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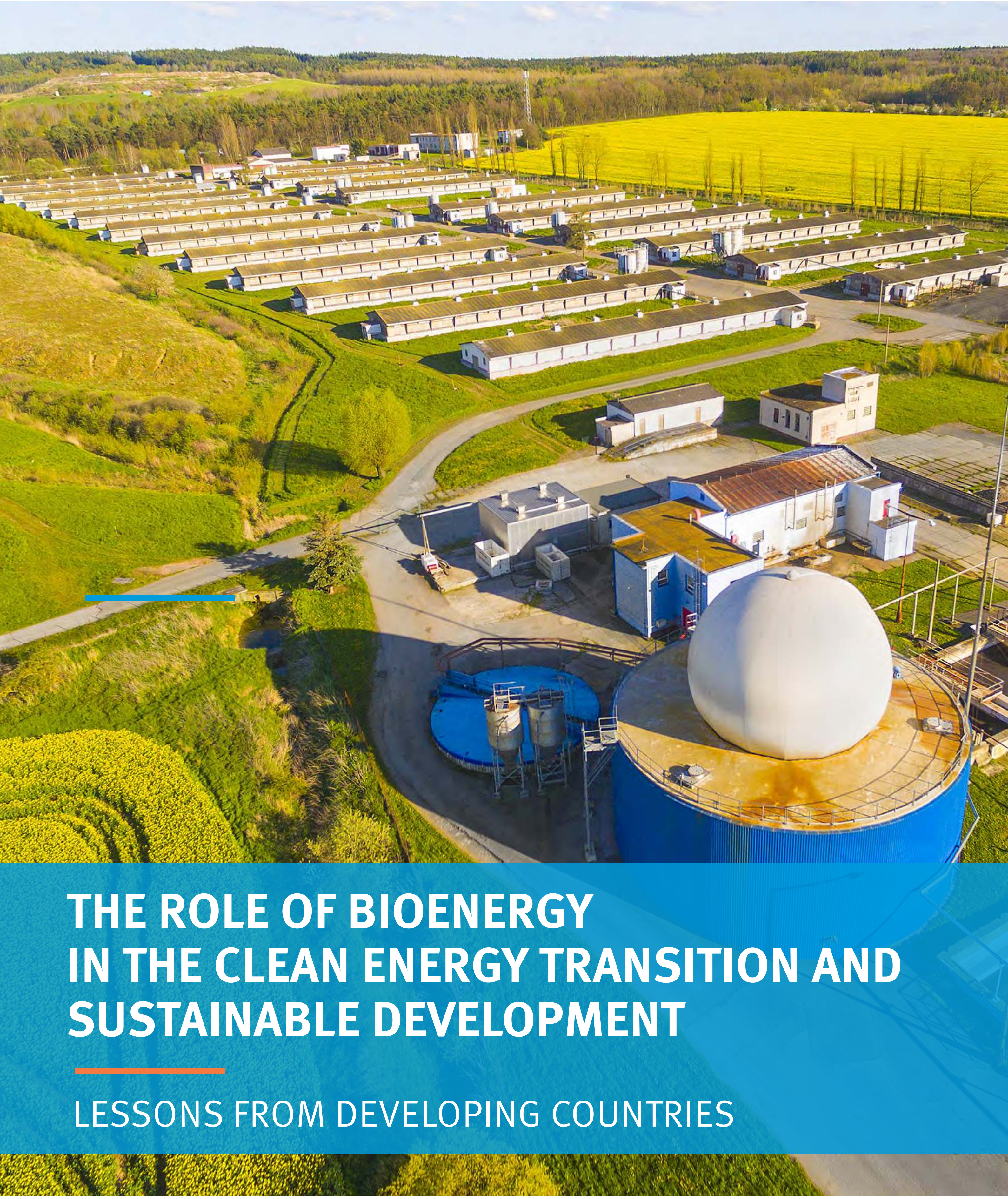

THE ROLE OF BIOENERGY IN THE CLEAN ENERGY TRANSITION AND SUSTAINABLE DEVELOPMENT

LESSONS FROM DEVELOPING COUNTRIES

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ACRONYMS AND ABBREVIATIONS

ACSD	Albanian Center for Sustainable Development	HHEA	Household Energy Economic Analysis	PDD	Program Design Document
ASEAN	Association of Southeast Asian Nations	HIC	High Impact Countries	PoA	Program of Activities
BEIA	Biomass Energy Initiative for Africa	ISBWG	International Sustainable Bioeconomy Working Group	PPA	Power Purchase Agreement
BRL	Brazilian Real	KMUTT	King Mongkut's University of Technology Thonburi	ProAlcool	National Alcohol Program
CCL	Consumer's Choice Limited	KSD	Khongsedone Ltd	PSGF	Private Sector Guarantee Fund
CC-SF	Clean Cooking Social Facility	kW_{el}	Kilowatt electrical	R&D	Research and Development
CHP	Combined Heat and Power	kW_{th}	Kilowatt thermal	RE	Renewable Energy
CO_2	Carbon dioxide	kWh	Kilowatt-hour	RFS	Renewable Fuel Standard
COP	Conference of Parties	kWh_{el}	Kilowatt-hour thermal	ROI	Return on Investment
CSTR	Continuous Stirring Tank Reactor	kWh_{th}	Kilowatt-hour electrical	SCIP	Strategic Climate Institutions Program
DC	Developing Country	Lao PDR	Lao People's Democratic Republic	SDG	Sustainable Development Goal
DFID	Department for International Development	LDC	Least Developed Country	SEI	Stockholm Environment Institute
EGM	Expert Group Meeting	LDO	Liquor Distillery Organization Excise Department	SME	Small and Medium Enterprise
EMD	Ethanol Micro Distillery	LHV	Lower Heating Value	SSA	Sub-Saharan Africa
EPA	Environmental Protection Authority	lpd	Liters per Day	SS-TT	South-South Technology Transfer
EUR	Euro	m^3	Cubic meter	TBS	Tanzanian Bureau of Standards
FAO	Food and Agriculture Organization of the United Nations	M&E	Monitoring and Evaluation	TIB	Tanzania Investment Bank
FIRI	Food Industries Research Institute	MEF	Market Enabling Framework	TPSF	Tanzanian Private Sector Foundation
FIT	Feed-in Tariff	MEL	Monitoring, Evaluation and Learning	US	United States
FWFCA	Former Women Fuelwood Carriers' Association	MW	Megawatt	USD	US dollar
GBE	Green Bio Energy	MWel	Megawatt electrical	VAT	Value Added Tax
GDP	Gross Domestic Product	NDF	Nordic Development Fund	VHG-SSF	Very High Gravity Simultaneous Saccharification and Fermentation
GEF	Global Environmental Facility	NSTDA	National Science and Technology Development Agency	VP	Vegpro
GHG	Greenhouse Gas	Nm^3	Normal cubic meter	WB	World Bank
GL	Gigaliter	O&M	Operation and Maintenance	WHO	World Health Organization

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FOREWORD

Reaching the targets set by the Paris Agreement, the 2030 Agenda for Sustainable Development and the related Sustainable Development Goals (SDGs) was always going to be challenging. The emergence and rapid global spread of COVID-19, however, has compounded the situation. While we are still in the midst of the global pandemic, with the true impacts still to be measured in the years to come, it is important to note that despite seemingly insurmountable challenges, we have witnessed unprecedented rapid, collective, transboundary and cross-sector action in the development and rollout of a vaccine; we have witnessed hope – a hope that the deadly virus could be eliminated, but perhaps so too that the world could unite to actively and decisively respond to recovery and fast track the way to SDGs with the same urgency.

It is, therefore, in this light that our efforts to work collectively to promote, advance and mobilize climate technologies must continue with zest. It is clear that knowledge sharing – through channels such as this report – will provide the leverage needed for others to learn, plan and implement their own bioenergy projects, ultimately contributing to our collective efforts in reaching self-reliance in energy and achieving the SDGs.

