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SUSTAINABLE DEVELOPMENT GOALS

UNLOCKING THE BIOETHANOL ECONOMY

A PATHWAY TO INCLUSIVE AND SUSTAINABLE INDUSTRIAL DEVELOPMENT IN DEVELOPING COUNTRIES

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Unlocking the bioethanol economy

A pathway to inclusive and sustainable industrial development in developing countries

This publication is based on a discussion paper entitled '*Establishing Ethanol Industries in Developing Countries – Opportunities and Challenges to achieve inclusive and sustainable industrial development*', produced for the Expert Group Meeting '*Clean Cooking: Potential for bioethanol Industries in high impact Countries*' which took place in June 2021.

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Preface: Why bioethanol?

Bioethanol is a renewable energy source that has a crucial role to play in boosting economic and environmental sustainability in developing countries. As this publication explains, the ethanol economy has the potential to relieve rural poverty, increase agricultural productivity, boost local and national economic growth, generate employment, save lives through sustainable clean cooking for households, promote equality, and bring about meaningful reductions in greenhouse gas emissions.

As a clean-burning fuel, ethanol can replace fossil fuels in whole or in part for use in vehicles and in household cooking. It is a biofuel that is manufactured from crops including sugarcane, corn (maize), and cassava.

Developing a bioethanol industry and value chain, by leveraging a vibrant agriculture sector and agro-industries in developing, least developed, and small island countries has the potential to bring about transformational changes. This can result in greater self reliance and energy security, as well as economic empowerment, and contribute to SDGs 7, 9, and 13, as well as help countries to meet NDCs.

This publication provides a detailed overview of the potential, challenges, and benefits of implementing a bioethanol industry and markets. It features research, case studies, and lessons learned in order to offer recommendations for unlocking the bioethanol economy to help countries become energy independent, raise standards of living, and make their contributions to climate action.

List of Abbreviations

bn – billion

$CO_{2\text{-}eq}$ – carbon dioxide equivalent

dLUC – direct land use change

E5 – blend of 10% ethanol with gasoline

E10 – blend of 10% ethanol with gasoline

E20 – blend of 20% ethanol with gasoline

E85 – blend of 85% ethanol with gasoline

E100 – hydrous ethanol (approx. 96% ethanol, 4-5% water)

EMD – ethanol micro-distillery

FAO – Food and Agriculture Organization of the United Nations

FFV – flexible fuel (flex-fuel) vehicle

forex – foreign exchange

GDP – gross domestic product

GHG – greenhouse gas

ha – hectares

IEA – International Energy Agency

iLUC – indirect land use change

IRENA – International Renewable Energy Agency

l – liters

LCA – life-cycle assessment

LPG – liquefied petroleum gas

LUC – land use change

m – million

NDCs – Nationally Determined Contributions under the Paris Agreement

PM – particulate matter

SDGs – Sustainable Development Goals

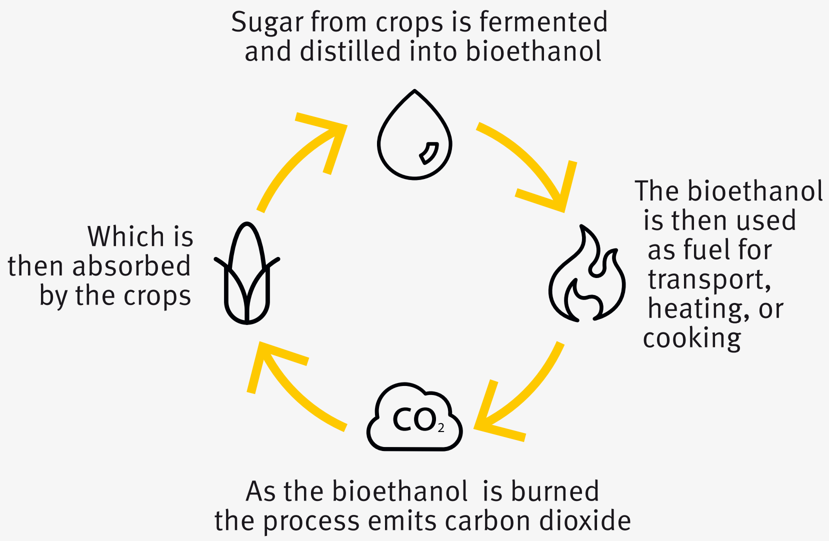
SMEs – small and medium-sized enterprises

UNIDO – United Nations Industrial Development Organization

WHO – World Health Organization

Introduction and background

Bioethanol – a green alternative for transportation and clean cooking



Bioethanol – or simply 'ethanol' – is a renewable energy source made by fermenting and distilling the sugar and starch components of organic matter – mainly sugarcane, potatoes, and crops like maize. Depending on the agricultural structures of the producing country, it might also be made from cassava flour, milk, grain, rice, bananas, grapes, or even dates.

Today, ethanol has many uses: it makes transportation more sustainable in ethanol-gasoline fuel blends for vehicles; it is a clean alternative to traditional cooking techniques, reducing indoor pollution; and it has applications in the medical, cosmetic, and food industries.

A sustainable, clean-burning fuel

When it is burned, ethanol produces heat (to cook food or drive an internal combustion engine in a car), as well as water vapor and carbon dioxide (CO_2). The emitted CO_2 can be reabsorbed by plants, which use it in photosynthesis in order to grow. This makes bioethanol a carbon-neutral fuel, as the crops cultivated to produce more ethanol recycle the carbon emissions.

Economic, social, and environmental benefits

When used as a clean cooking fuel, ethanol eliminates the health issues associated with traditional biomass stoves, which range from pneumonia risk in children, to higher risk of stroke and heart disease in adults. It also relieves women of the many hours spent obtaining wood as fuel, and helps to prevent deforestation (see more details of these benefits below, and in Chapter 2: Positive socioeconomic benefits).

Use of ethanol as a blending component in fossil gasoline enhances the combustion properties of the gasoline, and reduces life-cycle greenhouse gas emissions from the transport sector. In cooperation with the agricultural sector, domestic bioethanol production can be stimulated to create greater energy autonomy, generate forex savings through reduced petroleum imports, and strengthen the national economy (and the agricultural sector in particular).

Background: global bioethanol production and use

Bioethanol is already a widely produced commodity, with well-established industries in Brazil, Canada, China, the European Union, India, Thailand, and the USA. Global production climbed up significantly between 2000 and 2015 and is still growing, driven by an increasing demand for ethanol as a blending component in the transport sector. While the current market for ethanol as a transport fuel is much larger than the market for ethanol for cooking purposes, the market share of ethanol as a cooking fuel is also growing and has high potential for the future, in Asia and Sub-Saharan Africa in particular.

Today's ethanol industry began in the 1970s, when petroleum-based fuel became expensive and environmental concerns arose. Due to its ease of transformation into alcohol, corn (maize) became the dominant feedstock for ethanol production, followed by sugarcane. Farmers began producing bioethanol to add value to their corn. Demand for ethanol increased dramatically and is still growing.

Global production of ethanol amounted to 98.4 billion liters in 2018. More than half of this amount was produced in the USA in its approximately 200 ethanol production plants (primarily maize). The second biggest player was Brazil, producing about one quarter of global ethanol in close to 400 ethanol production plants (primarily sugarcane). Jointly, Brazil and the USA account for 85% of global ethanol production. About 5% of ethanol was produced in the EU, which has around 50 ethanol production plants (primarily wheat, sugar beet, and maize). Globally, about 46% of ethanol was produced from maize, followed by 38% from sugarcane and 5% from wheat. Figure 1 shows global production of biofuels since 2000, and the major contribution made by ethanol.

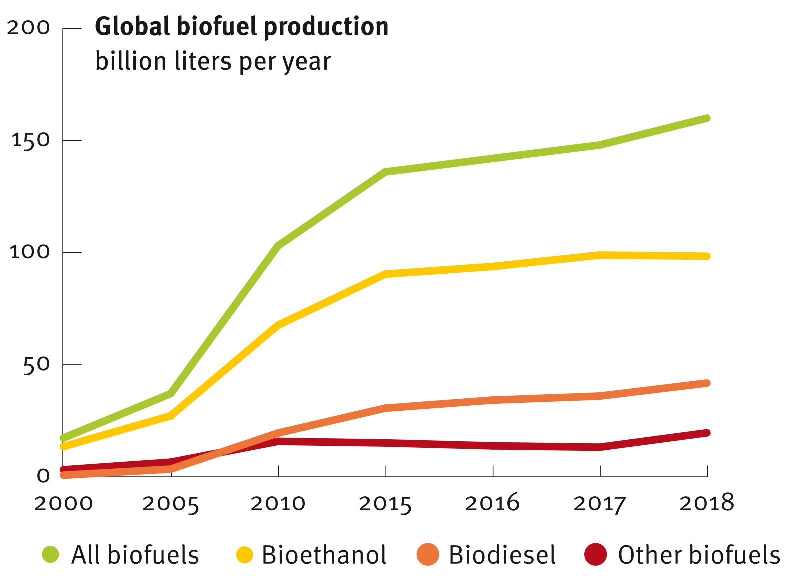
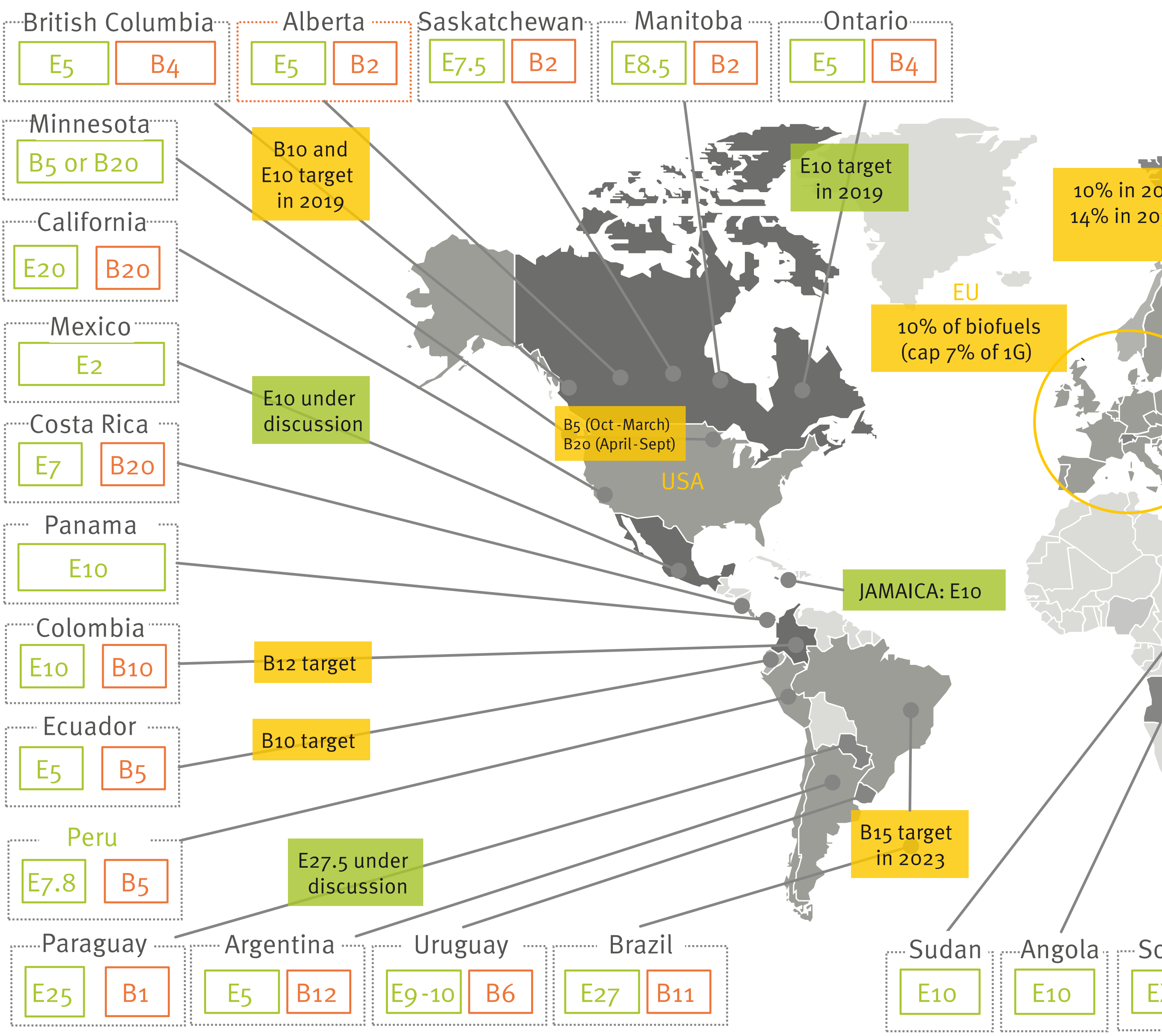


Figure 1: Global production of biofuels (World Bioenergy Association, 2020)

Figure 2: Global biofuel mandates in 2019/2020 [1]

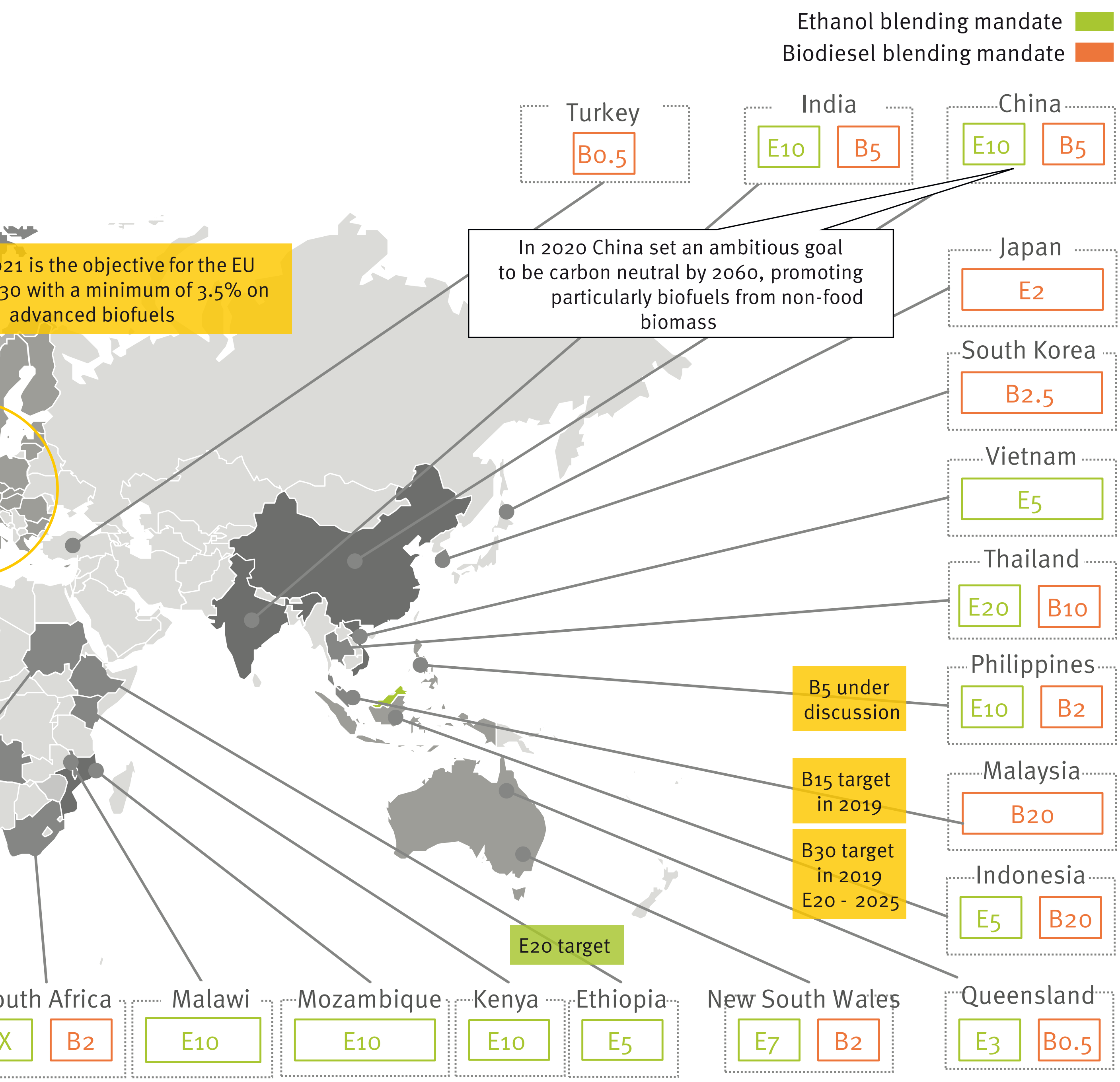


Source: Greenea analysis, government websites Note: It is notable that most oil-producing countries - particularly OPEC members - have not im

ETHANOL AS A TRANSPORT FUEL

The majority of biofuel production is policy-driven, mainly through regulations that make ethanol blending in gasoline at low levels mandatory, nationally or regionally. Such biofuel blending mandates are the most widely adopted policy for increasing the use of renewable fuels in the transport sector. They are prevalent across all continents and in place in more than 70 countries (see Figure 2), though they are not always enforced (REN21, 2020).

1. http://www.greenea.com/wp-content/uploads/2021/01/Greenea-Horizon-2030-Which-investments-will-see-the-light-in-the-biofuel-industry-1.pdf



plemented a biofuel mandate.

Fiscal incentives, for example lower taxes on fuels and certain vehicles, play an important role in increasing the competitiveness of biofuels as compared to fossil fuels. Market-specific challenges have to be considered, such as the investment climate, and ensuring the sustainability of ethanol production. Careful planning of ethanol implementation, with technical assistance if required, prevents adverse sustainability impacts such as indirect land use change. See Chapter 2: Positive socioeconomic impacts for further discussion of these issues, as well as Chapter 6: Conclusions and recommendations.

Production and consumption of ethanol in Africa is still at a low level, but it is growing. In Kenya, the State Oil Corporation has signed an agreement with the government to build a new ethanol plant to meet biofuel blending mandates. In Zambia, Sunbird Bioenergy Africa[2] has launched a program to develop a sustainable cassava supply chain for ethanol production in order to provide 20% (100 million liters) of the country's gasoline requirements (REN21, 2020). Additionally, Malawi is attempting to achieve a 20% fuel blending target.

As of 2015, the global share of renewable energy in the transport sector amounted to 4%. The International Renewable Energy Agency (IRENA) has predicted an increase to 22% by 2050 (see Figure 3). Because growth in vehicle numbers and use over this period will be greatest in developing countries, biofuel production and marketing needs to focus on these countries especially.

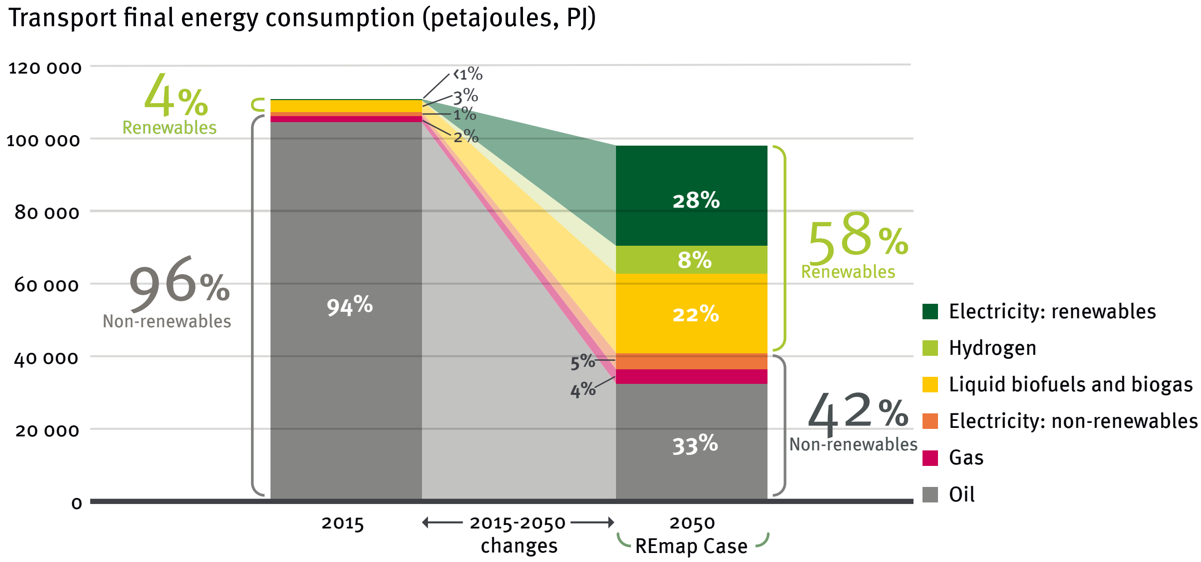


Figure 3: Transforming energy demand in the transport sector (IRENA, 2018)

BIOETHANOL AS A COOKING FUEL

Around 60% of the world population, equaling more than 4.35 billion people, has access to clean cooking fuels and technologies (principally natural gas, liquefied petroleum gas [LPG], and electricity), with the highest shares being in North America, Europe and Australia (ESMAP, 2018). Although millions of people have gained access to clean cooking facilities in recent years (including over 450 million in India and China since 2010), progress on the switch from traditional to clean fuels continues to be uneven across regions, and is often outpaced by population growth. In 2018, 63.1% of people without access to clean cooking energy lived in developing Asia, and 34.1% lived in Sub-Saharan Africa (REN21, 2020).

According to the standards set by the World Health Organization (WHO) Guidelines for indoor air quality: household fuel combustion (WHO, 2014), the currently available options that are clean at point-of-use include electricity, gas (natural gas, biogas, and LPG), ethanol, solar, and the highest-performing biomass stoves. In parallel, the guidelines discourage household use of solid fuels, such as wood, charcoal, and unprocessed coal, due to significant health risks from these fuels. Despite this, the latest data (2019) show that 2.6 billion people worldwide still do not have access to clean cooking (IRENA, 2021).

2 https://www.sunbirdbioenergy.com/projects/zambia-kawambwa/

Though ethanol, a clean and sustainably-produced liquid fuel, is still a niche fuel for clean cooking in developing countries, its market share is growing and its potential for the future is substantial (for details see Chapter 3: Bioethanol markets in developing countries). Ethanol is among the very cleanest household fuels when burned in proper cooking appliances (Puzzolo & Pope, 2017).

