.

Technologies need to be adapted to local needs and situations, but it is not necessary to reinvent the wheel. Small-scale gasifiers currently used in rural India or Cambodia could be used in cluster countries to produce electricity at a small scale below 1 megawatt. These gasifiers can handle rice straw or plantation waste as fuel. The resulting biochar can be used in fields to improve soil quality, increase yields and reduce the need for artificial fertiliser. Small industrial facilities could use these plants to produce electricity for direct use (no grid connection) or supplement diesel electricity in remote or off-grid communities.

## RECOMMENDATION 4

—

**Redesign or develop bioenergy technology adapted to local resources, capacities and feedstock, with a focus on lowering capital costs. Adopt other technologies, such as small-scale gasifiers, to better utilise agricultural residue for local electricity production and improve soil quality using the resulting char residue.**

**Subsidies:** Another concern identified by workshop participants is fossil fuel subsidies. Governments allocate a large portion of their budgets to subsidise imported fossil fuels bought at global market rates, primarily to safeguard local industries and assist low-income populations.

Additionally, some cluster countries import biofuels to meet their national targets without implementing protective tariffs for domestic production. It is imperative to create a level playing field between local bioenergy, fossil fuels and imported biofuels to promote bioenergy. Domestic bioenergy can potentially reduce fossil fuel and biofuel imports, alleviating the financial burden created by the current system. Phasing out fossil fuel subsidies will give biofuel a better chance to compete, improve trade balances and reduce government debt.

### RECOMMENDATION 5

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**Create a level playing field for bioenergy by phasing out fossil fuel subsidies. Provide equivalent support to bioenergy as to fossil fuels and consider protecting local producers against subsidised biofuel imports.**

**Project development:** Bioenergy projects tend to be complex and challenging to organise, involving more stakeholders than solar or wind energy projects. They need resource assessments and collaboration with multiple stakeholders to secure enough feedstock, sometimes developing novel and unproven supply chain concepts and can involve technologies unfamiliar to banks, investors or engineers.

Deploying bioenergy facilities requires expertise that often still needs to be developed. Specialised development companies that can replicate their approach with multiple projects over time can acquire this expertise. Ideally, such development companies should be social benefit companies focused on optimising the local impacts of new projects. Agricultural associations or co-ops could spearhead this development, ensuring that everyone involved, including local farmers, benefits from the project. Bioenergy projects often need a "critical mass" to be viable, requiring many smallholder farms to co-operate.

Finally, governments and development banks can de-risk investment through loan guarantees, public-private partnerships and direct project funding. Investors often remain cautious if and when they see the project risks are too high for them to engage.

### RECOMMENDATION 6

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**Farmers and their associations can establish development companies to build and replicate bioenergy projects. They can form co-operatives to ensure a sufficient feedstock supply year-round. Government support for the bioenergy sector should include loan guarantees and measures to de-risk projects and attract private investment.**

**General:** Several recommendations would apply to the entire agricultural sector, regardless of geographical region or circumstances. These elements are frequently "no-regret" measures that help establish the bioenergy industry on a sustainable footing and create a culture of using agricultural waste. Some of these measures are discussed in Chapter 4 and include:

- Developing a bioenergy strategy, as pointed out at the beginning of this chapter. The design should be based on national priorities and address specific barriers and target markets for each country.
- Updating and improving agricultural residue assessments and generate better statistical data and mapping to help identify opportunities for project development.
- Providing public funding for pilot and demonstration projects.
- Offering continued support for small, family-size digesters that reduce demand for unsustainable cooking fuel and manage animal waste.
- Creating regulations specific to agricultural digestate from biogas production, biochar and ash residue to facilitate their use as organic fertilisers and soil improvers rather than restricting their use to urban wastewater sludge (biosolids).
- Considering local solid biofuel production, such as the briquetting of low-ash residue from plantation waste and nut shells, to replace firewood currently procured from forests. Current approaches have mainly focused on promoting propane gas as a substitute but low-ash biofuel can also improve air quality and reduce pressure on forests. An exciting approach to consider is the production of high-quality biochar briquettes as a cooking fuel.
- Identifying and implementing best practices around harvesting, transport, storage and biomass residue use to reduce health hazards and maximise economic and social benefits.
- Pursuing international co-operation, including South-South co-operation between sub-Saharan Africa, Southeast Asia and South America, to learn from success stories and disseminate knowledge around bioenergy development.
- Encouraging target-setting and government leadership and education to reinforce the bioenergy opportunity and acknowledge its benefits.
- Developing campaigns and disseminating strategies to inform agricultural sector participants about available incentives, opportunities and benefits of bioenergy production, as well as available support programmes and financing tools to promote project development.
- Capacity-building and training for technical personnel to plan, build, operate and repair bioenergy equipment.

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