What follows in this report is an overview of bioenergy projects from around the world, mostly implemented by UNIDO, with funding from GEF. While the scope, technologies, applications, descriptions and results vary, they are united by the goal to achieve reliable, safe and affordable clean energy for people in low income countries, bringing clean energy to some of the world's most vulnerable and under-served people, at the same time, helping to reduce dependency on fossil fuels and the associated greenhouse gas (GHG) emissions. We are pleased to share with you a look into the relatively small, but hugely promising bioenergy sector.

From project planning, development and rollout, to key lessons learned, and a brief analysis of the sector at large, readers will gain helpful insights into what it takes to provide locally available bioenergy solutions at household, community and industrial levels.

While it is true that some of the lessons learned from the featured projects are context-specific – matters relating to political, financial or geographical locations, for example, have resulted in unique approaches – it is also true that we are not only limited to the act of replication for the project to be useful to others. The act of harvesting (taking what is useful) or leveraging knowledge (building on what is there) holds similar value in the face of increasing urgency.

The SDGs will not be reached in isolation and one way to work jointly for meaningful progress is to invest time in knowledge sharing and harvesting. By leveraging the knowledge of a wide range of successful and not so successful bioenergy projects, it may be possible to avoid certain challenges, be more resilient to challenges, save time and money, and ultimately accelerate climate action on the ground.

EXECUTIVE SUMMARY

Over the past decades and in multiple countries, bioenergy has supported the development of local economies, while helping to reduce the dependency on imported fossil fuels. If bioenergy resources are produced sustainably, their energy use can contribute to the reduction of GHG emissions.

Placed within the overall context of bioeconomy, bioenergy represents a major sector, spread across the globe, as bio-residues generated by other bioeconomy sectors are often used as raw material in bioenergy conversion processes. These bio-residues can be either bio-effluents, or solid residues from forestry, farming or wood and agro-industries.

Solid biomass is one of the most used forms of bioenergy. It has been and is still traditionally used for cooking or heating in many countries, especially in developing countries (DCs) and in least developed countries (LDCs). Gaseous or liquid forms of biofuels, such as biogas and bioethanol, are increasingly available and used, as biogas/biofuel projects are being implemented all around the world, using increasing amounts of performant conversion technologies.

Several bioenergy case studies presented in this document provide good examples of successful biomass, biogas, and bioethanol projects. Their key features are presented, together with their success factors and the lessons that can be learned from their implementation. Moreover, their sustainability is addressed vis-à-vis the SDGs.

The chapter on solid biomass highlights the following projects:

- commercial production of wood and torrefied pellets in Portugal;
- industrial use of residues from olive oil processing factories in Albania; and
- production and use of charcoal briquettes in Uganda.

All these projects have had a strong economic, social and environmental impact as they contributed (a) to the development of the local economy by creating new jobs, using locally available biomass that would often be left to rot, and (b) to the reduction of deforestation and mitigation of GHG emissions. It is key to use simple, if possible, locally made and fully proven equipment, and make sure that there is enough raw material and sufficient funding to sustain the projects.

In the chapter on biogas, different applications, based on various types of waste, are presented:

- cogeneration from the use of biogas produced from avocado waste in Kenya;
- cogeneration from biogas produced from swine and food waste in Brazil; and
- diesel substitution by biogas for power generation in Kenya.

All these biogas projects use proven technologies and well-trained personnel. They are commercial projects in which local investors expect to fully cover their own energy requirements. They have the confidence of financial institutions (banks and international donors), as their financial proposals were strong, and as the quality and quantity of the feedstock supply as well as the off-take of the produced energy (heat and/or power) had already been secured. They offer a great replication potential.

In the chapter devoted to liquid biofuels, all the projects are bioethanol projects:

- a cookstove and bioethanol delivery facilitation project in Tanzania;
- south-south cooperation in bioethanol production from cassava in Southeast Asia; and
- bioethanol production from a micro-distillery for household cooking in Ethiopia.

These are small-scale projects aimed at producing bioethanol from locally available feedstock. Micro distilleries keep the investment at a reasonable level and can easily be operated by well-trained local staff. Bioethanol used in transport is already utilized in many places worldwide, while the use of bioethanol

for clean cooking is still rather new. However, it shows a great development potential in tropical countries, given a large diversity of feedstocks generated by the agricultural and food-processing sectors. The demonstration projects implemented in Tanzania and Ethiopia are good references and should pave the way for broader uptake in countries with similar characteristics.

Successful bioenergy projects need to be broadly disseminated to build the confidence of national and local governments who have a key role to play in supporting their implementation. National action plans must be in place and provide all the needed support measures, project registration and licensing.

The dissemination of success stories must also target banks and financial institutions who are often reluctant to invest in bioenergy projects as they are not familiar with all their benefits. Evidence of the technical reliability and economic viability of such projects must be provided. Besides all the usual economic factors (investment and operation and maintenance (O&M) costs and revenues), project feasibility studies must include a critical analysis of the sustainability of the project feedstock supply and of the products sales generated by the plant.

Most bioenergy projects in DCs and LDCs result from technology transfer. The appropriateness of the technology, i.e. its ability to be easily operated and maintained, must be carefully assessed. Whenever possible, partial or total manufacturing of the equipment should be transferred to the recipient country. This requires comprehensive, in-depth capacity-building programs and awareness campaigns, not only for the local manufacturers and for the personnel responsible for the O&M of the bioenergy plant, but for all key stakeholders, i.e. biomass producers (farmers), bioenergy investors, banks and financial institutions, policymakers, as well as researchers and academics.

Bioenergy has a very promising future, as only a very small fraction of its potential has been exploited so far. Proven and reliable technologies are available and can provide solutions at household, community and industrial levels, provided that the biomass management and organization of the whole supply chain is well addressed. Capacity building at all levels is essential, along with public awareness campaigns on demonstration projects that have been successfully operated for a few years and their strong contribution to the achievement of the SDGs.

Biogas treatment plant in Brazil. (Source: Castrolanda)

1

THE ROLE OF BIOENERGY IN STIMULATING THE BIOECONOMY IN DEVELOPING COUNTRIES AND LEAST DEVELOPED COUNTRIES

1.1 Sustainable bioeconomy

In 2016, with the support of the German government, the Food and Agriculture Organization of the United Nations (FAO) produced guidelines on sustainable bioeconomy development and established the International Sustainable Bioeconomy Working Group (ISBWG)[1]. These principles consist of 10 key points in addressing the following sustainability issues for the bioeconomy[2]:

1. Supporting **food security** and nutrition at all levels
2. Conserving, protecting and enhancing of **natural resources**
3. Supporting competitive and inclusive **economic growth**
4. Making **communities** healthier, more sustainable and harnessing social and ecosystem resilience
5. Relying on improved efficiency in the use of **resources** and biomass
6. Applying responsible and effective **governance** mechanisms
7. Implementing existing relevant knowledge and proven sound **technologies** and good practices and, where appropriate, promoting research and
8. innovation
9. Using and promoting sustainable **trade** and market practices
10. Addressing societal needs and encouraging sustainable **consumption**
11. Promoting **cooperation**, collaboration and sharing between interested and concerned stakeholders in all relevant domains and at all relevant levels.

These principles are applicable to all bioeconomy sectors, and are in line with the United Nations' SDGs.

1.2 Bioenergy and bio-economy in DCs and LDCs

There is still an enormous global development potential for bioenergy and the bioeconomy in DCs and LDCs. The economies of these mostly tropical countries are still strongly based on agriculture and forestry.

Food processing industries (rice mills, sugar mills, palm oil mills, etc.) generate large quantities of solid and liquid residues, which can be used as fuel.

Forest and wood processing industries (sawmills, plywood/particle board factories) also generate significant amounts of solid residues, which can either be used as raw material in further downstream activities or as fuel (e.g. pellets, briquettes, package).

Manure produced by cattle and pig farms can be converted into biogas that can be used for cooking, heating and/or power generation.

1.3 Bioenergy and the Sustainable Development Goals

The following table shows how the development of bioenergy could contribute to achieving the SDGs.