Drivers of ethanol production

The global drivers of ethanol production and use have varied over the years. Initially, due to its higher octane number, ethanol substituted tetraethyl lead in gasoline. Then, following the oil crisis that began in 1973, ethanol began to substitute constrained gasoline supplies. More recently, environmental concerns and reducing indoor air pollution have become major drivers, as well as limiting climate change impacts through greenhouse gas reductions (Trindade et al., 2019). At a national level, the economic benefits of increased energy autonomy can also play an important role.

A range of benefits for developing countries

Establishing bioethanol value chains in developing countries opens up a range of environmental and socioeconomic benefits at the global, national, community, and individual levels.

Environmental

— Ethanol production and consumption cuts greenhouse gas emissions, helps to prevent deforestation, and reduces indoor and outdoor pollution.

Economic

— Building and linking up the ethanol industry mobilizes investment in the agricultural sector, reduces dependence on fossil fuel imports, and drives industrial development and GDP growth.

Social

— Implementing the ethanol economy creates jobs, boosts rural incomes and energy access, and has positive health impacts when ethanol is used as a clean cooking fuel, as well as enabling women to spend time on education, work, or leisure instead of gathering wood or other biomass for traditional stoves.

Emerging ethanol industries can be integrated with existing agricultural sectors, such as sugarcane or cassava production, and aim to exploit synergies between the energy and agricultural sector to boost productivity. Ethanol feedstock cultivation does not need to compete with food cultivation, and clean cooking plays an essential part in sustainable access to food.

Successful establishment of a new bioethanol industry requires government support, private sector investment, and the creation of functioning markets for ethanol as a transport and/ or a clean cooking fuel. A stable and consistent energy and biofuel policy framework needs to be implemented, serving national economic and development priorities. Government initiatives can ensure demand for ethanol through mandatory blending targets and/or programs to roll out ethanol cooking stoves, and establish an environment that enables ethanol to compete with other, less desirable fuels. Policies to encourage the (local) private sector to take up feedstock cultivation, ethanol production and distribution can be introduced. Finally, appropriate access to financing for the private sector needs to be assured in order to facilitate the necessary investment.

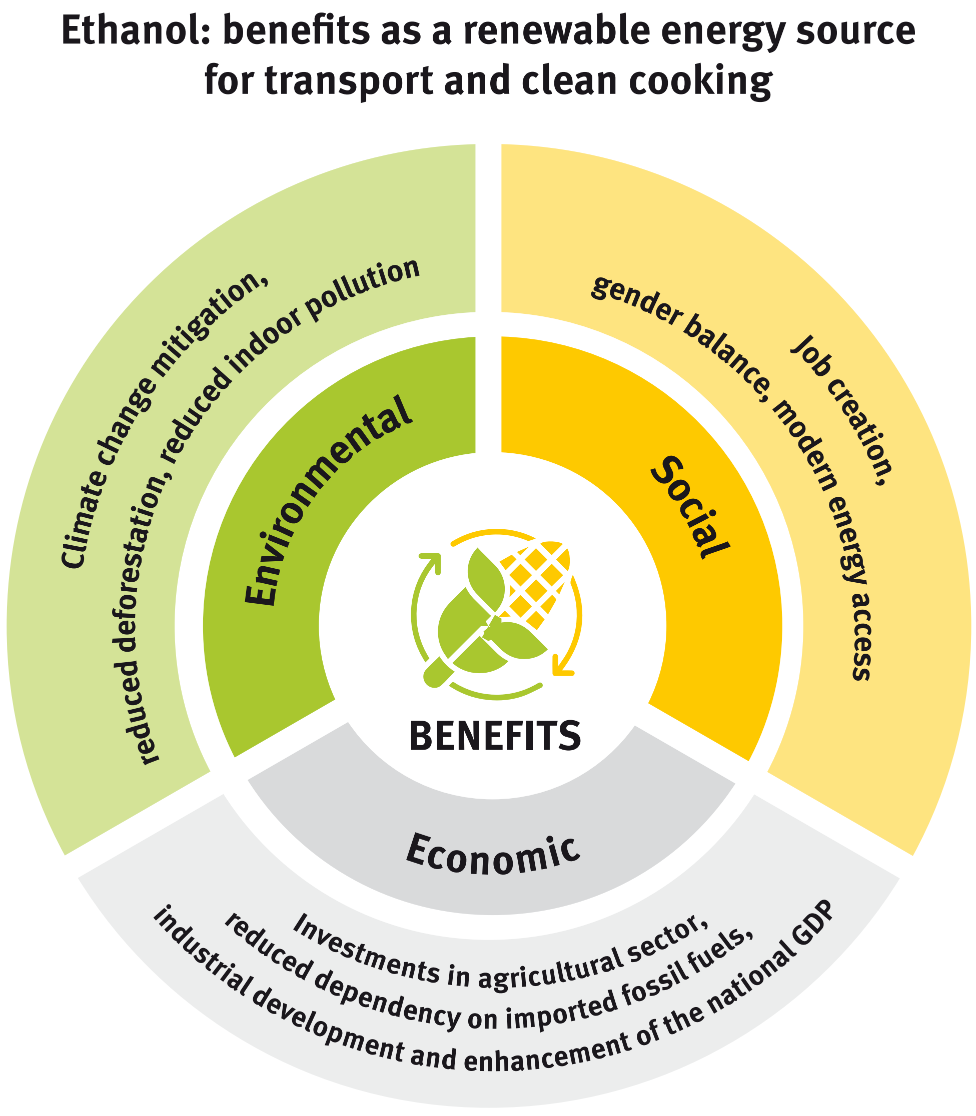


Figure 4: Benefits of bioethanol as a renewable energy source for transport and clean cooking

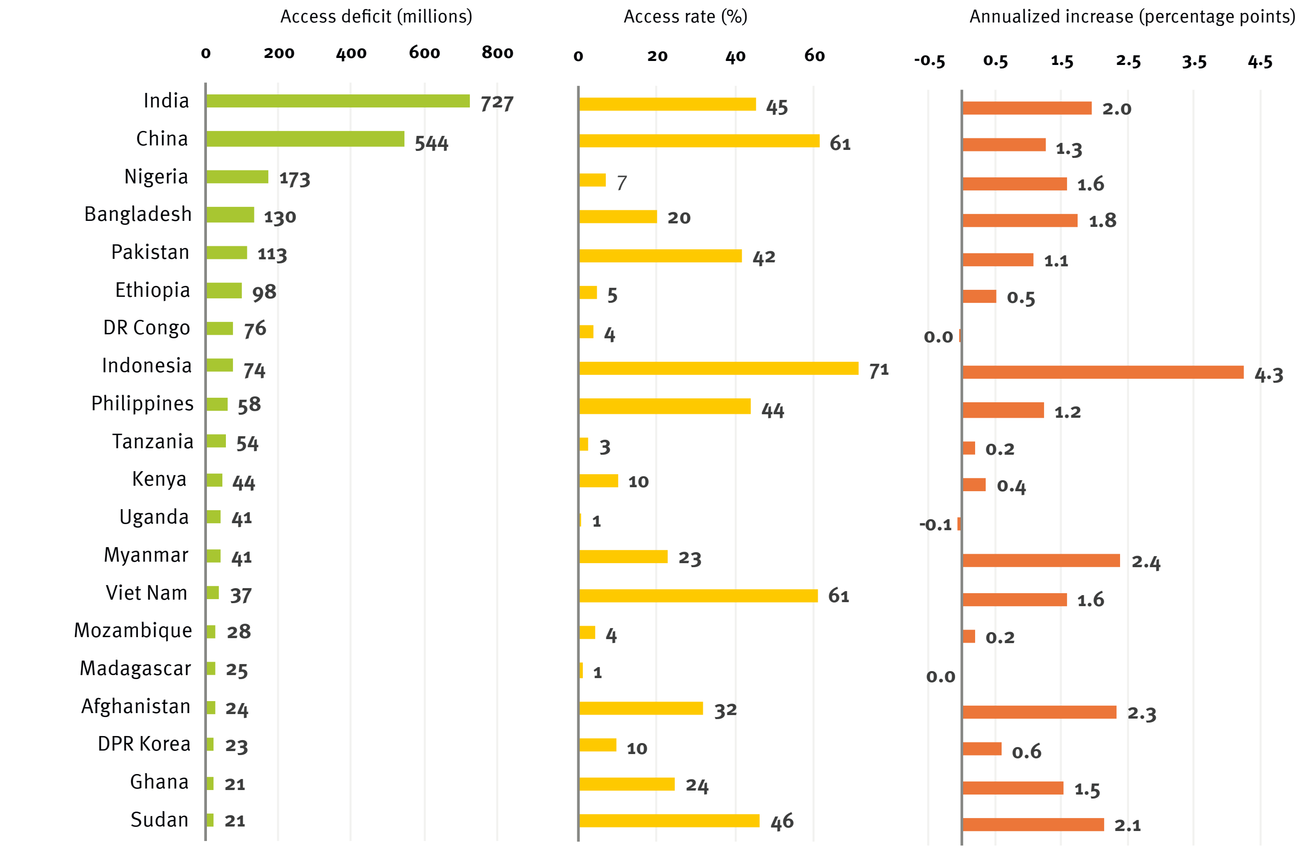


Figure 5: The 20 countries with the largest populations lacking access to clean fuels and technologies (World Health Organization)

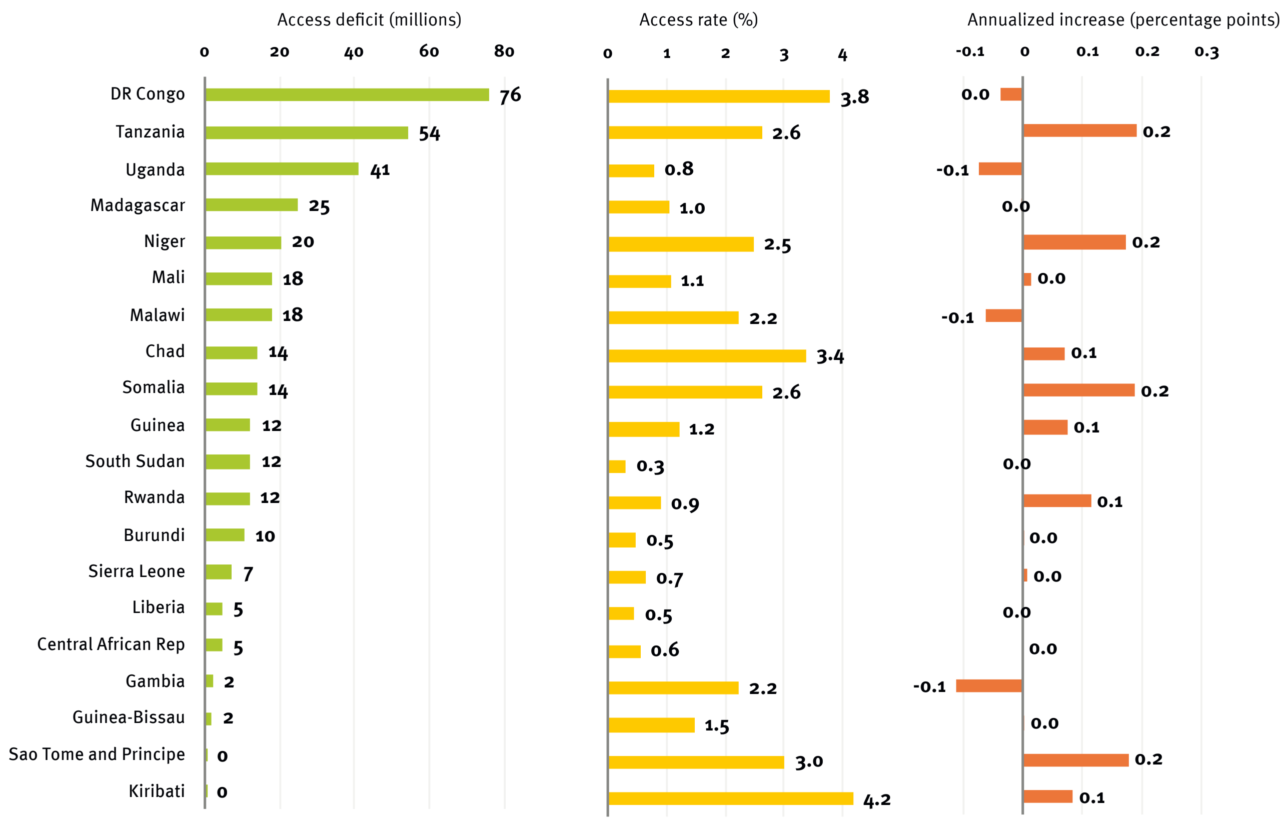


Figure 6: The 20 countries with lowest percentage of the population with access to clean fuels and technologies (World Health Organization)

Bioethanol in Brazil

The development of an ethanol industry in Brazil in response to the oil crisis of the late 1970s led to a number of remarkable environmental and socioeconomic benefits. Since then, Brazil has adapted its national ethanol programs in response to changes in economic and environmental priorities. Today, Brazil has a highly developed ethanol industry and market for ethanol fuel and vehicles. Most vehicles on Brazil's roads can run on any mix of ethanol and gasoline, and 100% hydrous ethanol is available at every filling station.

Brazil produced 36.0 billion liters of ethanol in 2019, with 33.8 billion liters consumed in the transport sector (EPE, 2020b). In 2010 the United States Environmental Protection Agency (EPA) issued a statement classifying sugarcane ethanol as an advanced biofuel, since its use as a fuel results in a 61% reduction in CO_2 emissions compared to gasoline (EPA, 2010). This means that in Brazil, the use of fuel ethanol instead of gasoline avoided the emission of about 53 million tons of CO_2-eq in 2019 alone (EPE, 2020a). Total greenhouse emissions in Brazil's transport sector amounted to about 190 million tons of CO_2-eq in 2019[3].

Brazil is net exporter of ethanol, resulting in a dependency on petroleum imports that is below zero (EPE, 2020b). The GDP value of Brazil's sugarcane energy sector amounted to 43 billion USD in 2018[4], contributing 2.4% of national GDP[5]. In 2019/2020, investment in sugarcane production amounted to about 10 billion USD (EPE, 2020c). Approximately 2.3 million jobs could be attributed to sugarcane, sugar and ethanol production, directly or indirectly, in 2019/2020 (Costa A., 2021). As 65% of sugarcane production was designated for ethanol in 2019, the number of jobs linked to ethanol production (including agriculture, industry and administration) can be estimated at 1.5 million[6].

Significantly, domestically sourced fuel ethanol has dramatically reduced Brazil's dependence on imported oil. The country's dependence on petroleum imports for energy consumption dropped from around 80% in 1980, to below zero in 2010 when accounting for ethanol exports (see Figure 5). Besides reducing vulnerability to oil price volatility, producing and using ethanol also results in foreign exchange savings as petroleum imports are reduced. The ethanol economy also boosts several sectors linked to the industry, such as capital goods for mill construction, investments in development and innovation, and investment in the entire agro-industrial market chain for ethanol production.

3. Estimation from EPE, based on (EPE, 2020b) and (IPCC, 2006)
4. https://observatoriodacana.com.br/
5. https://www.ibge.gov.br/
6. The number of jobs in the sugarcane sector in Brazil has reduced in recent years due to the replacement of manual harvesting by mechanisation. Estimates vary, e.g. a recent study by IRENA estimates that the liquid biofuels sector in Brazil accounts for about 0.85 million jobs in 2019 (IRENA, 2020)

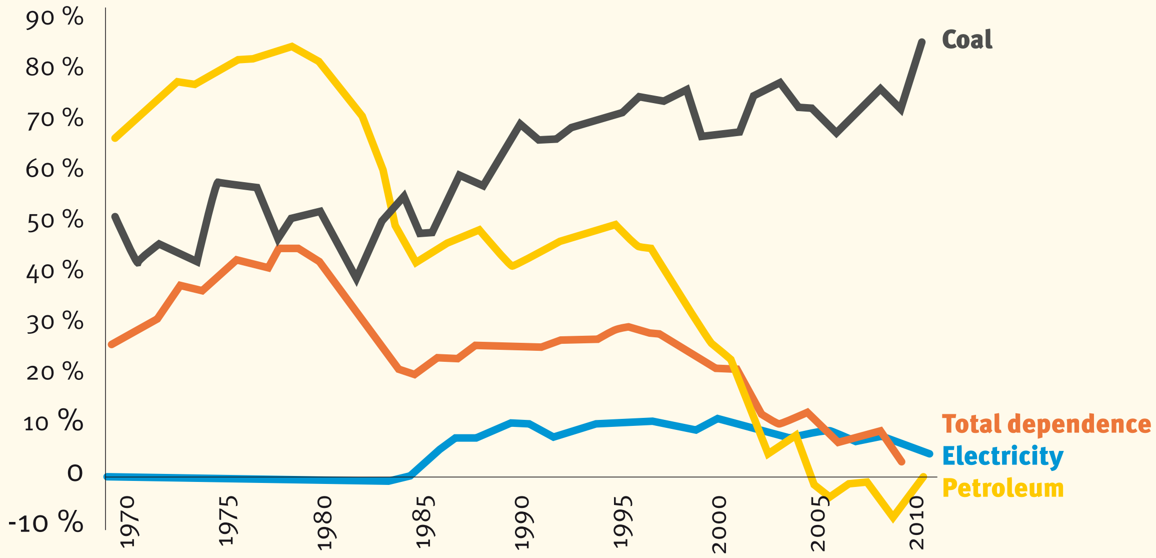


Figure 7: Brazilian dependence on energy imports (EPE, 2012)

Table 1: Socioeconomic benefits of fuel ethanol in Brazil

Socio-economic benefits of fuel ethanol in Brazil	
Ethanol fuel production (2019)	36.0 billion liters
Ethanol fuel consumption (2019)	33.8 billion liters
GHG emissions avoided (2019) *	~ 53 million tons of CO2-eq
Total GHG emissions in transport sector (2019) **	~ 190 million tons of CO2-eq
Dependency on petroleum imports (2019)	Below zero (Brazil is a net exporter of ethanol)
GDP value of sugarcane energy sector (2018)	43 billion US$
Contribution to national GDP (2018)	2.4%
Investment in sugarcane production (2019/2020)	~ 10 billion US$
Jobs attributed to sugarcane, sugar and ethanol production (2019/2020)	2.3 million (direct and indirect impact)

*Based on life-cycle assessment

**Based on combustion only

Framework for developing a bioethanol industry

Successfully establishing a new industrial sector depends on organization and planning in three crucial areas:

Establishing an enabling policy and regulatory environment	Access to financing and attraction of the private sector	Successful market development
Clear development priorities	Stable and guaranteed access to financing for the private sector to facilitate investments	Establishing a stable demand for ethanol
Protection of national bioethanol industry	Tailor-made financing schemes to support large-scale industries and local SMEs	Establishing a supportive environment to compete with other energy sources
Supportive agricultural, environmental, and innovation policies	Social financing schemes ensuring positive social impacts for household beneficiaries	Synergies between ethanol markets for transport and cooking

POLICY AND REGULATORY ENVIRONMENT

— A consistent energy and biofuel policy framework needs to be implemented, based on the defined policy drivers (e.g. health, deforestation, greenhouse gas emissions, import dependence, job creation).
— Policy drivers should be aligned with and reflected in clear development priorities, such as:
  — Creating a domestic market for ethanol blending in gasoline
  — Ethanol use as a clean cooking fuel
  — Production of ethanol for export markets
— Governments may opt to protect national ethanol industry development through import duties.
— A stable policy framework addressing pricing, tax, and tariffs as well as potential blending mandates is one way to provide long-term security for investment.
— Tax exemptions or other support schemes are often required to ensure that ethanol can compete with fossil-based and/or traditional alternatives, such as gasoline in the transport sector and charcoal or LPG for cooking fuels.
— Such policies can also include a national program to provide financial support to initiatives that boost the agricultural and bioenergy sector. Policies addressing agricultural development need to consider land use patterns, food security, and land use rights.
— Environmental policies must also be in place to avoid potential negative impacts.
— Supportive policies are also needed in the areas of research and innovation, trade, and industrial development.

Establishment of an ethanol industry should be based on a thorough biofuel-crop feasibility analysis, including a mapping and zoning initiative to identify land for production of biofuel crops and food crops. **Mapping and zoning provides information on soil and climatic conditions, as well as available water resources, and identifies priority areas for environmental protection.**

Careful country-level, regional and local analysis and planning of sustainable land use is an important prerequisite for biodiversity conservation, appropriate consideration of land use rights and the avoidance of any potential food-fuel conflict. Important lessons learnt on agro-ecological zoning may be transferred from experiences gained in Brazil (Strapasson et al., 2012) and Mozambique (Wilkinson, 2014).

Policies addressing the electricity sector are required, especially when ethanol will be produced from sugarcane, to facilitate the feed-in of surplus electricity generated from by-products (bagasse) to the grid. Such policies include independent power producer (IPP) schemes, electricity (feed-in) tariff levels, grid access and grid expansion, or construction of mini-grids to expand energy access in off-grid localities.

PRIVATE SECTOR ENGAGEMENT AND ACCESS TO FINANCE

Encouraged and attracted by a supportive policy framework, the establishment of an ethanol sector will be driven and implemented by private sector organizations. Such organizations cover the whole value chain including feedstock production and supply, conversion technologies and production of ethanol, logistics and fuel supply, and consumer use of ethanol as a transport or clean cooking fuel.

To encourage sustainable feedstock production, training in best practice for agricultural management, access to credit, and research into traditional crop breeding and new varieties can be supported. In order to ensure opportunities for smallholders, outgrower schemes need to be included in feedstock supply chains alongside larger scale commercial farms. Contracting models for small farmers need to be set up to guarantee a fair share of the profits.

Investments in ethanol production facilities provide opportunities for well-established agricultural industries. Establishing an ethanol industry can provide a basis for encouraging domestic entrepreneurship as well as international cooperation via cooperative research, technical cooperation, and joint ownership and licenses. Defined local content requirements (LCR) can facilitate the creation of a local manufacturing industry and contribute to job creation.