Bioenergy offers small farmers the possibility to increase and diversify their crop production and generate additional revenues.	1 NO POVERTY
Through bioenergy projects and revenues, small farming communities can have access to food, a better diet and improved health conditions, and thus enjoy better standards of living.	1 NO POVERTY; 2 ZERO HUNGER; 3 GOOD HEALTH AND WELL-BEING
The use of biofuels such as bioethanol can reduce indoor air pollution thanks to cleaner cooking.	3 GOOD HEALTH AND WELL-BEING
Vocational training and education in bioenergy raises the level of knowledge and understanding of these technologies and paves the way to new jobs, especially in areas with increased bioenergy potential, such as rural areas.	4 QUALITY EDUCATION; 8 DECENT WORK AND ECONOMIC GROWTH
Improved practices have a positive impact on gender equality, as women could improve their income and status.	5 GENDER EQUALITY
Some bioenergy technologies, like biogas production, specifically address the treatment of wastewater and help reduce water pollution.	6 CLEAN WATER AND SANITATION
Biomass, biogas and bioethanol technologies help to provide access to affordable, reliable, sustainable, and modern energy, particularly in LDCs.	7 AFFORDABLE AND CLEAN ENERGY
Bioenergy helps add value to biomass and allows the development of new activities and related jobs through the improvement of existing practices; the introduction of innovative technologies and the enhancement of infrastructure along the value chain.	8 DECENT WORK AND ECONOMIC GROWTH; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

The development of bioenergy projects in rural areas, close to biomass feedstock production, can contribute to the reduction of inequalities in less developed areas.	10 REDUCED INEQUALITIES
The management of organic waste via bioenergy conversion is key to making cities and communities more accommodating and sustainable.	11 SUSTAINABLE CITIES AND COMMUNITIES
Production, promotion and consumption of biofuels contribute to the improvement of the environment through the reduction of fossil fuel consumption and the reuse of waste material generated by bioeconomy activities.	12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Within the bioeconomy, the development of bioenergy is one of the highest contributors to the mitigation of GHG emissions and carbon sequestration.	13 CLIMATE ACTION
Bioenergy conversion of waste that would otherwise be discharged into rivers, canals and oceans can strongly contribute to the preservation of aquatic life.	14 LIFE BELOW WATER
The sustainable management of biological resources and the production and supply of biomass feedstock to bioenergy processes can help prevent land degradation.	15 LIFE ON LAND; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Bioenergy also supports rural communities through the creation of more equitable societies, which should generate more sustainable institutions.	16 PEACE, JUSTICE AND STRONG INSTITUTIONS
Many countries still face bioenergy implementation challenges. The exchange of experience and the creation of global partnerships can help bioenergy to keep growing steadily throughout the world.	17 PARTNERSHIPS FOR THE GOALS

Table 1: Bioenergy and the SDGs

1.4 Enabling policy environment

Over the last 50 years, bioenergy has received regular policy and financial support from national governments, as well as technical assistance and funding from international organizations, but that support has been fluctuating as it was mainly dependent on global fossil fuel prices. During the oil crises of the 1970s and 80s, funds were provided to institutions to carry out research and development on biomass combustion, gasification, digestion, torrefaction and densification technologies.

Performant, environmentally friendly equipment was developed to generate heat and/or power from straw, wood wastes and other bio-residues to competitively substitute the use of fossil fuels. New products, such as briquettes and pellets, appeared in both domestic and international markets.

The implementation of successful demonstration projects using these innovative technologies helped build the confidence of private investors, banks and financial institutions. In the meantime, the global fossil fuel market prices dropped and made these new technologies less attractive.

To keep some momentum in the bioenergy transition, some long-term support mechanisms and tools such as renewable energy (RE) targets, tax exemptions and feed-in-tariffs (FITs) for renewable electricity were required.

Countries like Thailand established specific funds to support investments in bioenergy projects. As an example, attractive electricity buy-back rates were offered for biomass electricity sold to local utilities. This stimulated the private sector to invest in high efficiency plants to optimize the use of their excess residues and generate additional revenues.

Currently, country-level support provided by governments towards bioenergy is targeted at the production and use of bioethanol for fuel blending. Incentives are required along the whole value chain, from biomass growers to final bioenergy consumers. Funding also needs to be provided to bioenergy capacity-building programs and to research and development projects aimed at developing innovative solutions to optimize the use of local bioresources.

Moreover, there must be an increase of focus on social acceptance of biofuels through public information campaigns. Such measures should focus on the benefits of fuel switching and the implementation of a sustainable bioeconomy via the reduction of dependence on imported fossil fuels, mitigation of greenhouse gas emissions, and stimulation of local economic growth and job creation, while maintaining food security and conserving natural resources.

1.5 Bioenergy projects: success factors

Besides the compliance of bioenergy projects with the SDGs, it is also essential to look at the sustainability of the project itself.

A comprehensive feasibility study must be carried out and should include a feedstock availability study, a technology assessment analysis and a market survey for the products generated by the project. Lessons were learned from the experience of the EC-ASEAN COGEN Programme (1991-2005)[3], which aimed to support the implementation of clean and efficient biomass energy projects in wood and agro-industries in Southeast Asia, including the following success factors:

- acceptance
- appropriateness
- reliability
- affordability
- bankability
- profitability
- replicability
- scalability
- environmental sustainabililty
- sustainability.

These often innovative commercial projects were implemented by the private sector. Private investors would only invest in proven technologies with a proper track record in similar conditions. The project investment level, its O&M costs, its generated revenues and savings would determine its viability, level of profitability and bankability.

2

BIOMASS AND TECHNOLOGIES

2.1 Introduction

Solid biofuels are one of the most heterogeneous energy sources in the world due to their content and combustion behavior, and include firewood, processed firewood like charcoal, forest and agricultural residues, and dung, which are considered traditional household fuels in most DCs and LDCs.

In Africa, solid biofuels cover more than 80% of the energy demand, especially for cooking. On the contrary, in developed countries like Austria, only around 30% of the total energy required for heating is provided by solid biofuels in different forms like logwood, wood chips and pellets.

Most traditional biofuels are not processed, except for size reduction and drying. The development of modern (processed) biofuels suitable for automated equipment started after the first oil crisis in the 1970s in the form of wood chips. Wood chips are now widely used in district heating systems and industrial applications, including power generation.

Pellets, which are compressed biomass – usually made out of industrial, agricultural and forestry residues, and energy crops – started being developed approximately 30 years ago. They have spread worldwide as a new and sustainable solid biofuel. As the first biofuel commodity, pellets are suitable for global commercial trade. They can be used in small-scale (e.g. cook stoves, heating stoves) but also in medium-scale and large industrial applications.

Despite biomass being used for at least 30 years, it remains challenging to use it efficiently and sustainably. Three critical success factors need to be considered:

- availability, quality and price of the raw material,
- conversion technology, O&M, and
- sustainability, including reforestation, carbon depletion and land use change.

Availability, quality and price of the raw material is probably the most important success factor. High resource potential assessed by an investor or user at one time, does not imply that it will remain available in the future. This is especially critical since investment in biomass projects is rather large compared to other conventional systems. Logistic chains must be considered as part of the supply cost. Raw material quality should also be considered. This will depend on current and future required quality of the final product. Pellets of low international standards may be sold in the beginning, but international trends show that the market demand will eventually be for best quality pellets.

Conversion technologies are manifold and cover an unbeatable wide range starting from less than USD 12 for a cook stove to billions for a modern power plant. Furthermore, price depends on suitability for different fuels, emissions and efficiency. Highly efficient equipment that complies with regulations in some countries e.g. Germany, proving to generate/emit low emissions, is expensive. If efficiency and emission regulation is less stringent, and manpower is available for a lower price, investors tend to use cheaper, more labor-intensive systems with drawbacks of lower availability, lower efficiency, higher emissions and often with higher safety hazards.

In general, the combustion of solid biofuels is more complex than the combustion of gaseous or liquid fuels, since solid fuels contain non-combustible fractions that can cause abrasion, slagging and fouling.

Additionally, solid particle emissions and waste disposal of residues must be considered. Thus, it is important that a proposed technology is fully proven and appropriate for the target market. Some technologies that looked promising, such as biomass pyrolysis and gasification, have regularly failed because of their inappropriateness in a local context.

O&M are essential but are often overlooked. Industrial systems need well-trained personnel responsible for raw material quality assurance, O&M, and servicing of the system. Their costs and the necessity of qualified personnel are often underestimated during project design.