Local SMEs need to be encouraged to contribute to all aspects of the ethanol value chain. This includes successful implementation of appropriate, stable and guaranteed access to financing for the private sector in order to facilitate the necessary investment:

- Tailor-made financing schemes are required to support both large-scale operations and local SMEs that will engage in the ethanol production and distribution value chain.
- Social financing schemes also have a role to play, ensuring positive social impacts for households switching to clean ethanol cooking fuel.
- Such financing solutions and partnerships may include:
  - Results-based financing models
  - Credit guarantee schemes
  - Pay-as-you-go plans
  - Mobile payments
  - Microcredits for households

MARKET DEVELOPMENT

Based on the clearly identified policy drivers, government initiatives need to facilitate stable demand for ethanol in order to create robust domestic ethanol markets. Demand can be established through mandatory blending targets in gasoline, and by programs to roll out ethanol cooking stoves.

Governments should aim to establish an environment that enables ethanol to compete with other, less desirable transport and cooking fuels. This can be achieved by subsidizing ethanol prices at the pump, subsidizing ethanol cookstoves and/or removing existing subsidies for fossil-based fuels. Synergies between markets for ethanol as a transport and as a clean cooking fuel may also be exploited.

Successful ethanol market development in developing countries also calls for the establishment of regulatory bodies, and the creation of knowledge and capacity to monitor ethanol quality and standards according to national and international market requirements. This includes aspects of ethanol blending with gasoline, operating and dispatching bagasse-based electricity, and the distribution and logistics of ethanol fuel to consumers.

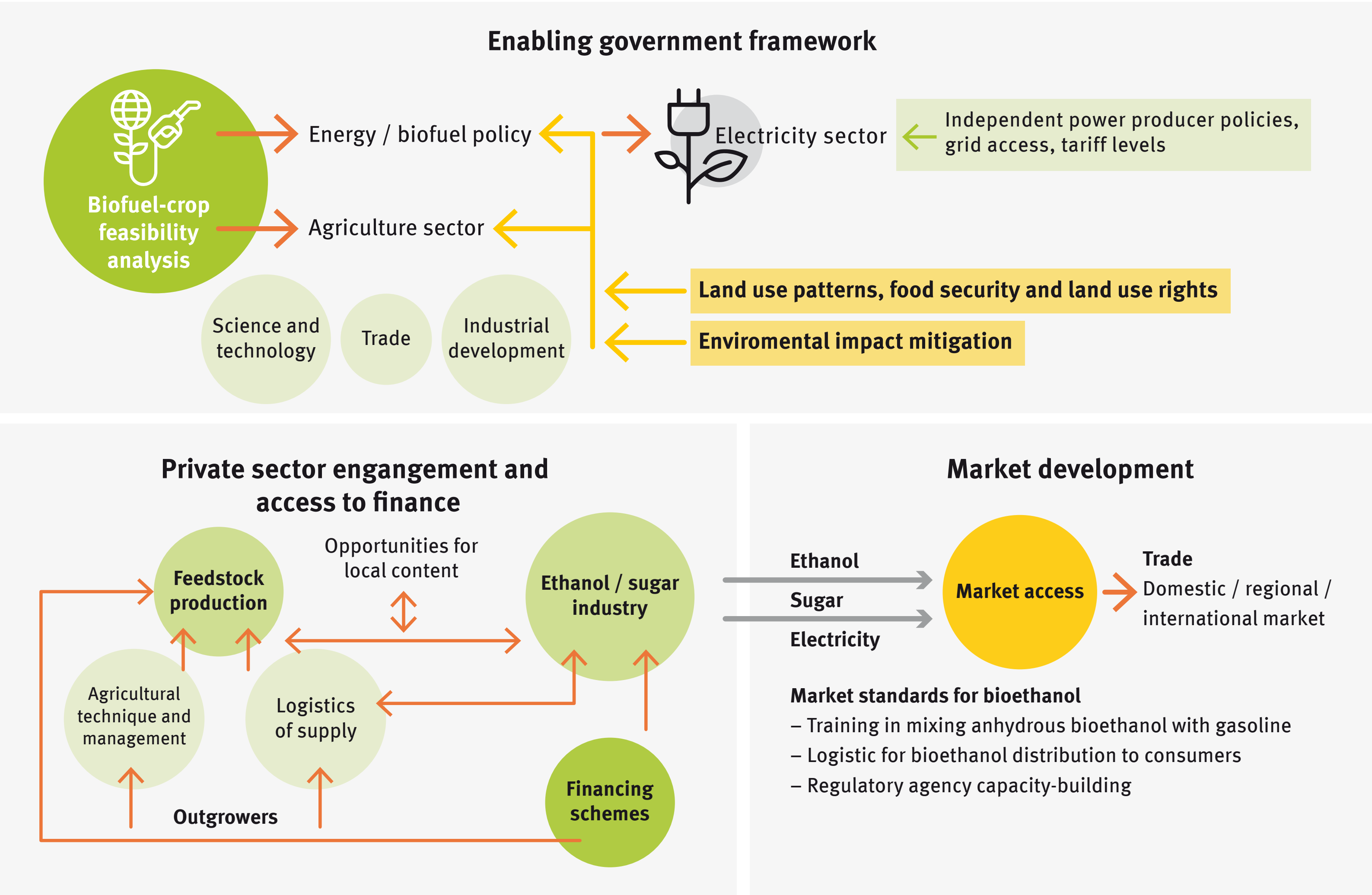


Figure 8: Enabling government framework for the bioethanol industry

For examples of how these measures have been applied in developing countries, see Chapter 4: Country case studies.

POSITIVE SOCIOECONOMIC IMPACTS

THIS CHAPTER highlights the wide range of positive impacts of establishing bioethanol industries and markets in developing countries, locally and globally, by outlining their contribution to a number of the United Nations' Sustainable Development Goals (SDGs, or Global Goals). There are major benefits in terms of reducing greenhouse gas emissions and other forms of pollution, as well as added value along the ethanol supply chain, and greater productivity from combining food and biofuel farming.

THE GLOBAL GOALS

The Sustainable Development Goals (SDGs) were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity.

The 17 SDGs are integrated—they recognize that action in one area will affect outcomes in others, and that development must balance social, economic, and environmental sustainability.[1]

While the main driver of introducing an ethanol economy has often been the resulting greenhouse gas emission reductions in the transport sector, sustainable ethanol implementation brings a wide range of socioeconomic benefits to countries and communities. These include reductions in fossil energy imports; increased energy autonomy; employment and income creation in agriculture, industry and commerce; reduced deforestation; and health and education benefits. This means the ethanol economy can contribute to a number of SDGs.

1. https://www.globalgoals.org/

SDG1 – No poverty
The ethanol industry can help reduce poverty, giving smallholders an opportunity to increase and diversify their crop production and generate additional income.

SDG2 – Zero hunger
Investments in bioenergy can increase overall agricultural productivity and food availability.

SDG3 – Good health and wellbeing
Ethanol as a clean cooking fuel creates healthier living conditions for households in developing countries, eliminating indoor pollution from smoke and soot.

SDG5 – Gender equality
Using modern bioenergy instead of traditional biomass means less time is required to collect firewood etc. This enables women and children to use this time for work, education or leisure activities.

SDG7 – Affordable and clean energy
Ethanol is a renewable, biogenic fuel that can be produced locally and reduce the need for imported fossil fuels. Ethanol implementation can help to provide access to energy in energy-deprived areas.

SDG8 – Decent work and economic growth
Crop production for biofuels generates productive employment in agriculture. Growth is boosted in other sectors as investments are made in processing plants and distilleries, and in distribution.

SDG9 – Industry, innovation and infrastructure
Ethanol production introduces innovative farming practices and agricultural zoning research. A clear concept for supply chains, involving local stakeholders from an early planning stage, supports several intersecting industries.

SDG10 – Reduced inequalities
Bioenergy implementation offers job opportunities in rural areas and harnesses growth in the agricultural sector to broaden rural development.

SDG12 – Responsible consumption and production
Sustainable bioenergy production helps to prevent deforestatio. Careful planning conserves environmentally sensitive areas, making use of and rehabilitating abandoned, intensively used farmland, or moderately degraded land.

SDG13 – Climate action
Bioenergy supports resilience against climate change. Ethanol can replace fossil fuels and traditional biomass, reducing greenhouse gas emissions.

Integration of bioethanol as transport fuel

Bioethanol is green in comparison to petroleum fuels: for example, pure ethanol produced from sugarcane cuts greenhouse gas emissions by an average of up to 88% as compared to fossil gasoline. Even when blended with gasoline at low levels (5-10%, E5 or E10), ethanol results in emission reductions that are otherwise hard to achieve.

In 2015, 196 countries came together under the Paris Agreement to set the world on a course towards sustainable development, aiming to limit global warming to 1.5° Celsius above pre-industrial levels. Each country had to define and communicate their post-2020 climate actions, also called Nationally Determined Contributions (NDCs), to achieve these long-term goals. **Introducing domestic ethanol production and use can play a vital part in meeting these obligations.**

INDIRECT LAND USE CHANGE (ILUC)

Mapping and zoning have a key role to play when introducing biofuel feedstock cultivation, in order to model any effects of indirect land use change (iLUC), which can mitigate the climate benefits of biofuels. This happens when feedstock displaces previous agricultural production on arable or pasture land, and the previous activity moves elsewhere - possibly taking over unsuitable land. Such changes can also negatively affect biodiversity. Measures to prevent iLUC effects include boosting agricultural productivity, which increases yields.

Mapping and zoning involves analyzing current land use, soil types, water resources, and other factors to determine areas (zones) for different types of agricultural production and that need to be protected.

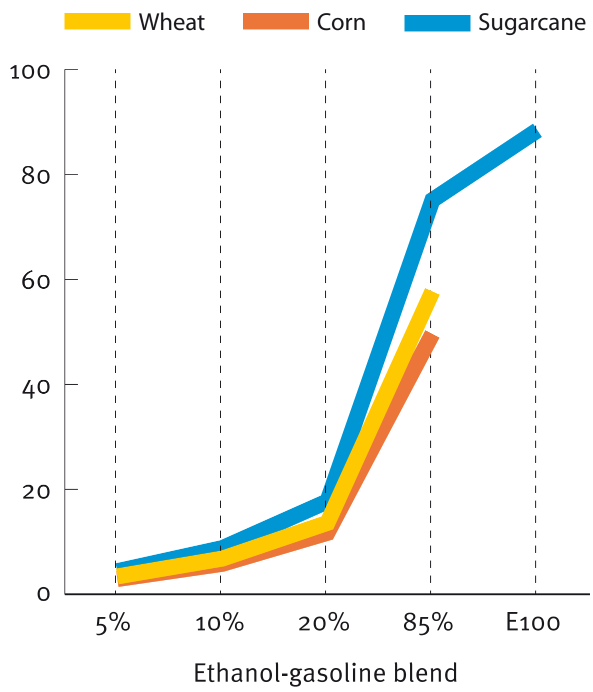
HELPING COUNTRIES MEET NATIONALLY DETERMINED CONTRIBUTIONS (NDCS)

Where ethanol is used to substitute gasoline or traditional cooking fuels, significant greenhouse gas (GHG) emission reductions can be achieved. GHG emissions are usually assessed using life cycle assessment (LCA) tools, covering the entire value chain from “well to wheel” – e.g. in the case of ethanol, from feedstock production, to transportation, conversion to ethanol, distribution, and finally consumption in internal combustion engines. While different LCA tools vary with respect to the data and method used, when underlying data and assumptions and allocation methods are harmonized, the tools do deliver similar results (Pereira, et al., 2019).

EMISSION REDUCTIONS FROM ETHANOL-GASOLINE BLENDS

Blending ethanol in petroleum gasoline leads to GHG emission reductions, since ethanol produces lower quantities of GHG over the entire life cycle. The more ethanol is blended, the lower the GHG emissions from the fuel. Figure 9 shows potential GHG emission savings when blending ethanol in different percentages (by volume) and from different feedstocks. These figures are guiding estimates; it should be noted that emissions can be greatly affected by external conditions such as ambient temperature, type of vehicle, and driving speed

Figure 9: Potential GHG emission savings through ethanol blending in gasoline



and only provide a rough estimation on potential GHG savings. So far, hydrous ethanol is only produced in Brazil and based on sugarcane.

Cooking with bioethanol: cleaner and greener

The use of clean-burning ethanol stoves to replace inefficient traditional cooking will significantly reduce indoor air pollution, which is a major health problem in developing countries, affecting mainly women and children.

The World Health Organization (WHO) summarized the global problem of indoor air pollution in 2021:[2]

— Around 2.6 billion people cook using polluting open fires or simple stoves fueled by kerosene, biomass (wood, animal dung and crop waste) or charcoal.
— Each year, close to 4 million people die prematurely from illnesses attributable to indoor air pollution from inefficient cooking practices using polluting stoves paired with solid fuels and kerosene.
— Indoor air pollution causes noncommunicable diseases including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer.
— Close to half of deaths due to pneumonia among children under five years of age are caused by particulate matter (soot) inhaled from indoor air pollution.

All of these problems are related to burning solid fuels and fossil fuels in inefficient stoves or fireplaces. Various studies on the health benefits of ethanol-fueled cookstoves been conducted, showing that cooking with ethanol is a cleaner and healthier alternative (Bailis et al., 2004; Diaz-Chavez et al., 2015).

2 https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

Figure 10 illustrates emissions of particulate matter from stoves, related to risk of childhood pneumonia. It shows that ethanol stoves are as clean as biogas or liquefied petroleum gas (LPG) stoves (USAID, 2017).

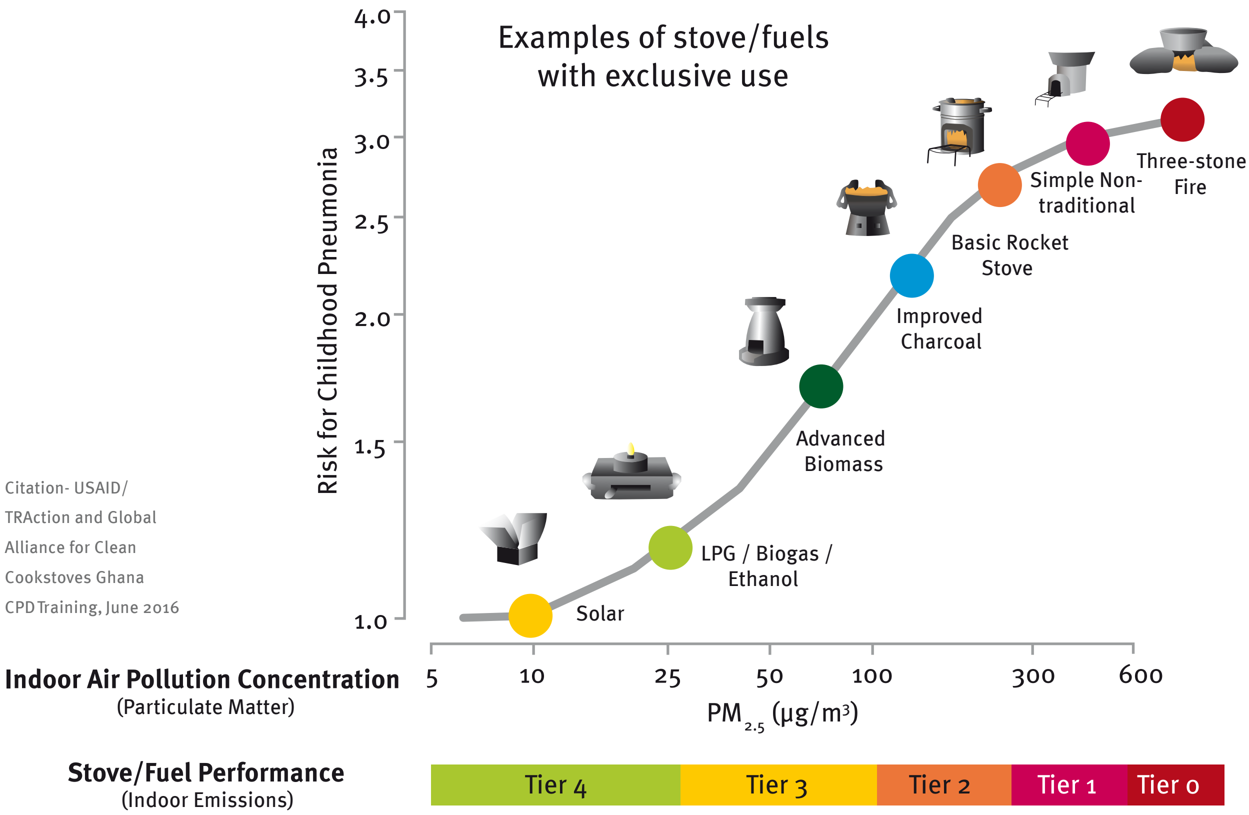


Figure 10: Emissions of PM2.5 from cooking stoves related to risk of childhood pneumonia (USAID/TRAction andGlobal Alliance for Clean Cookstoves, 2016)

The impact on indoor pollutants of using an ethanol stove instead of inefficient cooking with wood has been investigated in Ethiopia. Soot/particulate matter (PM2.5) and carbon monoxide (CO) are the two pollutants responsible for the bulk of the negative health impacts of indoor smoke. The use of ethanol stoves resulted in average reductions of 84% and 76% for PM2.5 and CO, respectively (Pennise, et al., 2009).

Several studies have also researched the impacts on pregnancy of using ethanol stoves. Overall, they show that ethanol-fueled cookstoves have a positive impact on health. For example, a recent study in Nigeria concluded that switching to ethanol-fueled stoves has the potential to provide needed protection for women and their developing fetus (Alexander et al., 2018).

According to USAID, which offers a “Clean and Efficient Cooking Technologies and Fuels Toolkit”,[3] the primary challenge in achieving respiratory health impacts through cookstove interventions lies in the fact that households not only need to use extremely clean stoves and fuels, but also need to use them almost exclusively (USAID, 2017).

3. https://www.usaid.gov/energy/cookstoves

The WHO has also developed a toolkit to promote clean and safe interventions in the home. The Clean Household Energy Solutions Toolkit (CHEST) provides the tools for countries and programs to create or evaluate policies that expand clean household energy access and use. CHEST4 is an analytical framework that was created from expert input. It contains tools for assessment of the current state of household energy use, indoor air pollution and health impacts.

Added value from field to fuel tank

Establishment of an ethanol industry benefits rural development by increasing the income of small farmers and improving agricultural productivity. Ethanol feedstock supply offers a range of economic opportunities, and the full ethanol value chain includes business opportunities in feedstock processing, production of ethanol and by-products, research, distribution, technical and financial support services, commercialization of products, and end use.

The establishment of an ethanol industry in developing and least developed countries provides significant economic and environmental benefits when ethanol is produced and used in a sustainable way. Rural development is promoted by increasing the income of smallholders and improving agricultural productivity. This is particularly interesting for many countries due to their large biomass resource potential, low-cost labor and large agricultural sector. Specific opportunities exist for ethanol production linked to optimization of the sugar value chain for sugarcane producing countries. Furthermore, ethanol use as a transport fuel blended with gasoline can reduce import expenses for fossil fuels, thereby improving energy security and reducing vulnerability to volatile fossil fuel prices.

Economic opportunities in feedstock supply include planting, crop management (e.g. weeding, irrigation), harvesting, in-field transportation, road transportation, off-loading, and feeding to the processing facility. Feedstock can be produced both by large estates and by outgrower schemes. **Involvement of smallholders under fair conditions is an appropriate means to increase the income of the rural population, leading to improved living conditions and enhanced food security.**

In addition to feedstock production, the full ethanol value chain includes business opportunities in feedstock processing, production of ethanol and by-products (in decentralized micro-distilleries or in larger facilities), research, distribution, technical and financial support services, commercialization of products, and end use (including ethanol export). In order to maximize benefits for the local economy, the participation of local SMEs in the provision of goods and services needs to be promoted and local employment and training needs to be encouraged. In this way, the ethanol sector can provide entrepreneurs and local communities with opportunities for business growth, improve entrepreneurial skills, and create more stable and diverse markets.

4. https://www.who.int/airpollution/household/chest/en/

Food and fuel production can be synergetic

Competition between fuel and food is sometimes raised as a potentially severe negative social impact of increased fuel production. Biofuels have been criticized for pushing out food production from agricultural land and leading to food price increases that affect the poorest people in developing countries. But food security is often challenged by access to food rather than by availability, and the links between biofuels and food security are complex. Biofuels provide both risks and opportunities in this regard. Through careful planning using modern technologies and tools, and incorporating optimization of existing agro-industries in the country, biofuels enhance food production and do not need to compromise it. This can be done through intensification of land use, the use of marginal and degraded lands, and the shift to integrated production systems that combine the production of food and fuels.

The United Nations Food and Agriculture Organization (FAO) projects that close to 50% more food and feed need to be produced in 2050 as compared to 2012 in order to meet the demand of the global population, which is forecast to grow by to 9.7 billion by 2050 (FAO, 2017). Agricultural output will need to more than double in Sub-Saharan Africa and in South Asia. Increasing food supply will crucially depend on yield increases through improved management practices and appropriate technology use, enhanced input-use efficiency, and the reduction of pre-harvest and post-harvest losses.

The food versus fuel debate first emerged in the US and the EU, in relation to the use of corn (maize) for the production of ethanol. The debate became increasingly vigorous in 2007 and 2008 due to strong increases in food prices which were largely attributed to biofuels by several stakeholders, even though there is no scientific consensus regarding the impact of biofuels on food prices (Rosillo-Calle, 2012). Opponents of biofuels criticize cultivation of biofuels instead of food as morally wrong and claim that large-scale biofuels production will lead to food insecurity worldwide. They also claim that land competition for food and fuel production will lead to negative environmental impacts (on water, soil, carbon stocks, and biodiversity), and that indirect land use change impacts seriously affect potential reductions in greenhouse gas emissions resulting from the use of biofuels (Searchinger et al., 2008).

The fact is that links between biofuels and food security are complex, and biofuels present both risks and opportunities (Kline et al., 2017). While higher food prices can threaten the food security of the least well off, especially poor urban populations, **no lasting price increases have been observed as a consequence of biofuel policies** (Ajanovic, 2011). **Rather, biofuels offer opportunities for rural populations by harnessing agricultural growth, promoting rural development and thereby reducing poverty** (FAO, 2008). Dual feedstock off-take for food and fuel contributes to the diversification of production and serves to stabilize local and regional agricultural processes, as well as leading to additional income opportunities.