Biomass projects are not the easiest to finance as banks and financial institutions are not familiar with these technologies and perceive them as riskier. The investment in biomass technologies, especially for larger projects, is not as attractive as conventional projects due to higher investments and longer pay-back times. Moreover, the sustainability of the biomass supply chain is often questioned by financiers. On the other hand, biomass projects create jobs and generate revenues for local populations, especially in rural and less developed areas.

In industrialized countries, the use and upgrade of waste, especially in wood industries, is of increasing importance as it boosts their profitability. A large sawmill may operate a cogeneration plant to cover its heat and power requirements, by using bark and other process residues. Heat is needed for timber-drying kilns and for pellet production where sawdust is the raw material. Both the combined heat and power (CHP) plant and the pellet production increase the income of the sawmill substantially. In Austria, energy from biomass (power, heat and pellets) currently represents about 25% of the income of the sawmilling industry, significantly increasing its overall competitiveness compared with other countries.

Biomass offers an excellent possibility for circular economy and for environmental balance due to its carbon neutrality. It provides some additional income for different groups like foresters, farmers, wood and food processing industries and communities. Biomass projects also offer the possibility for public participation (e.g. farmers). The best examples are cooperatives running district heating plants, where some projects have been successfully operated for more than 30 years.

In DCs and LDCs, where biomass is traditionally used for cooking, there are several negative aspects like the overexploitation of resources and deforestation, as well as domestic health and environmental problems due to poor combustion.

A more sustainable alternative is the use of local biomass in modern, efficient and low-emission equipment instead of conventional technologies. This would create local jobs and keep value added in the region mainly via small companies. As shown in the three case studies presented further on, modern biomass appliances may lead to poverty reduction and more gender equality.

White pellets from debarked wood and black pellets from torrefied wood. (Source: Futerra Fuels)

2.2 Case Study #1: Large-scale production of white and black pellets – Futerra Fuels, Portugal[4]

Installation of drying/torrefaction unit. (Source: Futerra Fuels)

2.2.1 Project background

One of Portugal's industrial sectors is wood pellet production. Portugal has significant forest resources that can only be used for energy production as low-grade biomass resources – including tops, limps, forest residues, remains from thinning and wildfires as well as material from short rotation crops (mainly Eucalyptus). Pellet production is the most efficient technology suitable for energy export. Therefore, pellet plants were built to mainly export to power plants in Western and Northern Europe.

Some markets/customers required different pellets properties. Some customers asked for pellets with higher energy content and high energy density as found with conventional wood pellets ("white pellets"). This led to the development of torrefaction and carbonization processes and development of "black pellets". Besides a higher energy content, black pellets have the advantage that they can be processed with conventional coal technology in coal-fired power plants and they are partly weather resistant in outdoor storage.

With torrefaction technologies gaining momentum in the early 2000s, companies such as Futerra Fuels were able to build on successful experiences in that field. After three years of research and study, Futerra Fuels was legally established in 2015 by Dutch and American investors with backgrounds in project finance, RE, energy trading and circular economies.

A pellet production project was initiated by Futerra Fuels International BV, which owns Futerra Torrefaçao e Tecnologia S.A. based in Valongo, Portugal.

The project was implemented in two steps. A pilot torrefaction line was first tested in the Netherlands in the second half of 2017 in order to validate the process. The commercial plant was then built between 2019 and 2020 in Valongo, near Porto, Portugal, a strategic location with road and rail connections to the ports of Leixões (16 km), Aveiro (70 km) and Viana do Castelo (85 km).

2.2.2 Feedstock sourcing, capacity, and plant layout

The municipality of Valongo provides access to 600,000 tonnes of biomass feedstock. The raw material consists of low-grade biomass resources coming from FSC-certified plantations within an area of 50-100 km from the plant.

The torrefaction lines are modular, compact and semi-transportable. This makes the design suitable for both small-scale and large-scale projects. The torrefaction technology is based on the unique swirling fluidized bed principle. The technology generates a fast heat transfer from hot flue gases to the solid input material. This results in a continuous torrefaction process, homogeneous quality and a clean final product with the following characteristics:

- low chlorine content,
- hydrophobicity, i.e. high water resistance,
- low emission levels of fine dust, sulphur oxides and nitrogen oxides,
- high calorific value of 19 to 22 GJ per tonne,
- clean combustion with less pollution, resulting in a 10% increase in boiler performance,
- strong shock resistance with very limited fines production during transport and handling,
- zero waste production as dust and biomass waste are used for heat generation, and
- the elimination of binding agents needed to pelletize yields a saving of +/- USD 12 per tonne in production costs.

The torrefaction lines are also capable of processing bagasse, grass and other agricultural and garden waste. The swirling fluidized bed technology in combination with the correct pre-treatment of the (herbaceous) biomass material leads to high-quality black pellets.

The plant capacity is as follows:

- annual production of white (wood) pellets: 85,000 tonnes,
- annual production of black (torrefied) pellets: 120,000 tonnes,
- onsite storage capacity: 18,000 tonnes, and
- loading capacity from site: 500 tonnes per hour.

The developers designed a flexible hybrid pellet production plant, capable of simultaneously producing white and black pellets, with multiple lines to ensure maximum capacity utilization. This makes the feedstock sourcing, feedstock preparation, drying and energy consumption more efficient.

From a market point of view, the plant can meet various client demands with respect to calorific value of the pellets but can always deliver white pellets if black pellet production is paused and vice versa. The equipment layout allows for the pre-treatment of some unusual raw materials such as tree stumps. The most critical requirements in the feedstock preparation are the particle size and the moisture content.

2.2.3 Replicability

The project has a high potential to be replicated in DCs and LDCs as the plant serves as a blueprint for pellet plant developers targeting commercial production of black and white pellets with outputs of 200,000 to 250,000 tonnes per annum. Given the system's modularity, smaller plant sizes are also feasible with a minimum capacity of 20,000 tonnes per year. Six parallel torrefaction lines each produce 2.5 tonnes per hour, i.e. a total of 120,000 tonnes per year.

Downscaling the plant allows the implementation of projects closer to the source of biomass feedstock and limits the need for transport of raw material and pellets.

The plant set-up can be replicated for greenfield projects like the Valongo plant or for retrofitting existing white pellet plants by adding modular torrefaction lines to existing plants, currently mainly in Northern America and Europe.

2.2.4 Problems and solutions

Commercially, securing investors and financiers for a greenfield torrefaction plant has been very challenging since most torrefaction projects have been unable to reach commercial scale for the past 15 years. Moreover, the development of large torrefaction plants is considered a risky business by off-takers and investors. The founders had to provide a large percentage of equity portion of the USD 13 million investment.

Technical problems included the fact that parameters of the swirling fluidized bed torrefaction reactor required re-engineering and adjustments because of the diversity of the raw materials used in the plant. A way to solve that problem is to homogenize the quality through pre-treatment. The unloading point from the reactor towards the pelletizers is a self-designed solution keeping out oxygen to prevent fires and/or explosions. Another solution is to treat the pellets in a way that would reduce the formation of dust during pellet logistics and storage.

2.2.5 Lessons learned

The plant design is based on units with an hourly capacity of 2.5 tonnes. Future torrefaction units will be container-based designs and scaled-up to 6 tonnes per hour (45,000 t/a), with containers assembled on site. By doing so, the plants can be tested in the Netherlands before being shipped and require less supplier presence on site for the start-up of the plant.

Based on its experience, Futerra is creating a franchise model with an integrated package of technology, offtake and know-how. This will lower the risks and barriers for new plant developers who want to enter this promising new market.

2.3 Case Study #2: Olive oil sector as a bioenergy supplier in Albania

Combustion system for dried olive pomace in an olive factory. (Source: BEA)

2.3.1 Project background

Albania's National Renewable Energy Action Plan 2015-2020[5] outlines the country's target of increasing the final energy consumption by 38% with renewable energy sources by 2020. Meanwhile, The National Energy Strategy 2018-2030[6] highlights that Albania has substantial biomass potential from agricultural residues, estimated at 2,300 GWh per year.

Biomass is widely used in Albania, predominantly in the form of firewood. The production and use of processed wood fuels such as pellets and briquettes increased in the last few years.

Agro-industrial residues are considered a suitable source of biomass for energy, but their use faces limitations because of their seasonality and their need to be collected, transported and pre-treated before being converted to energy e.g. olive tree or vine pruning.

Based on the national goals to increase energy from biomass, UNIDO in cooperation with GEF and the Albanian Government developed a project to promote the use of different agro-industrial residues, including olive mill residues.

The main objective was to demonstrate bioenergy conversion technology applications through the implementation of successful projects in targeted small and medium enterprises (SMEs) in the olive oil sector.

The UNIDO/GEF project started in 2014 and is expected to be completed in 2021.

Albania is one of the Mediterranean countries with optimal conditions for olive oil production. However, olive oil producers in Albania lack access to adequate technologies and have limited rural infrastructure (e.g. roads). This has led to high production costs and low margins. This project aimed to trigger investment in waste-to-energy projects in the olive industry through demonstration, development of appropriate financial instruments, capacity building and strengthening of the policy and regulatory environment.

Through its focus on development of appropriate financial, regulatory and policy instruments, the project aimed at implementing 15 bioenergy pilot projects with an indicative capacity of 1,000 – 1,500 kW_{th}. More than 40 companies were evaluated by financial institutions, with the support of four banks. Feasibility studies were prepared. Several enterprises are (still) negotiating with financial institutions for co-financing of their respective projects.

Besides UNIDO, four ministries, three universities, national agencies, NGOs, SMEs, technology suppliers and financial institutions are involved in this project.

2.3.2 Example 1: Implementation of bioenergy in an olive oil factory

Olive oil production consists of three major steps: (a) olive washing, (b) olive crushing, and (c) separation of oil and pomace (by presses). Pomace is one of the main residues of the olive oil industry. It can be burnt directly in boilers or may be converted into pellets or briquettes for use in boilers and stoves. In both cases, olive pomace must be dried.

For olive oil production, energy is required to heat the water needed for the crushing process. This energy is now produced by a new biomass boiler using the mill pomace. The boiler also heats the factory and the house of the factory owner. Excess pomace is sold to a pellet producer. According to the president of the Albanian olive oil association, energy savings of 60% are possible within the olive oil factory. Particle emissions are significantly reduced as the new biomass boilers are more efficient than traditional systems and are equipped with flue gas cleaning cyclones.

2.3.3 Example 2: Substitution of diesel heat generators at a farm

Two diesel heating systems (burners for greenhouse) were replaced by modern biomass systems (grate-fired biomass boilers) using dried pomace instead of diesel to heat a greenhouse at a tomato farm. With cheaper and more reliable heat generation, the plants grow much faster, and their yield has increased by 40%.

The largest part of the tomato production is exported to Germany, where it arrives without having to be frozen. Being fresh and branded as organic produce, tomatoes can be sold at premium price. Moreover, the farmer will now have three harvests per year instead of two. The long-term plans include installing more biomass boilers in his seven other greenhouses, which still do not have a heating system. The new boiler investment was around USD 85,000. The farmer could only afford them thanks to the support by the UNIDO/GEF project development.

2.3.4 Lessons learned

Agro-industries in Albania, especially in the olive oil and fruit processing sectors, produce large quantities of biomass residues that can be used as fuels. Before this rather broad UNIDO/GEF project, there was little public awareness on the production and possible uses of pellets as fuels. The organization of site visits and workshops to reference projects helped raise awareness.

Since there was no equipment available in Albania, it had to be imported. A key for success is that the imported equipment must be fully proven and reliable, i.e. certified according to international technical standards. Training programs must be organized to make sure that the new equipment is properly operated.

The legislation must be adapted to include equipment quality and efficiency requirements. Therefore, it is recommended to establish and implement a QI system, with an incentive program, a monitoring system and the necessary infrastructure, including testing, certification, accreditation and mechanisms for market surveillance.

Practitioner training should include the training of key stakeholders on (a) best international standards (b) the new regulatory framework, and (c) standards and certifications for technical staff of public entities in charge of formulating the policy and regulatory framework.

2.4 Case Study #3: Biomass/charcoal briquettes in Uganda

Charcoal briquette drying. (Source: GBE)

2.4.1 Project background

In Uganda's rural areas, there are not many alternatives to wood and charcoal for cooking food in households. Historically, charcoal and firewood have been a cheap and accessible source of fuel, but its use has become unsustainable, as forests are depleted.

In that context, biomass briquettes have emerged as one of the top three East African energy products, with Uganda witnessing the greatest concentration of briquette producers. Briquettes can be produced from resources other than wood and as a commercial product they can be transported to the customers. Although many individual companies are rather small, some businesses are getting larger as they work with local microenterprises.

The briquette market in Uganda consists of four segments: the domestic, institutional, industrial and export markets. The majority of briquette manufacturers supply peri- urban and urban centers. Carbonized briquettes are the main product, using charcoal powder as the raw material. They are sold to households, refugee camps, roadside food vendors, poultry farmers and institutional consumers. Non-carbonized briquettes are sold to brick factories, cement industries and as cooking fuel to restaurants, schools and hospitals as they can substitute wood without modification of their stoves.

Briquettes, especially those from carbonized biomass, can be made from a large variety of forest and agriculture residues. These residues may be sawdust, rice husks, rice straw, coffee husks, cotton seed hulls, maize cobs, banana fibers, cotton stalks and others. Usually, they are sourced locally from contracted farmers. Some residues are readily available on the local market from large commercial farms and agro-processing factories.

2.4.2 Example 2: Green Bio Energy[7]

Green Bio Energy (GBE) buys carbonized organic residues from surrounding communities produced with GBE carbonizing kilns and transports them to a central facility where they are ground, pressed into briquettes and dried. In parallel, GBE produces improved cookstoves that can burn charcoal or uncarbonized briquettes in a more efficient way.

In 2010, GBE started building a prototype of a mechanized briquette press. By January 2011, the company began to carbonize organic waste and sell briquettes in surrounding communities. With grants from Engie, a French utility, and from MIT's Harvest Fuel Initiative, they fine-tuned their process and moved to a site about 30 km outside of Kampala to begin full-scale production.

All GBE machinery is made in Uganda, making it easier to provide any assistance for maintenance and follow-up. This includes briquetting presses, carbonizing kilns, mixers, crushers and dryers. Equipment is designed with stringent requirements in terms of reliability, efficiency, and safety.

2.4.3 Example 2: Divine Bamboo[8]

Established and incorporated in 2016, Divine Bamboo has become the largest producer of bamboo seedlings in Uganda, with a capacity of 100,000 seedlings annually.

Divine Bamboo provides clean cooking fuel in the form of high-quality charcoal briquettes produced from local bamboo, grown by local farmers as additional product specifically for energy purposes on sustainable bamboo plantations in Uganda. The company trains rural women groups and youth to plant bamboo, providing them with seedlings and access to biomass technologies. This gives them the opportunity to produce bamboo briquettes, which simultaneously provides additional income, meets their in- house fuel needs and contributes to protecting the environment.

The technological component involves the use of efficient and improved conversion technologies to carbonize bamboo. The technologies used include:

- a drum carbonizer, which is a simple and easy-to-fabricate carbonizer with a lid and an inner cone to which a chimney is attached. The drum carbonizer costs about USD 100, has an efficiency of 20-22% and a capacity of 20 kg of dry biomass. Generally, the technology is about 40% more efficient than conventional conversion technology;
- a retort, which is a built carbonizer consisting of a cavity wall, a lid, a grate, a chimney with an air control mechanism and an outlet where the char is collected. The technology has a capacity of one to two tonnes of dry biomass, and costs about USD 1,220. Its efficiency is very high and estimated at 35-40%.

Charcoal briquettes. (Source: Divine Bamboo)

2.4.4 Economic, social and environmental impacts of biomass /charcoal briquettes

The development and improvement of biomass projects and technology have led to an overall improvement in terms of economic, social and environmental aspects.

Economic

The projects have provided new job opportunities to local communities and generated income through carbonization and charcoal briquettes production. In turn, this has improved households' standard of living as well as improving their nutrition since they can afford a more balanced diet.