Furthermore, the use of biomass for bioenergy can go along with food production, without direct competition. For example, modern sugar mills and sugarcane ethanol plants are usually integrated and produce either food (sugar) or energy (ethanol), or both (in variable percentages), depending on market prices. Additionally, by-products such as molasses (residues from sugar production) or vinasse (residues from ethanol production) can also be used for energy without competing with food production. Potentially, very large quantities of molasses are available for transformation to ethanol in Africa: as countries like Tanzania, Kenya, Ethiopia and Nigeria seek to make up sugar deficits for their own domestic consumption, they will also produce more and more molasses, which needs to be monetized in order for sugar factories to be competitive and profitable. **Sugar factories in India, as in Brazil, produce and sell sugar, ethanol and power; the same model can be applied in Sub-Saharan Africa in order for these operations to be competitive.**

With respect to the potential effects of biofuel cultivation on food security, the FAO underlines that no feedstock is inherently good or bad, and social and environmental sustainability will depend on how the biomass is produced (Gomez San Juan et al., 2019). The production of feedstock for biofuels should contribute to food production and not hinder it. This can be achieved through intensification of land use, use of marginal and degraded lands, and the shift to integrated approaches, such as integrated food-energy systems (IFES) (Bogdanski et al., 2010). IFES can either use land for multiple purposes (e.g. combining feedstocks for food and fuel production), or use biomass for a variety of purposes (e.g. cascading use of biomass or multi-purpose crops). Furthermore, as shown in the illustration below, IFES may also integrate different renewable energy technologies with agriculture, livestock, and fishing activities, suitable for both developing and developed countries (FAO, 2011).

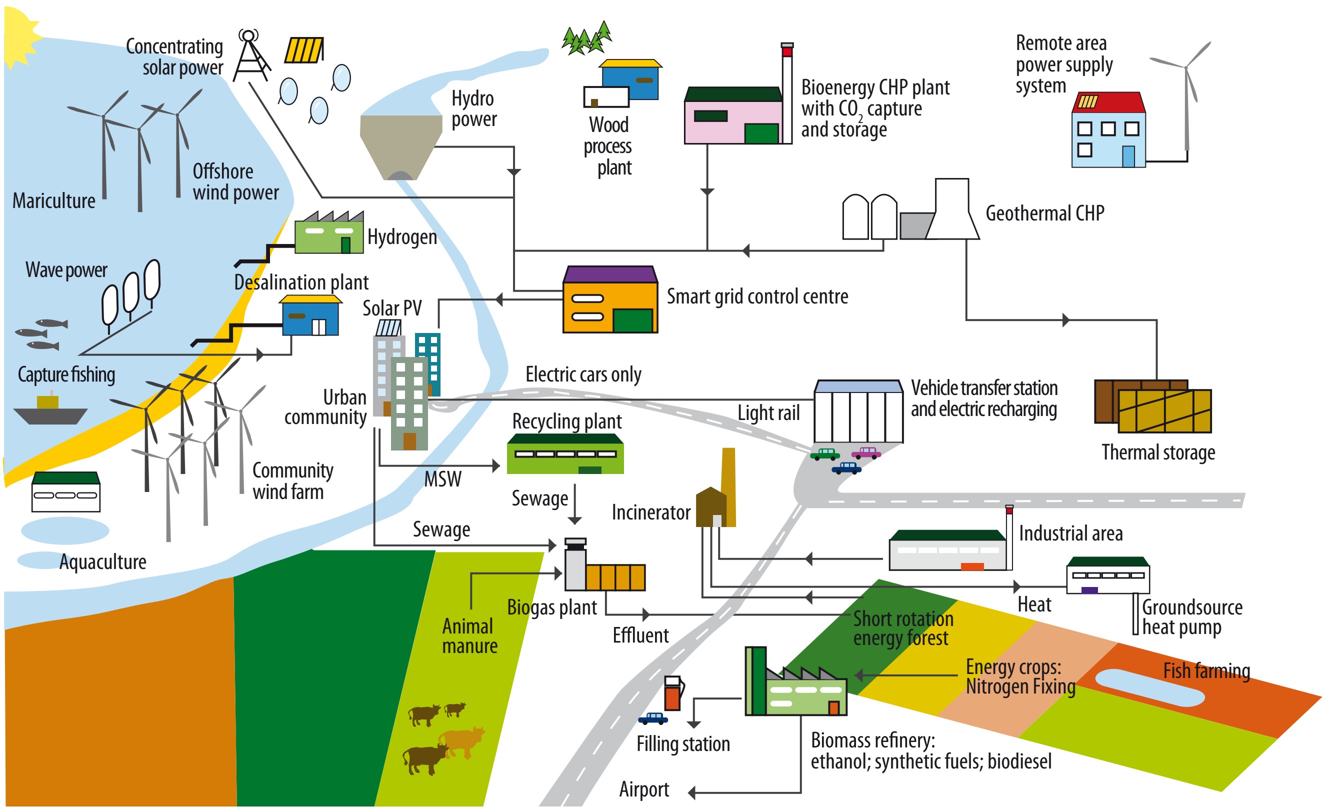


Figure 11: Conceptual integrated food-energy system that envisages a sustainable and secure food supply system in both high-GDP and low-GDP countries (FAO, 2011)

Food security is often challenged by access to food rather than production or availability. Access to food can be enhanced by improving tenure security and income for farmers, through increasing the value of crops. Furthermore, utilization of food can be enhanced by improved access to sustainable and clean cooking fuels (FAO 2019).

Finally, the promotion of both food and fuel production is necessary to ensure that biofuels contribute to sustainable development and negative impacts on food security are avoided. The Bioenergy and Food Security (BEFS) approach developed by the FAO supports sound decision-making, and specifies the following requirements:

— In-depth understanding of the specific local, regional and national food security situation and framework conditions for the production of biofuel feedstock. Related opportunities, risks, synergies and trade-offs need to be carefully taken into account.
— An enabling policy and institutional environment (taking into account food security aspects) with sound and flexible policies and effective means to implement these. Such flexible policies could include measures for variable demand (e.g. biofuel mandates adjusted to existing feedstock availability) (Gursel et al., 2020).
— Implementation of good practice by investors and producers in order to reduce risks and increase opportunities for food security, and appropriate policy instruments to promote such good practice.
— Proper monitoring of impacts of biofuel production on food security.

Ensuring positive land use impacts

The production and use of biomass for energy purposes, including ethanol for transport and cooking, has impacts on land use. The overall impact depends on the scale of the agricultural systems that support ethanol production: in general, smaller scale feedstock production performs better with regard to socioeconomic effects. A range of factors need to be considered, including use of fertilizer and pesticides, water use, biodiversity, and access to land and land use rights. Care should be taken to ensure that smallholders and village communities adequately share in the benefits of feedstock and ethanol production. Besides economic benefits, a major positive impact is that the replacement of wood fuels with ethanol cooking fuels contributes to the protection of forests by avoiding unsustainable wood harvesting and forest degradation.

Biofuel production naturally requires large quantities of feedstock, which does have effects on the way land is used. This is obvious with regard to dedicated energy crops, but feedstock that is currently categorized as “residues” or “waste” may also have impacts on land use in the long term, as general competition for carbon-based renewable sources increases. This is heavily influenced by prices for biofuels and biomass, as well as by prices for and availability of fossil-based sources (Rutz & Janssen, 2014).

Land use change (LUC) refers to a change from one purpose to another. Land use change also occurs when non-used land (virgin, abandoned, or degraded land) is converted to a specific use.

A distinction is made between direct land use change and indirect land use change. Direct land use change (dLUC) refers to a change in the use of a specific land area that is directly converted from one status (e.g. degraded pasture) to another status (e.g. sugarcane cultivation). If feedstock is grown on existing agricultural land, it may displace another crop which might then be produced, for example, on forest land. This is called indirect land use change (iLUC). The indirect effect manifests itself due to changes in demand for agricultural commodities, and their substitutes, in global markets.

For ethanol production, impacts of land use changes depend very much on the scale of the agricultural systems, as summarized in an overview focused on Africa (Rutz & Janssen, 2012). There is evidence that feedstock production on a smaller scale performs better in comparison to large-scale systems in terms of socioeconomic impacts. However, large-scale agricultural systems can be beneficial to the local population as well as to national economies.

Typically, production of ethanol for the transport sector is considered commercially viable when conducted at a large scale (Rutz & Janssen, 2012). Sugarcane ethanol production has been associated with environmental concerns related to fertilizer and fuel use. Pesticides and other pollutants can cause negative impacts. Smoke from burning harvested fields also needs to be considered, as well as the use of water for irrigation. Expanding ethanol production has also affected biodiversity where natural forest has been cleared to make way for cultivation. All of these sustainability concerns need to be addressed where ethanol is to be produced at a large scale (UN DESA, 2007). For cultivation of sugarcane for biofuel production in developing countries to be sustainable, small-scale farmers and village communities must adequately share in the benefits. This can be achieved, for example, by outgrower schemes, whereby smallholders can cultivate a biofuel crop which contributes to a larger, combined harvest.

Finally, land use issues are related to land ownership structures (land tenure, land use rights, land access) which can be highly specific in developing countries. Negative impacts on low-income populations must be avoided, as well as land grabbing, which is legal or illegal acquisition of large pieces of land in developing countries by domestic and transnational companies, governments, and individuals. Land grabbing has a long history, but the term resurfaced particularly following the 2007-2008 world food price crisis. Land grabbing by investors continues today in a variety of forms for the purpose of producing cash crops and other commodities, including bioenergy feedstock. It must therefore be guarded against when implementing ethanol production.

Replacing unsustainable wood fuel with ethanol cooking fuels promises to significantly support the conservation of forests in developing countries. Currently, unsustainable charcoal production and fuelwood collection – enabled by a lack of clearly defined and secure forest and tree tenure – constitute the main cause of forest degradation, particularly in Sub-Sahara Africa (FAO, 2017). Large-scale production of charcoal, especially in areas serving the markets of major urban areas, can have significant adverse impacts on the forests and other natural resources, putting their sustainability at risk. A study on the linkages between charcoal production and forest degradation or deforestation in Tanzania (SEI, 2002) found that charcoal production was responsible for the degradation of 25% of closed woodland, as well as the deforestation of 20% of closed woodland

and 51% of open woodland in the catchment area to the west and north of Dar es Salaam that supplied charcoal to the city. Similarly, as reported in Chapter 4, charcoal users in Maputo and Matola, Mozambique consume an equivalent of 1.8 million tons of wood each year, which corresponds to approximately 142 thousand hectares of destroyed forest annually (Atanassov et al., 2012).

Quantifiable macroeconomic benefits

Capital investment required to build a greenfield sugarcane-based ethanol production facility is estimated at 1.86 USD per liter of annual production capacity. The average agricultural area needed for ethanol production to support 10% blending with gasoline for 20 countries in Asia and Africa represents between 0.03% and 1.5% of total agricultural area in the selected countries, when assuming a global average yield of sugarcane of 4,550 l/ha. Benefits from introducing E10 include GHG emission reductions of about 8.8% and foreign exchange savings between 0.02% and 0.5% of GDP in the selected countries.

Tables 2 and 3 show estimates of potential ethanol demand, foreign exchange (forex) savings, capital investment, greenhouse gas emission reductions, and agricultural area required, as a result of introducing 10% ethanol blending in gasoline, in 20 different countries in Asia and Africa. Calculations are based on ethanol production from sugarcane, though this might not be the most appropriate feedstock in every country.

Ethanol demand is calculated as 10% of gasoline demand by volume, based on gasoline consumption in 2017. Forex savings are derived from average gasoline prices in the respective countries (in May 2021), which were multiplied by the fossil fuel savings resulting from substituting 10% of gasoline with ethanol. Gross domestic product (GDP) from 2017 was used to determine forex savings as a share of national GDP; this ranged between 0.02% and 0.5%.

Required capital investment was estimated using a multiplier of 1.86 USD/liter (l) (IRENA, 2019), based on a greenfield sugarcane-based ethanol production plant. When integrated into existing sugarcane mills (brownfield), capital investment falls to about 0.27 USD/l (IRENA, 2019). In comparison, a molasses-based ethanol production plant in Pakistan, integrated into an existing sugar mill, would require an investment of about 0.05 USD/l (Farooq et al., 2020).

Introducing a 10% ethanol blend based on sugarcane has the potential to reduce greenhouse gas emissions by 8.8% on average in the selected developing countries, compared to pure gasoline consumption. To calculate the greenhouse gas emission reductions, values from Table 7 and Figure 29 were considered and net emissions of 90g CO_2-eq per megajoule (or 2,923g CO_2-eq/l) for gasoline were assumed. The agricultural area required for feedstock cultivation was determined assuming that ethanol production is based on sugarcane, applying global average yields of

4550l/ha (FAO, 2008). Agricultural area needed for implementation of 10% ethanol blending from domestic production lies between 0.03% and 1.5% of total agricultural land in the selected countries.

It has to be stated that these calculations only provide a rough indication of the respective macroeconomic and environmental benefits.

Table 2: Potential impacts of introducing E10 in selected countries in Africa (rough estimations)

Selected countries Africa	Gasoline demand (million liters)[5]	Ethanol demand for E10 (million liters)	Gasoline price (USD/l)[6]	Forex savings (million USD)	GDP (million USD)[7]	Forex savings as share of GDP (%)
DR Congo	425	43	1.00	43	37,642	0.1
Ethiopia	522	52	0.51	26	80,561	0.0
Ghana	1,567	157	0.98	153	58,997	0.3
Ivory Coast	741	74	1.13	84	37,353	0.2
Kenya	1,741	174	1.16	202	79,263	0.3
Madagascar	160	16	1.08	17	11,500	0.1
Mozambique	580	58	1.09	63	12,646	0.5
Nigeria	17,409	1,741	0.45	790	375,745	0.2
Sudan	1,509	151	0.54	81	117,488	0.1
Tanzania	1,469	147	0.92	135	53,321	0.3
Uganda	790	79	1.17	93	25,995	0.4

GDP figures for 2017. | Forex savings based on gasoline prices in May 2021.
m = million | l = liters | tCO2-eq = tons of carbon dioxide equivalent | ha = hectares

5. https://www.theglobaleconomy.com/rankings/gasoline_consumption/
6. https://www.globalpetrolprices.com/gasoline_prices/
7. https://www.worldometers.info/gdp/gdp-by-country/

Table 2: Potential impacts of introducing E10 in selected countries in Africa (rough estimations)

Selected countries Africa	Capital investment, greenfield sugarcane (million USD)	GHG emission savings net (tCO_2-eq)	Agricultural area total (million ha)[8]	Agricultural area needed for E10 (ha)
DR Congo	80	110,000	32	9,000
Ethiopia	100	135,000	38	11,000
Ghana	290	405,000	15	34,000
Ivory Coast	140	192,500	21	16,000
Kenya	320	450,000	28	38,000
Madagascar	30	41,000	41	4,000
Mozambique	110	150,000	41	13,000
Nigeria	3,240	4,499,000	69	383,000
Sudan	280	390,000	68	33,000
Tanzania	270	380,000	40	32,000
Uganda	150	204,000	14	17,000

GDP figures for 2017. | Forex savings based on gasoline prices in May 2021.
m = million | l = liters | tCO_2-eq = tons of carbon dioxide equivalent | ha = hectares

8. http://www.fao.org/faostat/en/#data/RL/visualize

Table 3: Potential impacts of introducing E10 in selected countries in Asia (rough estimations)

Selected countries Asia	Gasoline demand (million liters) [9]	Ethanol demand for E10 (million liters)	Gasoline price (USD/l) [10]	Forex savings (million USD)	GDP (million USD) [11]	Forex savings as share of GDP (%)
Afghanistan	1,054	105	0.59	62	19,544	0.3
Bangladesh	580	58	1.05	61	249,724	0.0
China	199,270	19,927	1.11	22,119	12,237,700	0.2
India	34,412	3,441	1.26	4,319	2,650,725	0.2
Indonesia	33,542	3,354	0.74	2,472	1,1015,421	0.2
Myanmar	2,564	256	0.70	178	67,069	0.3
Pakistan	10,213	1,021	0.71	723	304,952	0.2
Philippines	6,267	627	1.05	656	313,595	0.2
Viet Nam	8,472	847	0.84	712	223,780	0.3

GDP figures for 2017. | Forex savings based on gasoline prices in May 2021.
m = million | l = liters | tCO2-eq = tons of carbon dioxide equivalent | ha = hectares

9. https://www.theglobaleconomy.com/rankings/gasoline_consumption/
10. https://www.globalpetrolprices.com/gasoline_prices/
11. https://www.worldometers.info/gdp/gdp-by-country/

Table 3: Potential impacts of introducing E10 in selected countries in Asia (rough estimations)

Selected countries Asia	Capital investment, greenfield sugarcane (million USD)	GHG emission savings net (tCO_2-eq)	Agricultural area total (million ha)[12]	Agricultural area needed for E10 (ha)
Afghanistan	200	227,500	38	23,000
Bangladesh	110	150,000	9	13,000
China	37,060	51,495,000	529	4,380,000
India	6,400	8,892,500	180	756,000
Indonesia	6,240	8,668,000	62	731,000
Myanmar	480	662,500	13	56,000
Pakistan	1,900	2,639,000	36	224,000
Philippines	1,170	1,619,500	12	138,000
Viet Nam	1,580	2,189,500	12	186,000

GDP figures for 2017. | Forex savings based on gasoline prices in May 2021.
m = million | l = liters | tCO_2-eq = tons of carbon dioxide equivalent | ha = hectares

12. http://www.fao.org/faostat/en/#data/RL/visualize

BIOETHANOL MARKETS IN DEVELOPING COUNTRIES: PROGRESS, OPPORTUNITIES, AND CHALLENGES

THIS CHAPTER illustrates progress made in ethanol use for cooking and transport markets in developing countries, and the major transition these two sectors are currently undergoing.

Recent rapid economic growth is bringing lifestyle changes to developing countries, which are driving an increase in energy demand. Such growth is evident in the electricity sector – to power household appliances such as lights, refrigerators, cooking stoves, washing machines, and air conditioners – as well as in the transport sector, as car ownership and use of other vehicles increases.

Ethanol markets in developing countries are currently dominated by the fuel blending sector, as countries introduce policies mandating or targeting ethanol use as an additive ("blending") to conventional fossil fuels for transportation. In contrast, volumes of ethanol use as a clean cooking fuel are currently very low, and limited to pilot initiatives.

Joint development of ethanol markets for fuel blending and for clean cooking presents opportunities and risks. While a larger combined market may strengthen ethanol value chains and stimulate investment in ethanol production, household cooking markets can face shortages in ethanol supplies due to competition with an economically stronger transport sector.

There is no doubt that the ethanol market is set for growth. In Africa alone, between 2013 and 2030 ethanol consumption for cookstoves is expected to grow from 13 petajoules (PJ) a year (equivalent to 554 thousand kiloliters) to 82 PJ/year (3.5 million kiloliters), fueling two million stoves. In the transport sector, projections show that the use of ethanol in Africa will significantly increase from being almost absent in 2013, to 123 PJ/year (5.2 million kiloliters) in 2030.[1]

1. IRENA, 2015

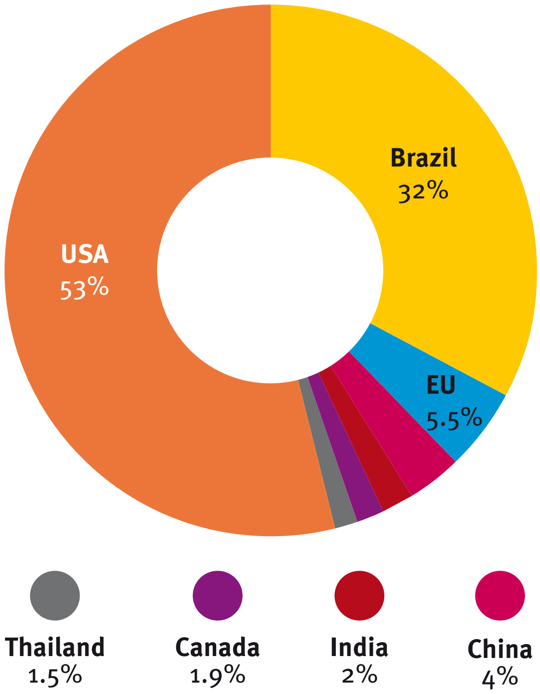
Growth potential of bioethanol as a transport fuel

Over the past decades, many countries worldwide have implemented policies to promote the use of ethanol as a transport fuel. These markets are policy-driven, targeting reduced fossil fuel imports and greater energy independence, lower greenhouse gas (GHG) emissions, and enhanced rural development.

Today, ethanol use in transport mainly comprises 5% (E5) and 10% (E10) ethanol blends in gasoline. These are widely available in many developed countries, and mass-produced vehicles can usually run on either blend. Blends with higher ethanol content (E15, E20, E85, E100) are limited to selected markets, such as for use in flex-fuel vehicles (FFV) in Brazil. The present ethanol fuel market is dominated by the United States and Brazil, followed by the European Union, China, India, Canada and Thailand (see Figure 14). Other countries currently account for ethanol production of about 4 billion liters (bn l) annually altogether (3.5% of global production). During 2020, global ethanol production was strongly impacted by the decrease in gasoline demand caused by the Covid-19 crisis. This led to a reduction of almost 15% mainly due to lower production levels in the US and Brazil whereas Asian markets remained relatively stable (IEA, 2020).

According to the OECD-FAO Agricultural Outlook 2020-2029, moderate growth in the global fuel ethanol market is expected in the coming years (adding about 15.5 bn l to 2029). The strongest growth is forecast in Brazil, mainly due to its RenovaBio program, which is aimed at emission reductions in line with the country's commitments under COP 21. Smaller increases are foreseen in the US, China and India, while a stable market is anticipated for the EU and Canada. The ethanol market in all other countries is expected to increase by between 1 bn and 5 bn l.