As charcoal briquettes burn longer and are (sometimes) cheaper than charcoal, each household using charcoal briquettes with improved cook stoves saves on their cooking fuel bill. Users reported that an improved stove is paid back within a month or two.

In the case of the GBE project, 500 tonnes of briquettes and 4,800 stoves were distributed every year between 2016 and 2018. The business expanded with the inclusion of a network of micro-entrepreneurs to test the potential market in Eastern, Western and Central regions of Uganda.

Both projects involve the use of efficient and improved carbonization technologies for either biomass residues or bamboo. The carbonizing equipment is cheap as its design is simple. In the case of Divine Bamboo, it costs about USD 100.

Social

These projects have a strong social impact on family well-being through the creation of new jobs, especially for women and young people all along the charcoal briquettes value chain. The project has brought together social groups that are now working towards a common financial stability.

As part of the social mission of the GBE, all pieces of equipment are produced locally. GBE invested in building partnerships with local workshops to design and manufacture all the machines required in the briquetting process. Local workshops gained particularly useful engineering knowledge and received work contracts and revenue thanks to the machinery orders GBE made.

In the Divine Bamboo project, the major social component is the empowerment of rural smallholding farmers, with a special focus on women and youth. 350 farmers and 205 youth were trained in bamboo planting and briquette production. This helped reduce poverty and gender inequality and increased income. Moreover, women and girls are less exposed to gender-based violence.

Environmental

90% of agricultural leftovers in Uganda's towns are currently treated as waste and left to rot. Rotting waste can contaminate rivers, ground water, or food meant for human consumption. What's more, Uganda remains at risk of losing most of its forest cover if nothing is done to identify alternatives to tree-based charcoal and firewood energy sources.

The engagement of converting biomass waste into charcoal briquettes is a strong move towards the mitigation of GHG emissions.

GBE help reduce deforestation by substituting charcoal and firewood with briquettes made of organic materials, mainly from agro-industries. Briquettes produce a much cleaner combustion than fuelwood and charcoal, hence reducing respiratory problems, cancer and cardiovascular diseases.

Divine Bamboo created awareness about bamboo as a sustainable climate-smart energy alternative. Bamboo plantations sequester over 2,000 tonnes of CO_2/ha/year and do not require fertilizers or pesticides.

2.4.5 Lessons learned

The key for success is mainly the management and organization of the supply chain, from the production and collection of sufficient raw material, its purchase at a fair price and its conversion into a final product that is attractive enough to be sold in a competitive market. Small price differences can have a substantial impact on the household budget for cooking fuel, and therefore, on the economic, social and environmental well-being of relatively poor populations. Briquetting equipment is generally basic, should be locally manufactured, especially for small production sites, and should be reliable and easy to operate after some training of the operators. However, there is still a significant potential for improving, replicating and upscaling the technology.

Key challenges such as a need for technology improvement must be addressed to support the growth of the briquette market in Uganda. Such improvements can help increase the production and quality of briquettes. The sustainability of the biomass feedstock quantity and price, the briquette production cost and the access to finance will need to be carefully looked at and secured to expand the use of briquettes throughout the country for the best of the urban, peri-urban and rural populations.

2.5 Biomass and the Sustainable Development Goals

As shown in Table 2, the three case studies address most SDGs. Evidently, biomass projects supply clean and renewable energy. This is in the form of heat, power or fuel for cooking, which can directly or indirectly make energy more affordable for rural populations (SDG 7). Sustainable energy is also supplied to cities, making human settlements more resilient (SDG 11). Given that forests and crops are managed sustainably, these projects ensure sustainable production patterns (SDG 12) and crop yields (SDG 2), restore and promote the sustainable use of terrestrial ecosystems (SDG 15), and contribute to carbon savings to combat climate change (SDG 13). The latter results in less pollution and black carbon emissions, thus greater health and well-being (SDG 3). The local design and manufacturing of biomass technologies helps develop industrial competence and infrastructure (SDG 9). This requires specific training in engineering (SDG 4). Modern biomass technologies create jobs in agriculture, forestry, raw material and fuel production and fuel distribution (SDG 8). One case study focuses specifically on women's employment (SDG 5). Stable income from these jobs and affordable energy reduces poverty where these projects take place (SDG 1). In turn, this reduces inequalities as there is a growth in income for farmers and rural populations (SDG 10).

2.6 Success factors and challenges

Since there is such a wide variety of options for the use of biomass, the selection of the best technology for a region, a company, a community or simply a household can be very challenging and requires a careful evaluation of the most appropriate solutions.

A key parameter for a successful biomass project is the availability of sufficient and proper quality raw material over the project lifetime. Another challenge is maintaining the sustainability of the supply while balancing biomass reserves, including a rational use of arable lands, reforestation, best use of residues and stable prices.

The use of proven technology is extremely important – biomass projects are long-term investments where the quality of the implemented technology is key. Saving on investment cost is short-sighted and often leads to project failure.

Due to the high investment required, financial support (grants, soft loans, incentives) is still a valid option to increase the number of projects in DCs and LDCs. There are too many examples of failed projects despite financial support from international organizations. There is a need to systematically check the factors that can lead projects to success and avoid mistakes that were made in the past.

SUSTAINABLE DEVELOPMENT GOALS (SDGs)	CASE #1: LARGE-SCALE PRODUCTION OF WHITE & BLACK PELLETS – FUTERRA FUELS	CASE #2: OLIVE OIL SECTOR AS BIOENERGY SUPPLIER IN ALBANIA	CASE #3: BIOMASS/CHARCOAL BRIQUETTES IN UGANDA
1	✓	✓	✓
2	✓	✓	✓
3	✓	✓	✓
4			✓
5			✓
7	✓	✓	✓
8	✓	✓	✓
9	✓	✓	✓
10	✓	✓	✓
11	✓	✓	✓
12	✓	✓	✓
13	✓	✓	✓
15	✓	✓	✓

Table 2: Biomass and the SDGs

3

FROM WASTE TO BIOGAS

3.1 Introduction

Biogas production is a natural process that occurs in swamps and in cow paunch. Biogas is produced by breaking down organic matter in an anaerobic (oxygen free) environment. It contains about 55% methane, 45% carbon dioxide and some traces of other gases. Methane is the energy carrier. It is possible to technically upgrade the biogas to more than 95% of methane, bringing it to an energy content comparable to natural gas. Biomethane can be used as fuel for electricity and/or heat generation, for cooking and for transport.

Setting up and running a successful biogas project requires a combination of factors: careful project design and management by experienced/skilled engineers and technical staff, strong bio-technological know-how and secured financing.

The following are ideal pre-conditions for industrial scale biogas plants to be implemented in DCs and LDCs:

- The feedstock for biogas production is free of charge without any competing use (or might even come with a discharge/tipping fee);
- The existing production of energy is fluctuating, i.e. unreliable. Additional electricity production from diesel - generating sets is expensive, i.e. 0.2 USD/kWh and over.

Combining both points can result in projects with payback periods of two to four years, without taking all other benefits into consideration. An ideal biogas plant generates a continuous amount that is turned into heat and electricity (cogeneration). People can benefit from cheap energy, job creation and by-products such as fertilizers, cleaner rivers, lakes or soils, while reducing bad smells.

It was reported that, in some DCs or LDCs, more than 70% of the biogas plants work below their original rated specifications. The main reasons for such underperformance are:

- too high capex,
- sound financing not available,
- unreliable feedstock supply,
- fluctuating feedstock price,
- poor management,
- political instability,
- unreliable off-takers,
- lack of qualified staff,
- technical and/or biological problems during operation
- poor technical and biological design.

Turning waste from food production or agriculture into energy is not just a source of green renewable energy. It can have a much broader impact, as it:

- prevents pollution of groundwater,
- solves a waste disposal problem and its related costs,
- reduces greenhouse gas emissions by mitigating methane emissions,
- provides organic fertilizers,
- uses untapped resources,
- creates jobs and value at regional (mostly rural) level.