Ethanol production
Percentage



Ethanol production
Worldwide: 114 billion liters

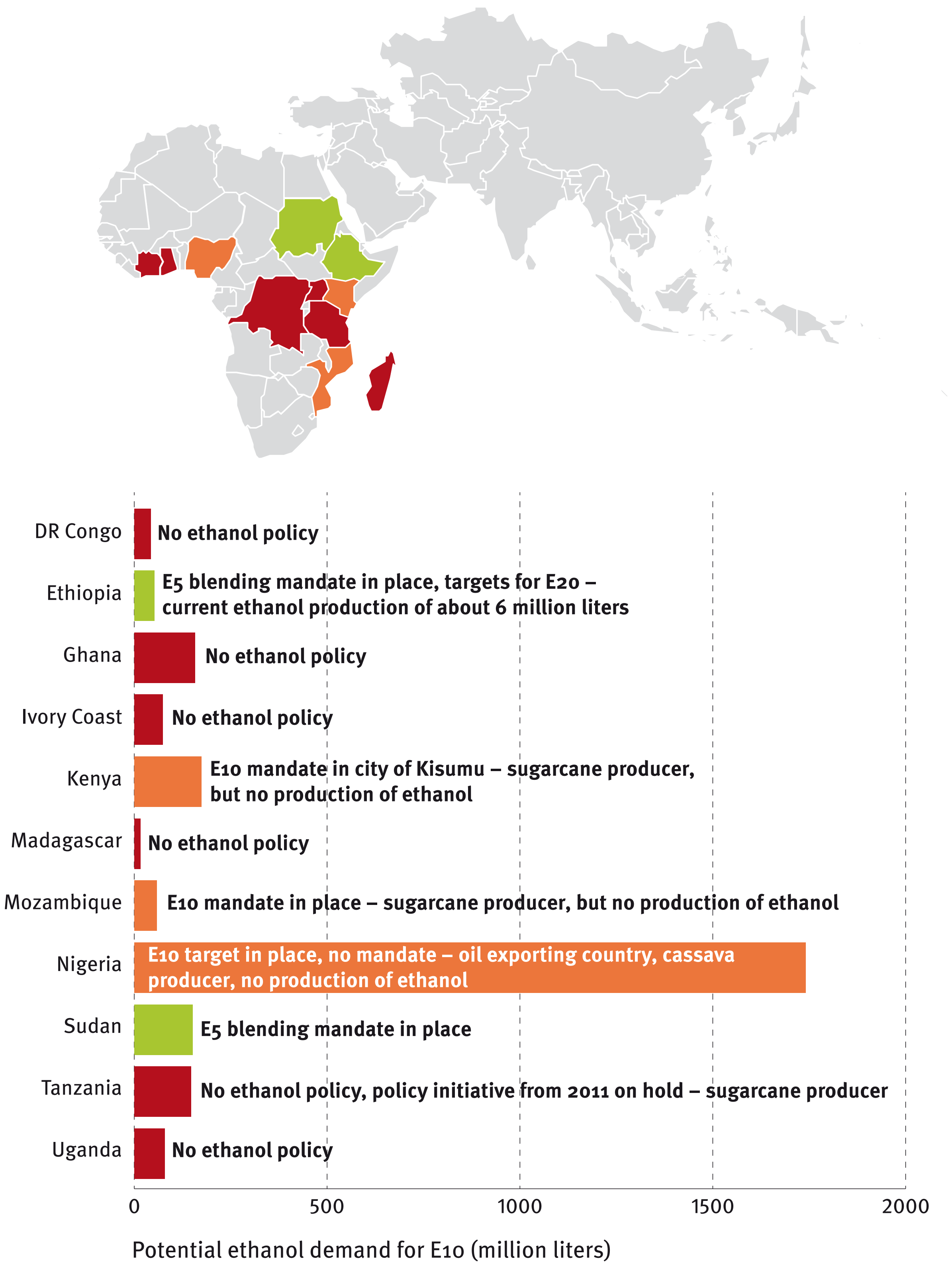
United States, maize	59,7	bn l
Brazil, sugarcane, maize	35.3	bn l
EU, sugar beet, wheat, maize	5.5	bn l
China, maize, cassava	4.0	bn l
India, molasses	2.0	bn l
Canada, maize, wheat	1.9	bn l
Thailand, molasses, cassava	1.6	bn l

Figure 12: Transport fuel ethanol production in leading countries in 2019 (REN21, 2020)

EXISTING ETHANOL POLICIES AND POTENTIAL DEMAND IN SELECTED MARKETS

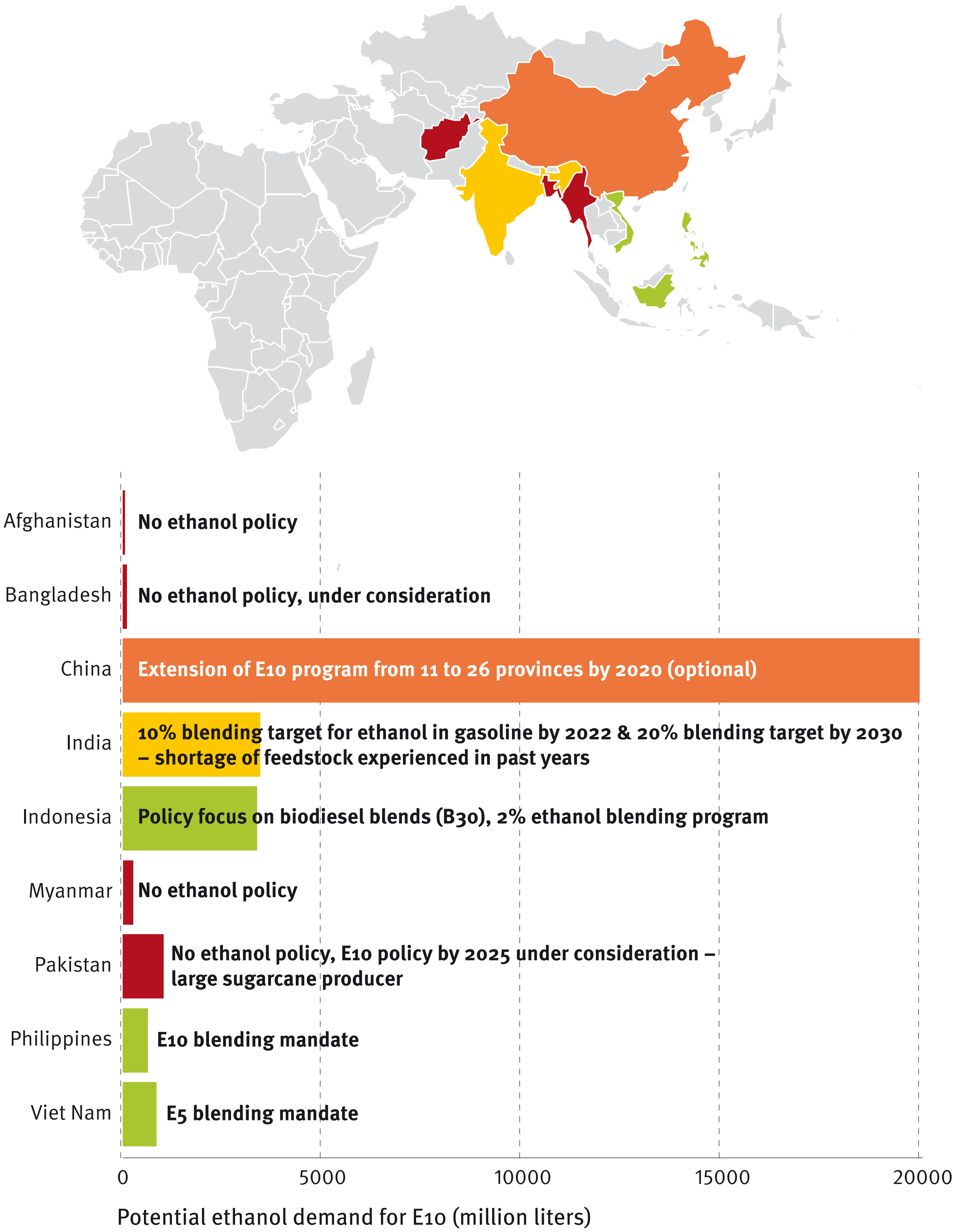
The charts below provide an overview of existing ethanol policies in a selection of countries in Africa and Asia, as well as the potential ethanol demand if an E10 blending mandate was implemented (estimated at 10% of present gasoline demand).

Figure 13: Potential impacts of introducing E10 in selected countries in Africa (rough estimations)



In Africa: Ethiopia, Kenya, Malawi, South Africa, and Zimbabwe have already introduced ethanol as a blending component, and ethanol blending policies are being discussed in Angola, Nigeria, Mauritius, Mozambique, Sudan, and Zambia. Due to generally low gasoline consumption in these countries, ethanol produced using molasses from existing domestic sugarcane processing facilities may be sufficient to implement E10 blending programs.

Figure 14: Potential impacts of introducing E10 in selected countries in Asia (rough estimations)



In Asia: China, India, Indonesia, Philippines, Pakistan, and Viet Nam have already introduced ethanol blending programs or are considering them, so the ethanol market is expected to grow. Growth is forecast in particular in well-established markets in China and India. An ethanol transport fuel policy is not currently being considered in Afghanistan or Myanmar.

Bioethanol cooking stoves to protect health and reduce carbon emissions

THE DISADVANTAGES OF TRADITIONAL COOKING FUELS AND THE CURRENT CLEAN COOKING STATUS

Every day, 2.8 billion people cook their meals using polluting traditional biomass fuels.[2] In addition to the major negative health impacts of indoor air pollution, carbon dioxide from cooking is one of developing countries' primary contributions to global warming.

Smoke from wood and charcoal stoves results in 4 million deaths each year and is a cause of illnesses such as cataracts, lung disease and cardiovascular disease. As a cooking fuel ethanol creates healthier living conditions for households in developing countries, combined with safe and efficient stoves. It burns cleanly with no smoke or soot, meaning there are no harmful health impacts. Ethanol is an emerging clean cooking option in numerous developing countries today, with ethanol cooking initiatives under way in Brazil, Ethiopia, Haiti, Kenya, Madagascar, Mozambique, Nigeria, and Tanzania.

Moreover, as areas around the world struggle with increasing deforestation, women – who are overwhelmingly responsible for cooking and fuel in communities using traditional cooking technologies – have to travel further and further to gather wood for cooking. **Trips for fuelwood are dangerous because women risk violence or sexual assault, particularly in conflict regions, and long hours spent collecting fuel prevent women and girls from pursuing an education or a source of income.**[3]

Despite these issues, since 2010 only small improvements in access to clean cooking have been realized overall. The annual rate of growth in access to clean cooking fuels and technologies was lower than 1% from 2010 to 2018, as population growth outpaced the number of people gaining access. Although Asia (mainly East Asia and South-East Asia) has made notable gains and the number of people lacking access to clean cooking fell from 1.0 billion to 0.8 billion, in Sub-Saharan Africa stagnant growth in access, combined with rapid population growth, has brought an increase in the number of people without access from 750 million to 890 million.

From 2014 to 2018, 20 countries accounted for more than 80% of the global population lacking access to clean cooking. 19 of the 20 countries with the lowest percentage of the population having access were least-developed countries in Africa.

Although liquefied petroleum gas (LPG) continues to dominate market growth for clean cooking solutions, other technologies such as biomass cookstoves, biogas and solar cookers, and electric cooking are being deployed and piloted in many developing countries. An estimated 125 million people worldwide used biogas for cooking in 2018, most of them in Asia (including 111 million in China and 9 million in India). Biogas production in Africa increased by nearly 40% between 2014 and 2018, to around 46 million cubic meters, mainly in the five countries engaged in the Africa Biogas Partnership Program: Burkina Faso, Ethiopia, Kenya, Tanzania, and Uganda.[4]

2. Data sources in this section: IEA, IRENA, UNSD, World Bank, WHO, 2020

3. Project Gaia, "The Problem" (https://projectgaia.com/our-approach/the-problem/)

4. REN21, 2020

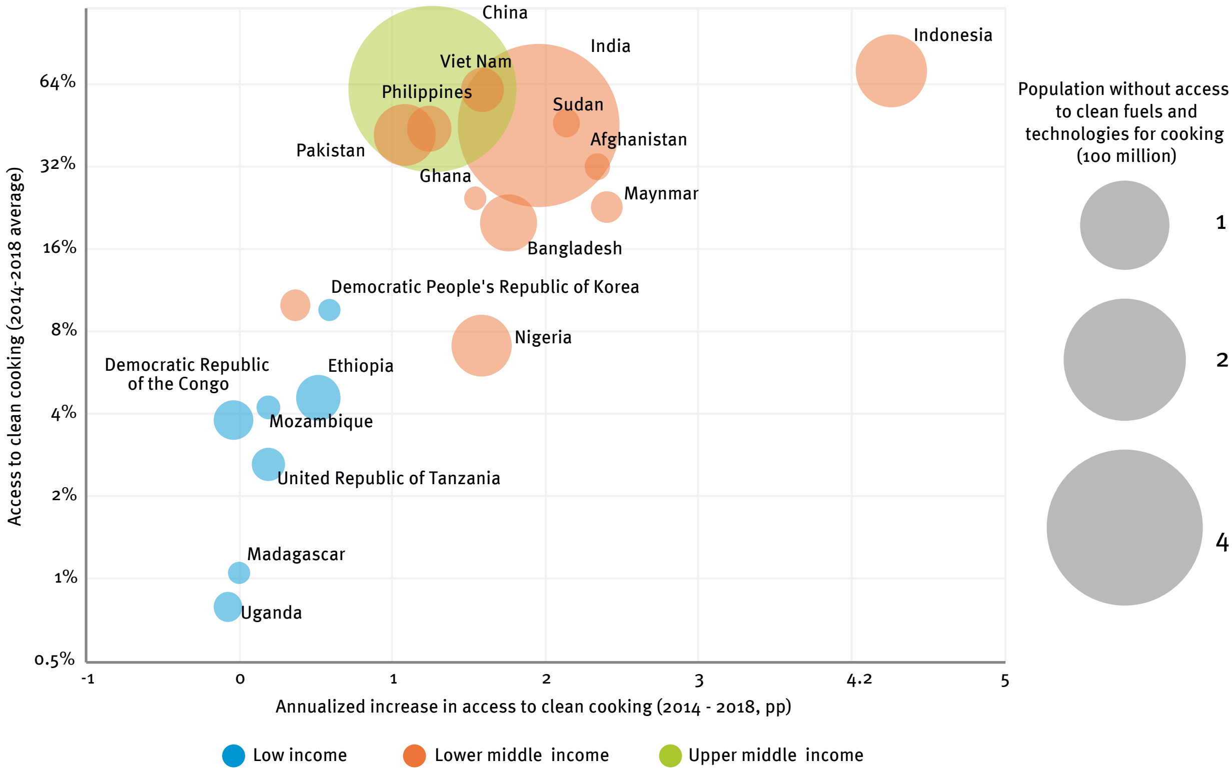


Figure 15: The 20 countries with the largest access deficits to clean cooking, 2014–18. (IEA, IRENA, UNSD, World Bank, WHO, 2020)

Among low and middle-income countries, the use of gaseous fuels (LPG, natural gas or biogas) increased consistently from 30% in 1990 to 49 percent in 2018, overtaking unprocessed biomass fuels (e.g. wood, crop waste, and dung, but excluding charcoal) as the dominant type of cooking fuel over the past decade.

Coupled with safe and efficient stoves, clean-burning alcohol fuels – including ethanol – create healthier living conditions for households in developing countries. Ethanol is an emerging cooking fuel option in a number of countries, either in its liquid form or as a gel. While ethanol as a gel is more expensive, liquid ethanol has been found to be competitive against charcoal and wood in Ethiopia, Malawi, Mozambique, Senegal, and South Africa (IRENA, 2015), but its unsubsidized end-use cost has remained above the price of kerosene (World Bank, 2014).

Nevertheless, at present ethanol is a seldom-used cooking fuel in many low and middle-income countries, as is also clear from the lack of official figures and up-to-date data. Across Sub-Saharan Africa, less than 6 million liters per year are sold for cooking purposes (2017 figure). This number is low not only in absolute terms but also in relation to the number of ethanol stoves that have been distributed (70,000-80,000) (ESMAP, 2020).

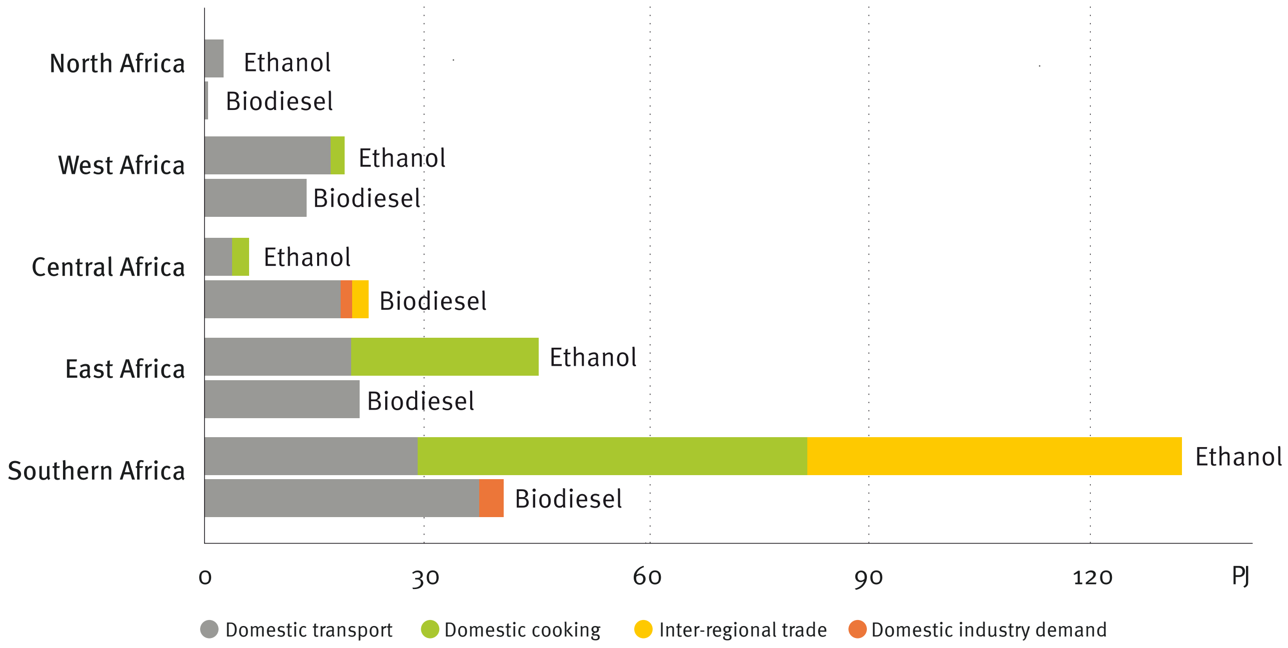


Figure 16: Bioethanol and biodiesel use in 2030 (IRENA, 2015)

Consumption of bioethanol as a liquid fuel for cooking

Ethiopia	6 million liters	Haiti	75,000 to 100,000 liters
Kenya	5 million liters	Madagascar	50,000 and 75,000 liters
Brazil	1 million liters	Nigeria	40,000 liters
Mozambique	300,000 to 400,000 liters	Tanzania	40,000 liters

Table 4: Consumption of bioethanol as a liquid fuel for cooking

These figures are estimates of liquid ethanol for use in ethanol stoves to date, based on ongoing clean cooking programs. They do not include consumption of ethanol as a gel fuel (used in a number of countries in Sub-Saharan Africa as well as in South-East Asia and in the Americas), or ethanol used in alcohol cookstoves (mainly present in Philippines, India, Indonesia, South Africa, other African countries, and widely in the Americas).

These figures show that ethanol for cooking is still a niche market in developing countries, even though it is a promising commercial and social impact opportunity, given its unique production attributes.

DISTRIBUTING BIOETHANOL AS A CLEAN COOKING FUEL

Ethanol can be bottled and distributed following either a bulk or itemized model. In the bulk model (sometimes also referred to as the “sealed bottle” model), ethanol is packaged into plastic disposable bottles at a large, centrally-located facility and transported across the market via trucks. Small shops sell ethanol bottles to consumers, who pour it from the bottle into their stoves (and then discard the bottle). In the itemized model (sometimes also referred to as the “automated refill” model), small retrofitted fuel tankers transport ethanol in bulk to dedicated tanks at stations. Fuel ATMs inside shops dispense ethanol into reusable containers, for which users pay digitally (ESMAP, 2020).

Ethanol’s clear potential as a clean cooking fuel is evidenced by the fact that companies are significantly investing in its development. R&D expenditure in the clean cooking sector in 2019 was driven by early-stage companies in the liquefied petrolem gas (LPG) and ethanol subsectors, which accounted for 81% of total sector R&D expenditure, despite accounting for just 16% of total revenues (Clean Cooking Alliance, 2021).

Currently, ethanol cooking enterprises and organizations (these include fuel and stove producers and manufacturers, distributors, and retailers), while few in number, are most highly concentrated in East and South-East Africa, and Brazil.

Currently, one of the main barriers to uptake of ethanol as a clean fuel for cooking is the high energy cost of clean fuels, which combined with the cost of stoves makes ethanol and other clean cooking solutions such as LPG and electricity unaffordable for the vast majority of households in developing countries.

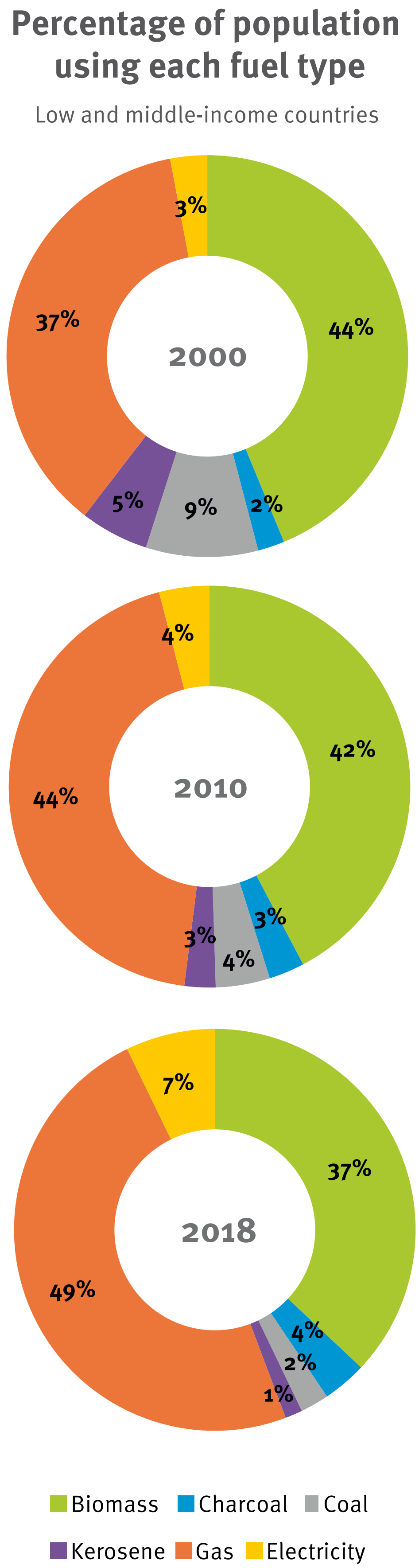


Figure 17: Comparison of the percentage of people using each fuel type among low and middle-income countries in 2000, 2010, and 2018 (IEA, IRENA, UNSD, World Bank, WHO, 2020)

Universal access to clean cooking remains achievable if serious efforts are made through large infrastructure investments, public sector subsidies, innovative business models and supporting regulations. Coherent packages of measures can accelarate the transition to clean cooking worldwide, particularly in sub-Saharan Africa, protecting a third of the global population from vulnerability to adverse health effects, and from to social and economic disadvantages (IEA, IRENA, UNSD, World Bank, WHO, 2020).

Table 5: Barriers and solutions effecting a global clean cooking transition

BARRIERS	SOLUTIONS TO EFFECT GLOBAL CLEAN COOKING TRANSITION
— High energy cost of clean fuels	— Targeted subsidies
— Household investment cost of new stoves	— Investment in infrastructure; innovative consumer financing (microcredits, credit guarantees)
— Lack of established value and distribution chains	— Implementation of innovative business models
— Competing interests	— Supportive regulatory environment

UNIDO is already providing technical assistance for framework development and financing solutions. The table below provides a comprehensive overview of recommendations, measures and actions which can help to create an enabling environment for increasing energy access, including in the clean cooking sector, in developing countries. It is adapted from recommendations developed by the UN Economic and Social Commission for Asia and the Pacific (ESCAP) in 2021.

Table 6: Creating an enabling environment for progressing energy access (ESCAP, 2021)

Factors	Description
Policy	Comprehensive national/local policy framework that: — Sets targets — Establishes energy distribution and technology strategies for urban and rural areas — Outlines action plans, incentivizes behavior change and provides overall direction for the sector
Data	To support data-driven decision-making, systems to collect data on: — Household and industrial energy use patterns — Local availability of off-grid solutions — Local availaibility of cooking fuels and stove models
Regulation	Regulations, standards and certification need to be introduced and maintained, to promote quality products that meet performance standards, and to prevent entry by illegitimate market actors.
R&D	— Research into consumer needs and preferences — Development infrastructure for high-performance products — Engagement with target user groups in development process — Evaluations of potential for behaviour change through education, product availability and affordability.
Infrastructure financing	Medium to long-term finance for companies to invest in: — Technology production facilities (e.g. stove production plant, pelletizing equipment, biodigesters) — Energy supply and distribution (e.g. product transportion, mini-grid connections, local retail operations) Access to capital for SMEs through local banks to support local supply chain development.
Consumer financing	— Mechanisms to provide end-users with options to finance investment in stoves and fuel: microcredits, pay-as-you-go models and rental options — Engagement of local lending institutions as partners in energy access programs to expand the consumer market for off-grid electrification and clean cooking technologies — Public financing critical in making selected clean cooking options cost-competitive when cheaper alternatives are available

Factors	Description
Energy pricing policies	— Effective taxation measures and subsidies to ensure energy is affordable for low income households — Methods to limit subsidies to prevent government over-spending
Inclusive planning and implemen-tation	Close collaboration with end-users, particularly women, during the design, planning and implementation phases of energy projects in order to ensure: — Positive user experience — Sustained use and — Context-appropriate implementation
Marketing strategies	Government awareness programs to help educate populations on the benefits of clean energy options, and to raise market demand.
Behavior change	Identification of key influencers of consumer behavior Employment of context-appropriate communication methods that educate, engage, and raise social acceptance around an energy product or service
Supply chains and after-sales service	After-sales care for consumers after sale of off-grid technologies and clean cooking products, e.g. fuel delivery, component repair and operational support. Development of sales-supply-service supply chains (and avoidance of one-off product distribution programs)
Monitoring, evaluation and feedback loops	— Plan for and establish regular monitoring and evaluatiion of the progress of energy programs — Creation of feedback circuits involving local users — Flexible program design to allow for adjustments based on feed-back

Photo: T photography / Shutterstock.com

COUNTRY CASE STUDIES: ENABLING BIOETHANOL

THIS CHAPTER focuses on attempts to develop ethanol industries and markets in four developing countries, illustrating a range of success stories and setbacks, as well as drivers of and barriers to ethanol implementation. The case studies are based on literature research and interviews with national experts. Each section attempts to highlight lessons learned and recommendations going forward. It is clear that in all cases, an enabling policy framework is needed to support the establishment of sustainable ethanol value chains for transportation and clean cooking.

Brazil: coupling sugar and bioethanol production

A large country with a tropical and subtropical climate, Brazil introduced ethanol production and use in 1931, based on an existing sugarcane industry. Ethanol is primarily produced in combined sugar and ethanol mills that can vary the output of sugar and ethanol depending on market prices. In addition, sugarcane bagasse (the fibrous material that remains after extracting sugarcane juice) is used to produce green electricity. Brazil has fostered research in crop breeding and agricultural practices, ethanol production technologies, and engine technologies, and almost all private vehicles in the country are flex-fuel vehicles that can run on any ratio of hydrous ethanol and regular gasoline.

BRAZIL

POPULATION	214 million
AREA	8.52 million km²
POPULATION DENSITY	25.6

BIOETHANOL INDUSTRY ESTABLISHED
1931 based on existing sugarcane industry
2nd largest ethanol producer WORLDWIDE

383 ETHANOL PLANTS in operation, total production capacity of 130 m l/day ethanol and 239 m l/day hydrous ethanol

Ethanol plants typically operate 180 days a year

LOCAL SUPPLIERS of plant and equipment for ethanol production
Highly developed infrastructure for use of ethanol as a transport fuel
85% FLEX-FUEL VEHICLES running on any mix of ethanol and gasoline

PERIODIC POLICY INTERVENTIONS to enable the market and in response to the changing environment

Ethanol is not used as a cooking fuel in Brazil – the country already has 96% access to clean cooking by other means

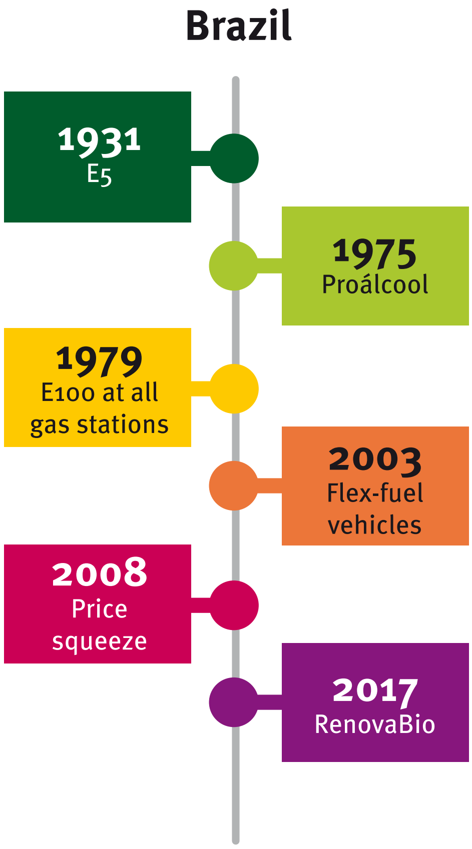
Statistics from UNData and the UN Energy Progress Report

Brazil is the second-largest producer of ethanol worldwide (after the USA), and its successful implementation of an ethanol industry for transportation makes it an ideal case study. Government, industry and the research sector have worked together to enable market development. The policy framework has changed over the years, but has always supported development of the ethanol economy. Ethanol production grew out of the domestic sugar industry and the two are efficiently combined. FFlex-fuel vehicles (FFVs) have been introduced in combination with the use of ethanol as a transport fuel. Successful market development was the result of applying knowledge along the entire value chain (feedstock production, sugar production, ethanol production, engine design), combined with policy measures addressing all parts of the value chain (Bacovsky, et al., 2020).

ETHANOL AS A TRANSPORT FUEL

Brazil implemented a compulsory blend of at least 5% ethanol in gasoline (E5) in 1931, in order to decrease dependency on petroleum imports and absorb excess production in the sugar industry. Between 1931 and 1975 the average content of ethanol in Brazilian gasoline was 7.5%.

As a response to the oil price crisis, in 1975 the Brazilian Government implemented the *Proálcool* program: increased blending of ethanol in gasoline of up to 25% (E25); mandated minimum levels of hydrous ethanol (E100: 95% ethanol, 5% water) for use in specially designed vehicles; mandated sale of hydrous ethanol at filling stations, with the consumer price for ethanol made lower than the price for gasoline; competitive prices for ethanol producers; development of favorable financial terms for mills to increase production capacity; reduced tax on new purchases of FFVs and reduced annual registration fees, and creation of ethanol storage reserves to ensure supply throughout the year. E100 has been available at all Brazilian gas stations since 1979.



The Brazilian Government revised its ethanol policies in 1985, due to the decline in oil prices and the strengthening of international sugar prices. Average financial returns in the sugarcane industry were reduced and production of sugar for export was stimulated. Additionally, government support for E100 was suspended.

Flex-fuel cars were launched in 2003 and were well accepted by consumers. Consumption of hydrous ethanol increased, and the sugarcane industry expanded rapidly, investing in more highly efficient sugar-ethanol mills. Ethanol exports also grew, due to new opportunities presented by the introduction of ethanol blending in gasoline internationally and increased demand around the world. However, in 2008 Brazil's ethanol production sector began to suffer from reduced price competitiveness and unfavorable government policies.

In 2017 Brazil introduced legislation to revitalize the biofuel sector and increase energy efficiency. The new regulatory framework, RenovaBio, entered into force in 2020. The policy aims to meet the government's annual decarbonization targets over a mimimum period of ten years. Biofuel production is certified by means of life-cycle analysis (LCA), resulting in "CBIO" greenhouse gas emission reduction certificates. One CBIO credit corresponds to one ton of carbon dioxide equivalent reduction in comparison to fossil fuel emissions. The government plans to increase ethanol production from 30 billion liters (bn l) to around 50 bn l by 2030 as a result of the RenovaBio scheme (Mendes Souza, et al., 2019).

COMBINED ETHANOL AND SUGAR PRODUCTION

Sugarcane is the main feedstock for ethanol production in Brazil. It is an ideal feedstock in terms of productivity and efficiency. There is an established network of local suppliers of sugar mill plant (pumps, crushers etc.). Bagasse, a by-product of sugar production, can be used for power generation. The sugarcane processing industry varies the proportion of sugar production to ethanol production depending on market factors, with production typically at a ratio of 40:60. However, the ratio can be varied flexibly, up to 75% on either side.

The situation today

— Sugarcane remains the main feedstock for ethanol production in Brazil.
— In 2018, 383 ethanol plants (including combined sugar and ethanol plants) were in operation, with total production capacity of 130 million liters (m l) of ethanol and 239 m l of hydrous ethanol per day.
— Ethanol plants typically operate 180 days a year.

- 642 million tons of sugarcane were produced in 2020. The sugarcane harvest season typically lasts six to seven months and sugarcane stocks cannot be stored, as the crop must be processed within a few days.
- **To use the available capacity outside the harvest period, corn (maize) has also been used for ethanol production in recent years.** In 2020 there were 16 plants processing corn or a mixture of corn and sugarcane in operation, producing about 1,620 m l of ethanol, representing 5.4% of total ethanol production.
- Flex-fuel vehicles produced in Brazil are or will be exported to 22 countries in Latin America (Horta Nogueira, 2021).
- Two commercial advanced ethanol plants and one demo plant were in operation in 2019, with total annual capacity of 127 m l. These advanced ethanol production plants are operating below capacity.
- Brazilian market regulation has been updated to allow the use of biofuels in aviation.
- Ethanol is not used for cooking purposes (Mendes Souza, et al., 2019).

Ethanol blending mandates (% of ethanol mixed with gasoline, by volume) increased from 18% to up to 27.5% in this period, with a current level of 27% (E27). In 2018, the share of ethanol in the fuel mix used by light vehicles reached 50.2%. **Every gas station in Brazil sells ethanol blend in one pump and pure hydrous ethanol in the other.**

Brazil has tax incentives for biofuel producers, blenders and users, including tax incentives for flex-fuel vehicles and for ethanol fuel. Science and technology funds are also used to stimulate production and use of biofuels as well as R&D investment.

Land use change (LUC) as a result of feedstock cultivation is a concern in Brazil. A recent assessment, assuming an increase in global ethanol demand to 26 bn l by 2030, concluded that an additional 3.7 million hectares of sugarcane must be cultivated in 2030 in comparison to 2012, representing 0.4% of the national territory. Land mapping and zoning has the potential to limit harmful Luc, by determining the best areas for cultivation of different crops and areas for environmental conservation, taking into account land use rights. Increasing agricultural productivity, among other measures, can significantly reduce the loss of natural vegetation and LUC-related greenhouse gas emissions.[1]

Summary: drivers and success factors – ethanol as a vehicle fuel in Brazil

- The main drivers of ethanol industry development in Brazil were energy security and economic factors
- More recently, government programs have been updated to address social and environmental concerns
- Principal success factors:
  - Major policy packages establishing a framework that promoted and supported supply-side and market development
  - Ethanol blending mandate for gasoline
  - Favorable conditions for ethanol production (the well-developed sugar industry)
  - An established automotive industry
  - Research centers for bioenergy
  - Cooperation of the national oil company

1. Van der Hilst et al., 2018

India: confronting challenges in a highly populated country

India is undergoing rapid growth in energy demand. To address demand in the transport sector, bioethanol was introduced as a blending component in vehicle fuels in 2003. Since then, further policy measures have resulted in a 10% ethanol blending target for gasoline by 2022 and a 20% blending target by 2030. A major challenge in this highly populated country is balancing land use for food production with land for biofuel crops.
While nationwide access to electricity has recently been achieved, access to clean cooking has only made significant progress in recent years. Government action on clean cooking has focused successfully on liquefied petroleum gas (LPG). To ensure a level playing field for ethanol, a government support scheme is needed so that ethanol can be rolled out as an equally clean but more environmentally friendly cooking fuel, possibly in combination with methanol.

With close to 1.4 billion people, India is the most populous country in the world after China and has a population density approaching 469 per square kilometer. This poses huge challenges for energy generation and use. While ethanol value chains already contribute to the energy supply in India, they may play an even larger role in the future – both in the transport sector and in cooking applications.

Ethanol in India is currently mostly produced from molasses, but some is derived from surplus food grains such as corn and cassava (IEA, 2021). A recent publication summarizes various actions taken to promote advanced transport fuels, including a policy to support second-generation ethanol biorefineries and cellulosic ethanol.[2]

BIOETHANOL AS A TRANSPORT FUEL

India introduced the use of ethanol as an automotive fuel in 2003, with mandatory blending of 5% ethanol in nine major sugar producing states and four union territories. The blending mandate was made optional in October 2004 due to an ethanol shortage, and resumed in October 2006, incorporating a gradual rise to 10%. Since then, the country has worked to establish a growing blending quota nationwide.

INDIA

POPULATION	1,393 million
AREA	3.29 million km²
POPULATION DENSIT	468.7

2nd most populous country in the world

ETHANOL BLENDING in transport fuel since 2003

CLEAN COOKING ACCESS rose from 22% in 2000 to 64% in 2019

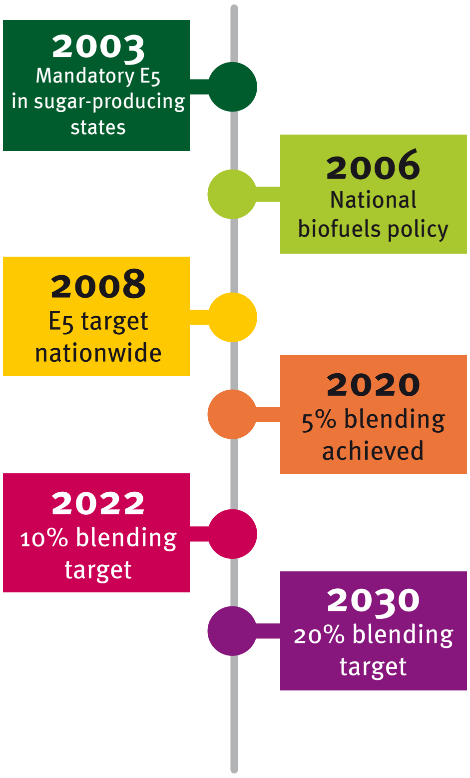
Clean cooking programs have focused on LPG

Potential of ethanol to create full access to clean cooking so far under-realized

Statistics from UNData and the UN Energy Progress Report

2. Gutpa et al., 2020

India



The National Policy on Biofuels was introduced in 2008. A nationwide bioethanol blending blending level of 5% bio-ethanol in gasoline was proposed from October 2008, with a target of 20% by 2017 (which was not met). The government's Ethanol Blended Petrol (EBP) program enabled disribution and sale of E10. In the 2019-20 ethanol supply year a 5% gasoline blending target was achieved, and the government has set a target of 10% by 2022 and 20% by 2030.[3]

Challenges for bioethanol as transport fuel in India[4]

— **Economic barriers:** Production of biofuels is still expensive. The external framework could be improved to promote production.
— **Technical barriers:** Fuel quality is not yet consistent and conservation technologies for certain biofuels are still immature (e.g. for synthetic biofuels)
— **Trade barriers:** Quality standards still need to be introduced for certain biofuels
— **Infrastructure barriers:** New or modified infrastructure is needed for different types of biofuel, especially for use of green hydrogen and biomethane.
— **Ethical barriers:** In many areas, biomass feedstock sources may compete with food supply sources, requiring careful management.
— **Knowledge barriers:** Knowledge about biofuels and their benefits needs to be transmitted more wodely among the general public, but also among decision-makers and politicians.
— **Political barriers:** Governments still subsidize kerosene, promoting inefficient and sometimes illegal use of this fossil fuel. Use of biofuels would be equally or more beneficial to the target population.
— **Interest group conflicts:** Internal conflicts between "promoters" of first and second-generation biofuels could weaken their overall development.

BIOETHANOL AS A CLEAN COOKING FUEL

Ethanol represents an excellent option for India for addressing access to clean cooking, but competes with other technologies. While electrification in India is progressing well (see Figure 9), the International Energy Agency (IEA) states that a full transition to clean cooking is one of the next major challenges for India. Access to clean cooking is not only about technical availability: it also encompasses issues of adequacy, reliability, convenience, safety and affordability (IEA, 2021).

Approximately 400 million people in India are exposed to indoor air pollution from cooking fires. Project Gaia,[5] an international non-profit organization dedicated to increasing access to clean cooking, states that over two-thirds of all Indian households still rely on traditional solid fuels such as wood, agricultural residues, and cow dung for cooking. While urban households are making progress in converting to cleaner-burning fuels, progress in rural households is slower. 85% of rural households rely on traditional solid fuels.

3. https://vikaspedia.in/energy/energy-basics/ethanol-as-fuel
4. Blanchard, et al., 2015
5. https://projectgaia.com/projects/india/

The government's most prominent efforts to increase access to clean cooking have centered on a program to provide subsidized LPG connections, reaching over 77 million households as of August 2019. A recent study claims that 94% of Indian households have an LPG connection as of 2019; nevertheless, in six of the most energy access-deprived states, only about a third of rural population use LPG as their primary cooking fuel (Patnaik et al., 2019).

Project Gaia emphasizes that both methanol and ethanol are appropriate cooking fuel solutions for India. Methanol can be produced from biomass waste and municipal solid waste, as well as natural gas and the country's vast lignite reserves. Small-scale, farm and village-based ethanol production could be the answer to providing clean liquid fuels to rural communities. Ethanol micro-distilleries (EMDs) can be owned and operated by and within communities, providing them not only with clean cooking energy, but economic opportunities as well. These EMDs can use otherwise wasted feedstocks, such as cashew apples and other tree fruits such as guava, mango, and jackfruit to produce clean cooking fuel. Gaia's partner CTxGREEN has already had success with its "village level biofuel" production model in the state of Odisha, as well as with the use of the CleanCook stove.

Project Gaia further points out that ethanol and methanol are not mutually exclusive in their use. When mixed, the combustion efficiency of ethanol can be improved, and greater energy content is achieved than in methanol alone. From a fiscal and practical perspective, a methanol fuel economy would make small-scale ethanol production for cooking more feasible, as it would provide a fuel infrastructure that ethanol could fit into.

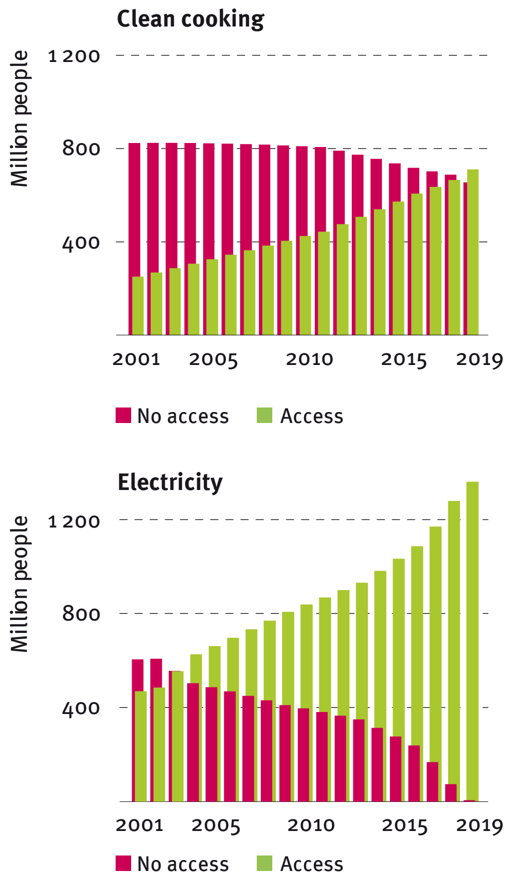


Figure 18: Access to electricity and clean cooking in India

India connected almost half a billion people to the electricity grid during the last decade; attaining universal access to clean cooking is the next big challenge (IEA, 2021)

Figure 19: Ethanol stove in operation in Namrup, India (Project Gaia)

Challenges: ethanol as cooking fuel in India

— Access to clean cooking remains a challenge in several Indian regions and political measures need to be taken to enable improvement.
— Ethanol is still largely seen as offering potential in the transport sector, while the focus for clean cooking has been on expanding LPG and electricity access.
— This means ethanol's promising features as a clean cooking fuel have been neglected – in particular, it is a renewable fuel and can be produced in micro-distilleries.
— Cooking with ethanol is more user-friendly and convenient for consumers and in order for them to benefit, similar incentives need to be established as for LPG, which is a fossil fuel.
— In order to develop an ethanol sector for cooking, access to financing for local stove distributors and small ethanol producers needs to be supported.
— Despite the major progress made on advanced cooking in India, there are still regions in the country that are lagging behind. In these regions, the application of ethanol as cooking fuel offers a solution.