3.2 Case Study #1: Waste from food processing for captive power – biogas from avocado waste in Kenya [9]

Biogas from avocado waste in Kenya. (Source: Olivado)

3.2.1 Project background

Located in Murang'a County in Kenya, Olivado EPZ Limited sources organic avocados from local farmers. The fruits are either exported to Europe or processed into avocado oil. The company is the number one organic avocado oil producer, with 90% of the global organic extra-virgin avocado oil production. The conversion of process residues, such as skins, stones and wastewater, covers all energy needs of the factory (electricity and heat). The project implementation took three years from its conceptualization to its commissioning in 2020.

3.2.2 Technical details

The biogas plant consists of two digesters with a capacity of 1,400m^3 of substrate each. There is a double-membrane gas holder on top of each digester to store the biogas. Biogas can be stored and constitute a buffer in case of fluctuations in production or demand. The plant was designed to produce 3,500 Nm^3 of biogas per day.

The feedstock comes directly from the processing plant. The avocado seeds are crushed; the pulp and green process water are then pumped into a 24 m^3 mixing tank. The feedstock is then fed into the digesters.

The biogas is used in a CHP plant with a total thermal capacity of 931 kW_{th} and electricity generation capacity of 400 kW_{el}. Additionally, there is a biogas bottling plant where the methane concentration of the biogas is increased to 97% before being bottled. With a 97% methane content, the biomethane can be used to fuel the company's vehicles.

The digestate is separated into two phases: a solid digestate used as organic fertilizer and a liquid digestate recycled back into the mixing tank to inoculate the fresh feedstock.

3.2.3 Input and output

The feedstock input is about 3,600 tonnes per year. It comprises 1,200 t avocado skins and stones and 2,400 t of oil-free pulp.

From the biogas output, about 410,000 kWh_{el} of electricity and 200,000 kWh_{th} of thermal power can be produced annually. As a result, the plant can cover the complete captive power of the avocado processing, cooling facilities and packaging. The thermal power is mainly used for process water heating.

3.2.4 Economics and finance

The main drivers of the project were affordability, development of local capacity, simplicity of design and locally sourced material wherever possible.

The total project costs added up to USD 1,200,000. Financing this investment was challenging. Eventually, a combination of self-funding, the SUNREF program (via commercial banks), UNIDO incentive-based support and a DEG grant made the project possible.

The project payback is estimated to be just over three years, without taking into account the value of the organic fertilizer.

3.2.5 Lessons learned

Turning production waste into biogas and using it for captive power can be highly profitable. The biogas plant at Olivado's processing factory is an economically successful project. By using the production waste and dealing with it in a sustainable manner, it is a perfect example of circular economy. The waste is transformed into valuable organic fertilizer that is returned to the avocado plantations.

The biogas produces electricity, heat and fuel for vehicles, substituting fossil fuel and, therefore, mitigating GHG emissions. The reliability of the electricity production contrasts with previous electricity blackouts and boosts the productivity of the factory. Moreover, there is no need to worry about waste disposal and its associated costs anymore.

Building a biogas plant can turn into big technical and organizational challenges. The availability of equipment was not easy to manage: it took time to build up a reliable network of suppliers, locally or abroad. In April 2016, extreme weather conditions damaged the gasholder membrane and delayed the project. More delays were caused by late equipment delivery from third-party suppliers from abroad. Finally, financing, especially from a local bank, turned into a big challenge.

Perseverance and determination are key drivers. The success of the project lies in the determination of the investors who took the initial risk of using their own funds.

This type of project has a high replication potential in the food processing and agro-business.

3.3 Case Study #2: Biogas-based electricity generation for export to the grid from food production residues in Brazil[10]

Biogas from agro-industrial residues. (Source: Castrolanda)

3.3.1 Project background

Castrolanda Cooperativa Agroindustrial, together with Frísia Cooperativa Agroindustrial Capal Cooperativa Agroindustrial, and Unium Bioscience Limited, commissioned a biogas plant to treat the wastes generated by their industries in a proper and sustainable manner. Among the nine different types of wastes used as substrate, the main ones are sludge from slaughterhouses, potato wastes and wastes from a dairy producing UHT milk. The plant was installed in Castro-PR in 2019.

3.3.2 Technical details

The biodigester is of the Continuous Stirring Tank Reactor type. Its capacity is 4,900 m³. Biomethane is used in four power generators with a total capacity of 1.2 MW_{el}.

The plant can treat 13,000 tonnes of waste per year. The main feedstock (6,000 t/year) comes from reverse logistics from UHT milk production. Sludge from swine slaughterhouses accounts for 4,000 t/year, while the balance comes from the residues generated by a potato chip factory.

With this input, 8,910,000 kW_{el} of electrical power and 9,720,000 kW_{th} of thermal power can be produced. Electricity is fed into the grid while the thermal energy is only used for digester heating. A future use of thermal energy is planned for refrigeration via absorption chillers.

3.3.3 Economics & finance

The total investment cost was BRL 13.8 million (USD 3.54 million), with the biodigester representing some 57% of the total cost. The balance covers the cost of the four generators, of the biorefinery and other peripheral equipment.

The biogas plant annual O&M costs are in the order of BRL 1.2 million (USD 300,000).

The annual revenues from the sales of electricity amount to BRL 3.4 million (USD 900,000). In addition, the CO_2 supplied to the meat processing unit of the agro-industrial complex generated annual savings of around BRL 1.4 million (USD 360,000).

The project was funded by 70% equity and 30% from the regional development Bank BRDE (Banco Regional de Desenvolvimento).

3.3.4 Lessons learned

The investors in the biogas project see great value in the development of the biogas value chain in the Campos Gerais region.

By bringing their wastes to the biogas plant, the wastes generated in the respective factories are no longer a cost factor, but an additional revenue stream. Treating the wastes in a biogas plant allows for proper waste disposal and traceability, and prevents environmental pollution.

The main challenge was the approval of the project by local authorities. This took a long time, mostly due to a lack of experience and understanding from state officials. The transfer of a European technology had to be adjusted to tropical conditions. That meant a know-how and technology transfer and a partial relocation of the equipment production to Brazil.

The following conclusions can be drawn from the project:

1. combining several waste streams can lead to a proper sizing of a biogas plant;
2. providing training on biogas technology and its benefits can help speed up the approval process by the state authorities;
3. finding a good balance between the use of imported and locally produced equipment is essential.

3.4 Case Study #3: Waste from agro-business for biogas production from captive and grid – power biogas from vegetable residues and maize stalks in Kenya

Biogas plant in Naivasha, Kenya. (Source: Vegpro)

3.4.1 Project background

This grid-connected biogas-based plant has an installed capacity of 2.4 MW_{el}. It is a good example of agricultural waste turned into electricity to tackle the unreliability of the local grid and the high cost of electricity produced by diesel gensets. The plant supplies power to the host factory for its cold storage and vegetable packing. Excess power is exported to the grid. The feedstock consists of maize stalks and pea waste.

Vegpro (VP) Group is a large vegetable producer and exporter, mainly to the European market. Together with Tropical Power as an operator and Snow Leopard Projects GmbH as an engineering and technology provider, the project was completed within two years. The 2.4 MW biogas plant is located in Naivasha, Kenya[11].

Since the beginning of its operation in 2015, the plant has continuously processed agricultural residues from vegetable production. The main objective of VP was to become independent from the grid's frequent fluctuations, which led to problems and regular repair needs for their electrical motors. The grid is now just providing back-up power.

3.4.2 Technical details

The plant is a two-stage biogas plant with hydrolysis as pre-treatment before the digester. This technology is ideal for fibrous feedstock such as maize straw as it provides higher yields and a better controlled biogas production process, compared with a single biological-stage biogas plant. The plant has two hydrolysis tanks of 759 m^3 each, a 5,652 m^3 digester and a small digestate storage (759 m^3). The digester is equipped with a biogas storage on top. The plant is fully automatic with a state-of-the-art control system, which can be accessed remotely.

The digestate is separated into a liquid and a solid phase. Some of the liquid phase is recycled back to inoculate the new feedstock in the hydrolysis. The remaining digestate is used as bio-fertilizer in the vegetable fields, substituting for the usual chemical fertilizer.

The daily feedstock input is about 150 tonnes. Its amount and composition vary according to the availability of vegetable waste. The daily tonnages may vary depending on the dry matter content of the available feedstock.