Photo: Phuong D. Nguyen

Thailand: bioethanol to support climate commitments

Promoting biofuels is one of the measures that Thailand has taken to fulfil its nationally determined contributions (NDCs) under the Paris Agreement. Ethanol was introduced as a blending component in transport fuels in 2001, taking advantage of its high octane rating and supporting the phase-out of leaded gasoline. Since ethanol production is more costly than gasoline, subsidies are provided by the State Oil Fund to make E10 blends cost-competitive at the pump.

Ethanol is mainly produced from molasses and cassava. Ethanol imports and exports are restricted and require government approval. So that food security is not compromised, national feedstock production capacity is carefully monitored in relation to domestic demand for ethanol.

Thailand committed to reducing its greenhouse gas emissions by 110-140 million tons of CO2 equivalent (20-25% of 2015 emissions) by 2030 at the Paris Climate Conference in 2015. The country's NDC roadmap, published in 2016, targets 113 million tons of emission reductions in the energy and transport sectors. Promotion of biofuels and increasing renewable energy in households were included as measures in the roadmap.

The objectives of Thailand's energy policy are secure energy supplies, fair energy prices, and the reduction of pollution. The country revises and publishes an Alternative Energy Development Plan (AEDP) periodically. The overall goals of the 2015 AEDP were that 30% of total energy consumption will come from renewables by 2036, with biofuels contributing 6.65% of the energy mix, while a biofuel share of 25% of total fuel consumption is targeted by 2036. In addition, an annual ethanol consumption target of 4.1 billion liters (bn l) by 2036 was set (from 1.2 bn l in 2015); in 2018, this ambitious target was revised down to 2.7 bn l.

Ethanol production is focused on providing environmentally friendly transport fuel. The main feedstocks for ethanol production in Thailand in 2017 were molasses (60%, approx. 868 m l), cassava (35%, approx. 523 m l) and sugarcane (5%, approx. 71 m l). The share of cassava-based ethanol decreased in 2018, as prices for cassava rose, while the share of molasses-based ethanol

THAILAND

POPULATION	70 million
AREA	513 thousand km²
POPULATION DENSITY	136.9

80% OF THE POPULATION has access to clean cooking (LPG has boosted access)

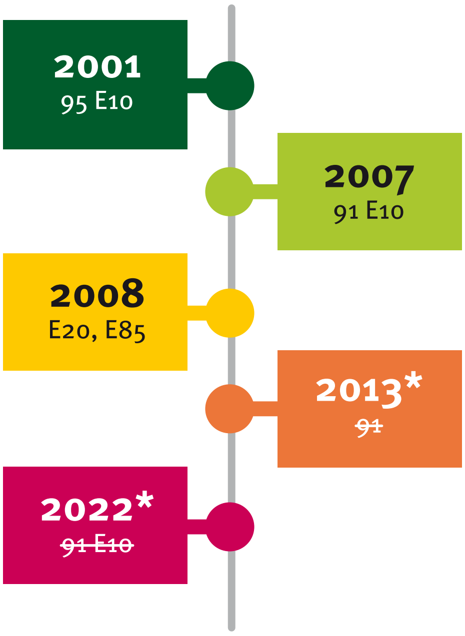
27 ETHANOL PLANTS in operation with total production capacity of 2,300 m l. a year

E10, E20, AND E85 gasoline widely available and price-subsidized – 96% of gasoline sales were ethanol blends in 2018

Government support for manufacture and sale of vehicles running on high ethanol blends

Statistics from sources cited below, UNData and the UN Energy Progress Report

Thailand



* **Fuel 91** was phased out in 2013 and **Fuel 91 E10** in 2022.

increased. Ethanol production plants using sugarcane as feedstock were operating at full capacity. Further ethanol production plants are planned.

Agricultural productivity for biofuels is below the target under Thailand's biofuels development plan. The average sugarcane yield is 44-75 tons per hectare (t/ha),[8] compared with a target of more than 94 t/ha. For cassava the figure is around 22 t/ha, compared to the target of 31 t/ha. **However, Thailand exports cassava, which indicates that food supplies are not being negatively affected by ethanol production.**

BIOETHANOL AS A TRANSPORT FUEL

The government promotes ethanol blends through price incentives at gas stations, which are paid for by the State Oil Fund. A 10% ethanol blend in gasoline (E10) is 20% cheaper than regular (95) gasoline, and E20 and E85 blends are 30-40% cheaper. The government has also introduced an excise tax reduction for cars that can run on E20 and E85. The AEDP does not set production targets for second and third generation biofuels, but research is being conducted at universities. In 2020, approximately 4,700 gas stations offered E20 and 1,300 gas stations offered E85.[9]

The situation today

— 27 plants producing ethanol, mainly for use as transport fuel.
— Total ethanal production capacity approx. 2,300 million liters a year.
— Thailand follows the ASTM standard for ethanol (99.5% pure)
— In 2017, ethanol production amounted to 1,461 million liters (about 80% of capacity at that time).
— Production has slightly exceeded demand in recent years. Ethanol is not imported for use as a transport fuel, and exports are marginal.

Historical gasoline/ethanol consumption in Thailand

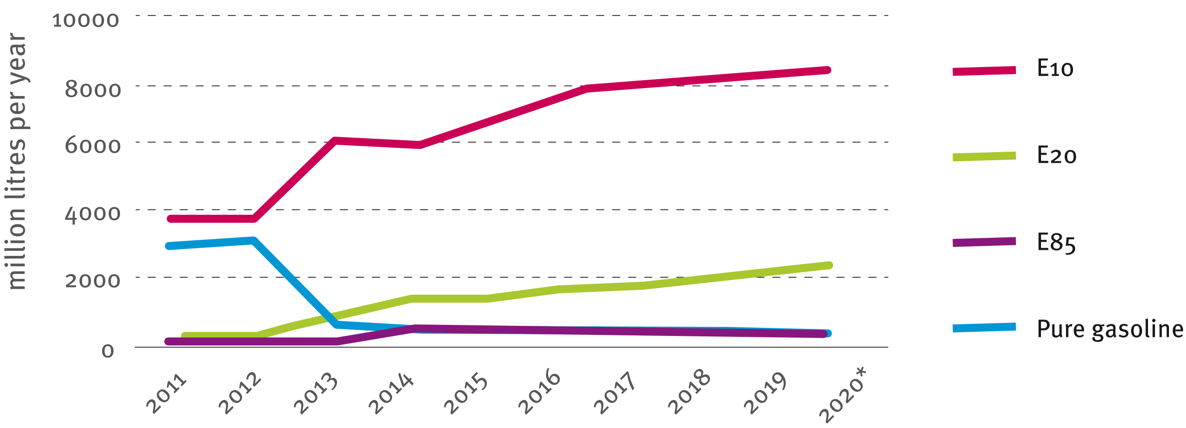


Figure 20: Historical gasoline and ethanol consumption in Thailand in million liters per year

8 http://www.ocsb.go.th/th/board_enactment/mission.php?id=254&SystemModuleKey=mission
9 Wuttimongkolchai, 2021

In 2018, ethanol blends accounted for about 96% of total gasoline sales. Historic gasoline and ethanol consumption in Thailand are shown in Figure 12. The government had planned to eliminate 91 gasoline blended with 10% ethanol (91 E10) by 2022, with consumption of E20 rising correspondingly. However, doubts regarding the availiability of biomass to produce the required ethanol for E20 demand resulted in postponement of the decision to boost E20 by abolishing 91 E10.

Nevertheless, thanks to price incentives, overall ethanol consumption is still growing. Demand for gasoline, including ethanol blends, is expected to decrease over the medium to long term due to the commercialization of electric vehicles (with a target of 1.2 million vehicles on the roads by 2036), as well as implementation of double-track railways and high-speed trains in the next five years.[10]

In Thailand liquefied petrolem gas (LPG) rather than ethanol is used for clean cooking (Wuttimongkolchai, 2021).

Historical ethanol production in Thailand

Figure 21: Historical ethanol production in Thailand (million liters)
*prediction

Summary: drivers and challenges – ethanol as a vehicle fuel in Thailand

— Ethanol industry development in Thailand is driven by the government's commitment to reducing greenhouse gases

— Ethanol development also supports an overall energy strategy to guarantee security of supply and fair energy prices, and reduce petroleum imports

— Under current conditions, feedstock supplies for ethanol (molasses, cassava) may not be sufficient to meet Thailand's biofuels consumption targets for 2036

— Public acceptance of alternative fuels needs to be boosted to remove barriers to the growth of E20 and E85 use

10. Prasertsri & Chanikornpradit, 2020

Mozambique: policy frameworks to safeguard sustainability

Due to favorable biophysical conditions, a well-developed sugar production sector and an existing policy and regulatory framework, Mozambique possesses large potential for development of a national ethanol industry. Overall, land availability is not expected to be a constraint on cultivation of feedstock for ethanol production. Mozambique introduced its National Biofuel Policy and Strategy in May 2009, providing guidelines for the development of a biofuels industry. And Maputo, the capital of Mozambique, was the first major city in Sub-Saharan Africa to benefit from large-scale commercialization of ethanol for clean cooking, through a private sector initiative.

MOZAMBIQUE

POPULATION	32 million
AREA	799 thousand km2
POPULATION DENSITY	40.9

POLICY FRAMEWORKS have been developed, investment is lacking

PRIVATE ENTERPRISES spearheaded successful establishment of ethanol distribution for cooking purposes in Maputo

ONLY 5% of population have access to clean cooking

Well-established sugar cane sector

Sensitive land use modeling in place for energy crop cultivation

Mozambique's principal objectives in actively encouraging the introduction of biofuels were to save foreign currency outflows, to curb the environmental impact of a growing transport sector, to reduce dependence on volatile oil prices, and to contribute to rural development through generating employment and increasing income opportunities.[11]

BIOETHANOL AS A TRANSPORT FUEL

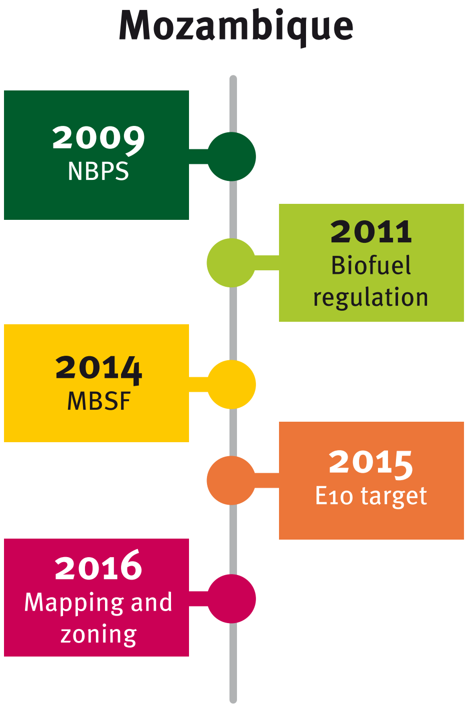
With a clear vision for establishing the country's biofuels sector to support energy security, and socially and economically sustainable development, the government of Mozambique published a National Biofuels Policy and Strategy (NBPS) in 2009. A biofuel regulation was approved in 2011 addressing production, storage, distribution and sales, and introducing biofuel blends (E10, B3) in fossil fuels by 2015. National standards were established for a variety of biofuels, as well as technical and licensing regulations. The overall aim was to create a favorable framework to stimulate national and international investment for establishing a domestic biofuels industry.

Detailed resource assessment and research identified sugarcane, cassava, and sweet sorghum as suitable feedstocks for ethanol production. An agro-ecological zoning initiative to avoid potential food-fuel conflicts identified about 7 million hectares suitable for land-based economic activities, of which 3 million hectares were judged appropriate for agricul-

11. Janssen & Rutz, 2015

tural investments.[12] Resource assessments were supported by spatiotemporal land use modelling to assess land availability for energy crops.[13] Nevertheless, negative local, national and international public perceptions regarding biofuels, due to concerns about possible land grabbing, food versus fuel conflicts, and inadequate project planning, have proven to be a barrier to development.

In response to the favorable policy framework for the development of a biofuels industry in Mozambique, several investment proposals were submitted in the period 2008-2012. However, due to the financial crisis in the following years, a strong economic recession in Mozambique in 2015, and low global crude oil prices, most biofuel projects were suspended, with the exception of the initiative by Cleanstar Mozambique to produce of ethanol from cassava feedstock (see below).



In order to ensure environmentally, economically and socially sustainable production, promotion and use of biofuels in Mozambique, the Mozambique Biofuel Sustainability Framework (MBFS) was drawn up in 2014, with support from the Netherlands Programs for Sustainable Biomass.[14] As a result, compliance with established sustainability criteria is a prerequisite for approval of investment proposals for commercial production of biofuels.[15]

The situation today

Despite an existing ethanol blending mandate (E10), a well-developed sugarcane sector and the availability of suitable land for feedstock production, ethanol is currently not used as transport fuel in Mozambique, due to lack of the investment required to establish fuel ethanol value chains. Current annual ethanol production in Mozambique amounts to about 45 million liters, with small production facilities scattered around the country, and the end use of the ethanol largely unknown.[16] According to recent news, the Government of Mozambique is planning to relaunch the national biofuels blending program in the coming months.

BIOETHANOL AS A COOKING FUEL

In Mozambique traditional biomass fuels dominate the household cooking sector, with only 5% of the population having access to clean cooking as of 2021.[17] Fuelwood and charcoal account for 59% and 23% of cooking fuel demand and urban households predominately use charcoal for cooking, regardless of their income level. Furthermore, the charcoal sector plays a prominent role in the national economy, employing between 136,000 and 214,000 people on a full-time basis.[18]

12. Wilkinson, 2014; Tostão, Henley, Tembe, & Baloi, 2016
13. Van der Hilst & Faaij, 2012
14. Visser & Chidamoio, 2014
15. Schut et al., 2010
16. Venichand, 2021
17. https://trackingsdg7.esmap.org/country/mozambique
18. European Union Energy Initiative (EUEI), 2012; Castán Broto et al., 2020

The widespread use of charcoal raises concerns regarding large-scale deforestation and ecosystem service degradation. Charcoal users in Maputo and Matola consume an equivalent of 1.8 million tons of wood each year. This is not to mention the negative health and pollution impacts of charcoal stoves.

Activities to introduce ethanol gel fuel stoves in Mozambique were initiated by Zoe Enterprises, a family business, in 2006. Building on the infrastructure and clean stove distribution networks established by Zoe Enterprises, another private enterprise, Cleanstar, implemented a large-scale program focused on the capital and largest city, Maputo, promoting ethanol stoves as a clean alternative to charcoal. Sales effectively started at the end of 2012. Rapid market penetration was achieved through 160 ethanol distributors, reaching 34,000 consumers and a monthly ethanol consumption of 70,000-140,000 liters.[19]

The Cleanstar initiative included an ethanol production component in the city of Beira (Central Mozambique) with cassava sourced from smallholder farmers in the north of the country. However, ethanol production was suspended in 2013 and distribution was transferred to Zoe Enterprises under its NDZiLO brand. The halt in production resulted in a shortage of ethanol supply on the market; initial imports of lower-quality ethanol from South Africa often caused underperformance and canister malfunction, leading to consumers switching back to charcoal and LPG.[20] To address this problem and revive the ethanol stove sector in Mozambique, NDZiLO started importing high-quality ethanol from South Africa. In July 2015, ethanol demand in Maputo was about 80,000 liters per month with 10,000 consumers, constituting the largest urban consumer base for ethanol stoves in Sub-Saharan Africa. However, in the ensuing years high prices for imported ethanol led to a significant decline of the ethanol cooking market, and Zoe Enterprises closed its business in 2018.

OUTLOOK: BIOETHANOL AS A COOKING FUEL

A recent study of consumer perceptions of the adoption and use of ethanol fuels and cookstoves in Maputo identified benefits of and barriers to the use of ethanol as a clean cooking fuel. Based on household interviews, focus group discussions, and expert interviews with actors along the ethanol value chain, it was found that ethanol has mainly replaced other clean cooking fuels such as LPG, rather than replacing charcoal. Furthermore, clean cooking fuels (electricity, LPG, ethanol) are largely used in combination with charcoal.

According to users, ethanol stoves compare favorably against charcoal in terms of cooking time, convenience, cleanliness and easiness to use. However, high ethanol fuel prices, low fuel quality and accessibility, and stove malfunctions due to poor design have led many ethanol stove adopters to switch back to charcoal.

Effective, lasting uptake of ethanol will require correction of the factors that tend to discourage its use, in particular high initial and operational cost, poor fuel quality, unreliable fuel supplies, and poor stove design. Furthermore, locally produced ethanol is a key success factor, to assure fuel availability, local value creation, and income opportunities.

19. Mudombi et al., 2018

20. Costa C., 2019; Mudombi et al., 2018

Recently the government has implemented a program promoting LPG produced from domestic natural gas reserves as a clean cooking fuel, in Mozambique's five largest cities. Tax benefits ensure that LPG costs are competitive. As a result, ethanol-based cooking may be limited to areas outside the big cities and demand for ethanol as a cooking fuel is expected to remain limited for the foreseeable future, according to Thelma Venichand, the director of Zoe Enterprises.

Figure 22: NDZilo sales store for bioethanol stoves and bioethanol fuel in Maputo (Project Gaia)

Policy recommendations for establishing a successful ethanol cooking market

The following factors supported initial rapid market penetration of ethanol stoves in Maputo in 2012:

— An enabling policy and institutional environment. The National Biofuels Policy and Strategy (NBPS) provided clear guidelines to the public and private sectors, as well as incentives and subsidies for ethanol producers

— Effective utilization of pre-existing market channels. Market penetration was based on the existing client base and distribution networks for ethanol gel.

— Extensive awareness-raising campaigns and capacity-building efforts: spreading information on ethanol stoves through TV commercials, billboards, and door-to-door visits by sales teams

— Effective post-acquisition customer services and support. This was implemented by staff from Zoe Enterprises.

Lessons learned: recommendations for lasting, successful development of bioethanol for clean cooking, based on experiences in Mozambique.

— Governments in developing countries need to design and implement comprehensive policies that support a range of end uses for ethanol as well as initiatives and actors along the ethanol value chain. In Mozambique, both local and international actors were attracted to invest in the biofuels sector. This supported the development of infrastructure for fuel and stove distribution, awareness raising and user education.

— Ethanol stove and fuel costs need to be competitive to achieve large-scale market uptake. High ethanol fuel costs are considered the main barrier by users in Maputo today. Governments can limit taxes on ethanol, in support of its health and environmental benefits, and provide subsidies for stoves and fuel, boosting affordability for consumers.

— National and local ethanol markets and value chains need to be developed and strengthened jointly by the public and private sector. Governments can provide support through research and innovation activities, technical capacity building, awareness raising and educational campaigns. Mandatory blending of ethanol can create a viable market and contribute to cost reductions for ethanol production, thereby also benefitting ethanol use as a cooking fuel.

— Efforts to promote ethanol markets in African countries need to take into account and appropriately address the specific local and regional framework conditions. Ethanol markets have been successfully developed in Brazil, the US and Europe. However, such initiatives have failed to gain lasting traction in most African countries, including Mozambique.

— Ethanol development can have both positive and negative environmental, social and cultural impacts. Adopted policies need to carefully address potential trade-offs and aim to minimize negative impacts. In Mozambique, a national sustainability framework was developed in order to ensure environmentally, economically and socially sustainable production, promotion and use of biofuels.

Deployment challenges

Due to the range of challenges, developing an ethanol industry requires careful planning. This chapter provides an overview of challenges related to feedstock production, ethanol production, ethanol consumption, and market issues, as well as strategies to overcome them.

Strategies to overcome challenges regarding feedstock production

Challenge	Strategies
– Effect on food availability and food prices	– Monitoring of food security – Balancing the incentives (blending mandate, subsidies) with national feedstock availability
– Direct and indirect land use change with negative effects on vegetation such as rain-forests – Loss of biodiversity through large-scale monocultural plantations	– Resource assessment to identify promising feedstocks – Agri-ecological zoning to identify suitable cultivation areas – Sustainability framework to safeguard the deployment of ethanol – Crop rotations and intercropping – Supporting small-scale plantation systems
– Inefficient land use	– Support of R&D in breeding and new varieties
– Air pollution and health risks from harvesting techniques	– Mechanical harvesting
– Displacement of small-scale farmers from their land	– Inclusion of land use patterns and land use rights in mapping and zoning
– Biomass supply chains	– Clear concept for supply chains – Involvement of local stakeholders from early planning stage
– Mobilization of residues and waste	– Setting up waste management structures – Monitoring of alternative uses
– Feedstock yields	– Resource assessments to identify promising feedstocks – Agri-ecological zoning to identify suitable cultivation areas – Support of R&D in breeding and new high yield varieties

Table 7: Strategies to overcome challenges regarding feedstock production

Strategies to overcome challenges regarding ethanol production

Challenge	Strategies
– Ethanol produced results in low greenhouse gas (GHG) emissions reduction	– Obligatory calculation of life-cycle GHG emissions of all ethanol used – Minimum GHG emission reduction requirement – GHG reduction quota instead of volume- or energy- based blending mandate
– High energy consumption of conversion facilities since there is surplus biomass and no possibility to feed in surplus electricity	– Independent power producer schemes – Green electricity tariffs – Grid access / grid expansion / local mini-grids
– (Seasonal) lack of ethanol availability	– Storage reserves for feedstocks – Storage reserves for ethanol

Table 8: Strategies to overcome challenges regarding ethanol production

Strategies to overcome challenges regarding ethanol consumption

Challenge	Strategies
– Lack of consumer acceptance of ethanol blends for vehicles or ethanol as cooking fuel	– Adequate fuel standards – Fuel quality control – Fuel labelling at the pump – Information campaign about vehicle compatibility
– Reluctance of consumers to purchase alternative fuel (E85) vehicles	– Tax reductions for alternative fuel vehicles – Reduction of annual registration fees for alternative fuel vehicles
– Distribution of clean cooking fuel to remote areas and to households with low income	– Encourage local ethanol production e.g. through micro-distilleries – Pay-as-you-go schemes, mobile payments
– Access to ethanol cooking stoves	– Support investors in cooking stove production – Support acquisition of cooking stoves (once off capital subsidies)
– Functionality of cooking stoves	– Standard for ethanol cooking stoves – Standards for ethanol as cooking fuel

Table 9: Strategies to overcome challenges regarding ethanol consumption

Strategies to overcome market issues

Challenge	Strategies
– Local population does not receive fair share of added value; large-scale or foreign investors obtain most added value	– Local content requirements – Outgrower schemes for production of feed-stock by small farmers – Investments in education, national R&D for agricultural practices and conversion technol-ogies
– Blending mandates encourage imports in-stead of supporting national production	– Only allow provision of domestically pro-duced ethanol – Require permits for ethanol imports or ex-ports
– Lack of investment	– Clear framework for investors (including policies) – Funding for investments into the agricultural sector and the biofuel manufacturing sector – Access to credit, loan guarantees – Tailor-made financing schemes to support large-scale industries and local SMEs – Social financing schemes (results-based financing practices, pay-as-you-go schemes, mobile payments, microcredits)
– Production price for ethanol higher than for current fuels for transport and/or cooking	– Tax exemptions – Remove/decrease fossil fuel subsidies to make ethanol competitive
– Volatility of fossil fuel prices	– Variable ethanol subsidies
– Negative public perception of biofuels due to e.g. land grabbing, land use change, inappro-priate project planning, lack of understanding of the agricultural sector by potential inves-tors	– Early introduction of safeguards to avoid negative effects
– Cost of installing new pump at filling stations to provide ethanol blend	– Replace low-octane gasoline with ethanol blend

Table 10: Strategies to overcome market issues

Conclusions: How to develop a bioethanol industry

Developing an ethanol industry, both for clean cooking and for substituting gasoline in transport, provides opportunities for developing countries to gain considerable socioeconomic benefits. Moreover, enabling an ethanol market for both fuel blending and clean cooking will contribute to ten of the 17 global sustainable development goals.

The broad scope of these benefits ranges from reduced fossil fuel consumption by transport to lower indoor air pollution, creating healthier living conditions, especially for women and children. Ethanol is a renewable biogenic fuel, leading to reduced emissions of greenhouse gases when substituting non-renewable petroleum fuels. Fuel import dependencies are decreased, while national industrial and economic development is strengthened. In-country production improves energy security and self-reliance, and energy access is provided to energy-disenfranchised communities. Decentralized production creates jobs in rural areas, building upon synergies with the agricultural sector.

The development of a significant ethanol industry requires careful planning in order to make the most of the potential socioeconomic benefits and avoid adverse effects. Existing ethanol programs, such as Proálcool in Brazil, demonstrate that an ethanol industry can be successfully established if all stakeholders are involved and a well-balanced set of measures is adopted.

Recommendations for sustainable implementation of ethanol production

- Establish collaboration with countries that also aim to develop an ethanol industry to discuss regulatory options, identify peculiarities and similarities, and jointly evaluate the impact of measures and progress towards targets.

- Collaborate with countries that have already successfully implemented an ethanol industry to learn about how they have addressed challenges, and the impact their specific set of measures has had. Collaboration can take place with individual countries as well as through existing collaborative platforms, such as Biofuture Platform and IEA Bioenergy,

- Create a policy framework that addresses all six critical policy issues identified in the Biofuture Platform Policy Blueprint: strategic priority, policy clarity and certainty, market access, financial support, sustainability governance, and innovation support.

- Identify the country-specific drivers of establishing the ethanol economy (e.g. rural income, reduced indoor air pollution, greenhouse gas emissions reductions) and set clear targets (e.g. percentage of ethanol used in transport, percentage of households switching to ethanol as a cooking fuel).

- Involve representatives of all stakeholders along the value chain in the development of a well-balanced set of measures, including farmers' associations, existing sugarcane or cassava industries, conversion technology providers, fuel producers and distributors, cooking stove vendors, investors, and researchers in the fields of agriculture, fuel production and the automotive industry.

— Carefully assess country-specific risks and barriers and develop strategies to overcome these challenges (e.g. loss of biodiversity, negative effects on food availability or price, inefficient ethanol production facilities, lack of consumer acceptance, lack of investment).

— Develop a set of measures to create the market for ethanol (e.g. obligatory blending, clean cooking programs), make it affordable (e.g. tax exemptions, subsidies for stove purchases), and stimulate feedstock production and investment along the value chain (e.g. access to credit guarantees), while minimizing negative impacts (e.g. through land mapping and zoning, implementation of ethanol fuel standards, local content requirements).

— Appoint and authorize appropriate institutions to implement and drive forward all measures against clear time lines and with clear achievement levels.

— Ensure that a certain percentage of ethanol produced is reserved for cooking fuel markets when aiming to introduce ethanol both as a blending component for transport fuel and as a cooking fuel. Require the ethanol supply chain to hold strategic stocks to ensure no short-falls in cooking fuel.

— Make use of pre-existing infrastructure and markets for feedstock production, ethanol production, and final use in transport and clean cooking applications.

— Create awareness within communities of the health and social benefits of switching to ethanol cooking, and implement feedback mechanisms to monitor the societal effects of switching to ethanol, and to prevent switching back to "dirty" fuels.

— Promote and support research and innovation to develop and strengthen local ethanol markets and value chains.

— Frequently evaluate progress towards identified targets, as well as all impacts, and adapt the set of measures accordingly.

APPENDIX: TECHNICAL ASPECTS AND BENEFITS OF BIOETHANOL APPLICATIONS

THE MOST COMMON PRODUCTION PROCESSES for bioethanol – using sugarcane, cassava and corn (maize) – are outlined here, as well as the technical requirements and benefits of ethanol for use as transport fuel and as cooking fuel.

Bioethanol production processes

A variety of agricultural feedstocks can be used to produce bioethanol. In developing countries, the most-used feedstocks are sugarcane, cassava and corn (maize).

ETHANOL FROM SUGARCANE[1]

The diagram below (Figure 23) illustrates the production process in a combined sugar and ethanol plant. Juice is extracted from sugarcane and treated, then used to produce ethanol or sugar. The proportions of sugar and ethanol produced are flexible, so production can be adapted depending on demand. In the ethanol process, the treated sugarcane juice is fermented with syrup and molasses from sugar production. The resulting wine is distilled to produce ethanol.
Production of anhydrous ethanol (99% purity, with water content removed), for use in gasoline fuel blends for conventional vehicles, requires an energy-intensive extra purification stage. However, in sub-tropical and tropical climates, hydrous ethanol can be used, omitting this final step.
Bagasse, the fibrous sugar cane material remaining after juice extraction, can be used for process energy generation, improving the net energy balance of the process and reducing greenhouse gas emissions.

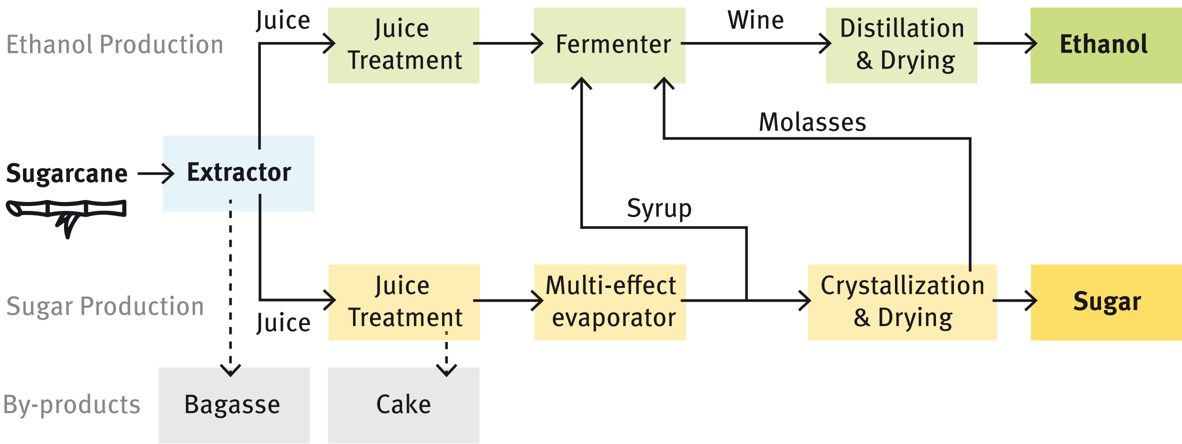


Figure 23: Simplified integrated sugarcane ethanol production process

ETHANOL FROM CASSAVA

Cassava flour is required to produce cassava ethanol. The first two steps are liquefaction and saccharification, simple chemical processes which convert the cassava flour into a broth, which is then fermented and distilled. The end products are ethanol and the dry sludge, which can be used as fertilizer. Figure 24 shows a simplified cassava ethanol production process.

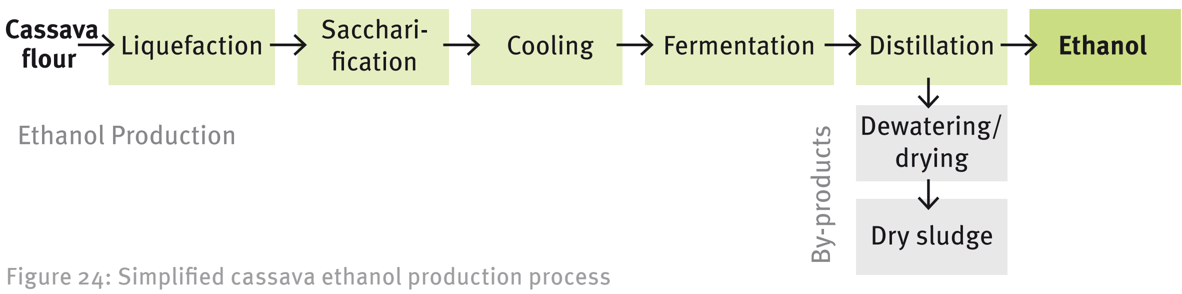


Figure 24: Simplified cassava ethanol production process

1. https://www.e-education.psu.edu/egee439/node/647

ETHANOL FROM CORN

For the production of corn ethanol, maize is milled and the gluten is separated and dried. After saccharification, the milled feedstock is fermented and distilled. Protein-rich residues are separated and dried. Dried distillers grains with solubles (DDGS) are a by-product of the process and can be used as high-value animal feed. Figure 25 shows a simplified corn ethanol production process.

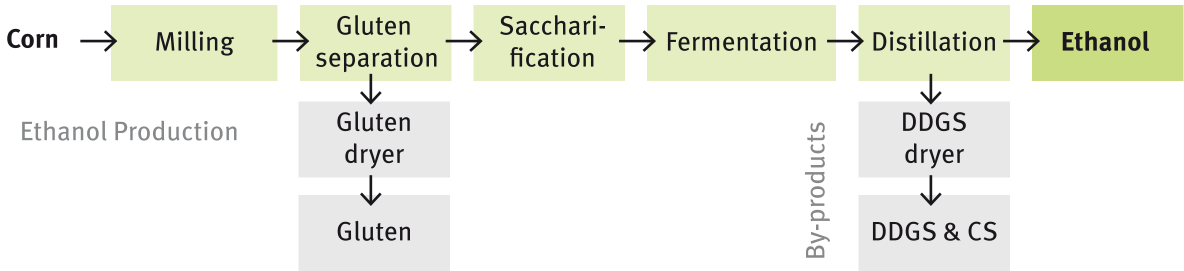


Figure 25: Simplified corn ethanol production process

The figures below show typical crop yields (tons per hectare) and ethanol yields (liters per hectare) from sugarcane, cassava and maize, globally and in selected countries with established production.

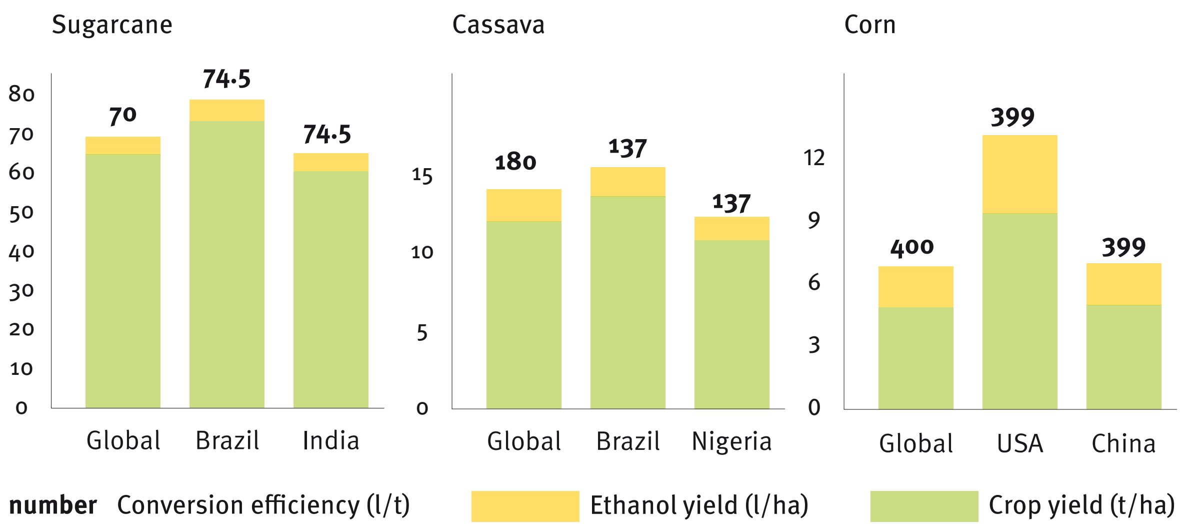


Figure 26: Biofuel yields (FAO, 2008)

Different applications for ethanol have differing technical requirements. While ethanol for transport fuel requires industrial production, ethanol for use as a cooking fuel can be produced in micro-distilleries.

Low level bioethanol blends for existing vehicle fleets

Blending gasoline with ethanol is beneficial to combustion, since ethanol improves the octane rating of fuel. Most gasoline-fueled vehicles are compatible with low ethanol blends, such as E5 and E10 (5% ethanol and 10% ethanol, respectively). High blends (e.g. E85) require dedicated vehicles, such as flex-fuel vehicles. Hydrous ethanol, which is more economical to produce, can be used in tropical and sub-tropical climates.

Ethanol is a light alcohol that burns with an almost invisible flame and is biodegradable. It has a series of technical advantages as a fuel for petrol engines. First, ethanol has a very high octane rating. Adding ethanol enhances the quality of the resulting gasohol (gasoline-ethanol blend) fuel, giving the fuel a strong resistance to knock and potentially improving engine performance. Second, ethanol has a high heat of vaporization, enabling an air-cooling effect on the engine. This enhances cylinder filling efficiency, partly offsetting ethanol's lower energy content per liter. Finally, the presence of oxygen in the ethanol molecule enables a more homogeneous fuel-air mix, permitting low-temperature combustion, which reduces polluting emissions of unburned or partially burned molecules (hydrocarbons [HC], carbon monoxide [CO], and nitrogen oxides [NOx]). Low-percentage ethanol-gasoline blends (E5, E10) can be used effectively in most conventional gasoline engines without technical adaptations. Higher blends require flexible fuel vehicles (FFVs), which can run on any gasoline-ethanol blend up to 85% (E85).

Despite these advantages, some negative properties of ethanol as a vehicle fuel also have to be considered. The oxygen content in ethanol results in greater fuel consumption, and ethanol's ability to oxidize into acetic acid causes compatibility issues with some materials used in engines, such as certain metals and polymers. Ethanol may also contain metallic ions and other impurities that increase aggressiveness towards materials. The high latent heat of vaporization can cause running difficulties in cold conditions, especially cold starts; and ethanol's chemical qualities can cause volatility issues, as well as the fact that it is miscible with water, which can lead to acetaldehyde emissions.[2]

HYDROUS ETHANOL

Hydrous ethanol (96% ethanol) contains a small percentage of water. Its production does not require the final, energy-intensive distillation step. In Brazil, pure hydrous ethanol is available at every filling station. FFVs are able to run on gasoline, high-blend ethanol or pure hydrous ethanol of any mixture, and can even switch fuels while on the road. The storage and stability of ethanol blends are special issues due to ethanol's affinity with water and the risk of phase separation, which is harmful to cars and infrastructure. In Brazil, there is long experience of blends of around 20% ethanol with gasoline (currently E27). In tropical and sub-tropical climates, hydrous ethanol can be used without the risk of phase separation.

2. https://www.etipbioenergy.eu/index.php?option=com_content&view=article&id=329

Bioethanol stoves: clean and convenient

Cooking with ethanol is easy and more convenient than using traditional fires, as the temperature can be regulated easily, and the stove can quickly be turned on or off. Operation is safe, combustion is very clean and emissions are low. The technology of ethanol stoves is mature and a variety of stoves are available on the market.

Ethanol used for cooking fuel is ethyl alcohol, the same type of alcohol found in alcoholic beverages. It can be produced from sugar or starch crops at small or large scale. An example of the entire process of ethanol production for cooking, using cassava, is shown below in Figure 27. Ethanol production from lignocellulosic materials (plant fibres) at large scale is currently under development, with the main intended purpose being production of transport fuel; however, the cooking sector may benefit from its development as well.

LIQUID ETHANOL OR ETHANOL GEL?

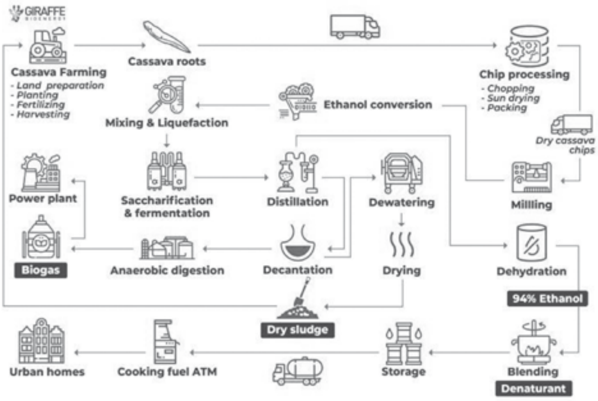


Figure 27: Process of ethanol production for cooking from cassava

Two types of ethanol for cooking exist: pure liquid ethanol, and ethanol gel. Different types of stove are required for these two forms of ethanol. Fuel gel consists mainly of ethanol, with additives than give it a gel-like consistency. The original idea behind using ethanol gel instead of its liquid form was to address safety issues.

However, there are major disadvantages to gel fuels, as described 2007 in a study.[3] Gel fuels are not satisfactory largely because they release significant quantities of pollutants when burned, due to the flame being inherently diffusive. Another issue is that gel fuels carry much less energy than the available alternatives, so cooking a standard meal requires about three times more gel than other fuels, measured by weight. The flame temperature of ethanol gel is much lower (about 600-750°C) than liquid ethanol (900-1,000°C). This means that the price of gel fuel needs to be about one-third of alternative fuels in order to be competitive, and there are no signs that they can be marketed at this price level. As a result, ethanol gel fuels are a niche application, while liquid ethanol is the mainstream form of ethanol fuel for cooking.

Liquid ethanol is used as an uncompressed liquid alcohol that burns without odor. It can also be considered safer than compressed gas such as butane, as it is flammable but not explosive (except under certain circumstances). It is relatively safe to use and hazards are very rare.

ETHANOL STOVES

The technology of ethanol stoves is mature and a number of models are available on the market, both single and double-burner. Some models are made from aluminum or stainless steel to prevent corrosion. Major production facilities of liquid ethanol stoves are located in Durban, South Africa,

3. Lloyd & Visagie, 2007

(CleanCook), as well as in China (BlueFlame) and India (Koko). CleanCook is seeking to license production of its stove in other African countries as well. Among other stove designs, their stoves have been promoted by Project Gaia in campaigns to promote the transition to clean cooking. NGOs and research institutes have also been involved in developing alcohol-fueled stoves, such as the NARI or TERI, both from India.

Stoves may have refillable or replaceable, non-pressurized fuel canisters, and use simple, safe technology to store the fuel and supply it to the burner, removing the danger of leaks, spills or explosions.

In the EU the technology is mainly used for marine and mobile leisure applications, while in developing countries ethanol stoves represent a simple and effective way to replace traditional firewood cook stoves. However, stoves fueled with alcohol (ethanol and methanol) are still not widely used. Use is largely limited to areas where targeted studies and projects have fostered and supported this technology. The potential for alcohol-fueled stoves is huge, due to high consumer acceptance, easy and safe operation, and potential advantages in overall lifetime cooking costs.

Figure 28: CleanCook NOVA 2 in operation in Africa (Project Gaia)

COMPARISON WITH OTHER TYPES OF COOKING FUELS

Ethanol vs. traditional fuels

The convenience and ease of use of ethanol stoves, clean burn and low emissions are all advantages over like firewood and charcoal, which generally produce more smoke and cannot be regulated easily. However, the fuel price of solid biomass fuels is often lower than for ethanol. For this reason, households with ethanol stoves often use them only for preparing hot water or short cooking processes, while solid fuels are still used for cooking meals that need to cook for a longer time, such as beans.

Ethanol vs. liquefied petroleum gas (LPG)

LPG is tax-exempted in a number of developing countries, due to its immediate availability to governments endeavoring to assist households in moving to a clean cooking solution. This results in a a clear consumer price advantage over ethanol, which is often not subsidized due to the newness of the technology and small-scale of programs so far. **In order to promote ethanol, subsidies need to be revised, since ethanol offers major advantages over LPG in terms of safety, ease of distribution, sustainability, and the local and national economy.** Ethanol stoves are safe and operate at ambient pressure, while LPG needs to be pressurized. Furthermore, ethanol is renewable and can be produced at small scale. Finally, the roll-out of ethanol for cooking could also prepare the market for a roll-out of methanol, which it will be possible to produce from renewable sources at large scale in the medium-term future.

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