3.4.3 Economics & finance

The investment for this plant was USD 6.5 million; 100% equity was provided by the local investors, which sped up the project implementation. The feedstock is provided for free from VP, who get the fertilizer back in return. The payback period is just under six years.

3.4.4 Lessons learned

The renewable electricity produced by the biogas plant replaces an estimated amount of six million liters of diesel fuel previously used by VP to run gensets in the absence of grid electricity. Besides the cost savings, greenhouse gas emissions are saved as no fossil fuel is combusted anymore.

Bio-fertilizer from the biogas plants replaces the chemical fertilizer that was previously used. Although the residues usually stay in the fields, by treating the residues in the biogas plant, the fertilization effect is much higher for the soil than leaving the waste untreated in the field.

One of the main success factors was the commitment of all parties from the conceptualization of the project to its commissioning in spite of numerous challenges, such as a lengthy process to secure a Power Purchase Agreement (PPA) and the construction itself. As the partners were committed to building a plant with high quality and industrial standards, the identification of experienced and qualified contractors and suppliers proved difficult. The project team eventually managed to complete the construction within 12 months, despite the size of the plant and its remote location. It was essential for the local operating personnel to be trained properly in order to ensure a stable performance of the plant after commissioning.

The following conclusions can be drawn from the project:

1. a mixture of agricultural residues and by-products can be good raw material for biogas production;
2. the digestate from a biogas plant is a better ferti lizer than the raw waste;.
3. industrial size and quality biogas plants are viable in Africa;
4. trained and qualified operating personnel is key to the continuous performance of a plant.

3.5 Biogas and the Sustainable Development Goals

The treatment of wastewater or liquid/solid waste from cattle or food industries helps to reduce pollution of lakes, rivers and waterways (SDG 6 & 14). It is a clean and often cheap fuel to produce, making it very affordable (SDG 7). When integrated into agro-industries, biogas plants help solve waste management problems while covering factories' energy needs. This is a good example of inclusive and sustainable industrialization (SDG 9). Biogas production is also applicable to communities, helping manage waste, reduce pollution, build resilience and generate energy and revenues (SDG 11). The use of biogas at industrial or domestic levels and of fertilizers in agriculture are good examples of sustainable circular economy (SDG 12). Biogas production has a strong impact on the mitigation of GHG: it prevents the uncontrolled degradation of wastes and the subsequent release of highly damaging methane into the atmosphere. It also substitutes the use of fossil fuels (SDG 13) and of wood and charcoal, preserving forests and biodiversity (SDG 15).

Biogas projects implemented in off-grid areas bring in energy that can stimulate new income-generating activities (SDG 8), reduce poverty (SDG 1), and improve women's lives (SDG 5). The fertilizer produced from the biogas plant can be used to enhance the soil condition (especially together with biochar). Through this, better crop yields can be achieved (SDG 2). Food security, water sanitation and job creation contribute to better health conditions and well-being (SDG 3). The implementation of the most recent biogas systems in industry and collaboration with academic institutions allow the training of young technicians and engineers who can then participate in the design and in the operation of other plants and stimulate the replication of the technology (SDG 4). It can lead to specialized jobs and enhance economic growth (SDG 8), especially in rural areas, thus helping reduce inequalities between rural and urban areas (SDG 10).

All the above is summed up in Table 3.

SUSTAINABLE DEVELOPMENT GOALS (SDGs)	CASE #1: BIOGAS FROM AVOCADO WASTE IN KENYA	CASE #2: BIOGAS FROM FOOD PRODUCTION RESIDUES IN BRAZIL	CASE #3: BIOGAS FROM VEGETABLE RESIDUES AND MAIZE STALKS IN KENYA
1 NO POVERTY	✓		✓
2 ZERO HUNGER	✓		✓
3 GOOD HEALTH AND WELL-BEING	✓		✓
4 QUALITY EDUCATION	✓	✓	✓
5 GENDER EQUALITY	✓		✓
6 CLEAN WATER AND SANITATION		✓	
7 AFFORDABLE AND CLEAN ENERGY	✓	✓	✓
8 DECENT WORK AND ECONOMIC GROWTH	✓	✓	✓
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	✓	✓	✓
10 REDUCED INEQUALITIES	✓		✓
11 SUSTAINABLE CITIES AND COMMUNITIES	✓	✓	✓
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	✓	✓	✓
13 CLIMATE ACTION	✓	✓	✓
14 LIFE BELOW WATER		✓	
15 LIFE ON LAND	✓	✓	✓

Table 3: Biogas and the SDGs

3.6 Success factors and challenges

3.6.1 "Only profitable projects survive"

The succession of successful and failed biogas projects over the last 25 years has shown that the long-term success of a project is directly linked to its profitability for local investors and partners. The person, family, or company who gets profit from the project ensures its daily production and O&M.

A well-designed, very promising project can eventually turn into a failure. Supported by international donors and constructed within a community, some biogas plants were successfully commissioned and properly operated. After a while, some repairs had to be made, but it was not clear whose responsibility it was and who would eventually pay for it. Repairs could not be made, and the project was finally abandoned.

A key takeaway is that project stakeholders' rights and responsibilities must be clearly specified and agreed on from the very beginning.

3.6.2 "Adopt a simple business model"

A successful biogas project design must combine investment, feedstock, and electricity usage (generating revenues and profit). That concretely means:

- securing the full investment before starting the construction;
- making sure that the feedstock for the biogas production is available in sufficient quantities throughout the lifetime of the project; and
- generating continuous profit through the sales of electricity, of biogas and, whenever possible, the residues from the biogas production.

Raising finance for an industrial biogas plant can be challenging. Its price can vary from a few hundred thousand to several million dollars. The capex that is required for an industrial biogas plant is generally too large for small lenders and too small for large lenders. Access to finance is easier when the owner of the plant is already involved in a large and profitable business with a good track record with banks and financial institutions and when feedstock supply and project revenue risks are minimized.

Bear in mind that financing risks are minimized when investment, feedstock supply and electricity are in one strong hand.

3.6.3 "Know your feedstock and its source"

The feedstock is the most important input into a biogas plant. It is key to know and control its quality, quantity and price, as it influences the design, size, and profitability of a biogas plant.

The feedstock **quality** varies from liquid (factory effluents) to very dry feedstock such as rice straw, from energy-rich (grease) to fibrous feedstock. A biodigester ideally runs on feedstock of constant quality.

The feedstock **quantity** should be guaranteed throughout the year to secure a smooth operation of the biodigester at full capacity.

The feedstock **price** varies widely, depending on whether a gate fee is paid by the waste producers, whether the feedstock is generated on site or comes from energy crops and could cost a few hundred USD per tonne.

Best cases are when the feedstock is a residue of the production line of the factory where the biodigester is implemented. Worst cases are when the feedstock supply fully depends on external suppliers whose business might not be sustainable or who would, at some stage, stop selling their feedstock.

In terms of price, if the feedstock is an in-house generated waste, it might be free, and even sometimes have a negative value, if one needs to pay to get rid of it.
If the waste comes from external sources, it might be free at the start, but its price might rise once there is a growing demand for it. Remember that feedstock quality, quantity and price must be under control throughout the lifetime of the project.

3.6.4 "Know your revenue streams"

It is key to assess how strong, secure and sustainable the revenue stream is. The revenues for a biogas plant can come from different sources:

- gate fee (for treating waste)
- electricity (self-consumed / supplied to third party / grid)
- biogas sales
- heat generation
- fertilizer (liquid, solid)

It can also be savings from not having to dispose of the residues, and/or not buying electricity from the grid.

Biogas plant in Kenya. (Source: VP Group)

3.6.5 "Building cheap is building twice"

Investors often consider the capital cost as their main selection criteria. It is a natural attitude for first buyers with a limited budget. They are not familiar with the technology and tend to buy the cheapest one. They should rather consider the O&M costs and the return on investment (ROI) rather than just focusing on the capex.

Investing in environmentally friendly projects using RE is a long-term investment. As biogas plants will run for decades, the weight of the O&M costs gets higher over time.

3.6.6 "Your 24/7 working staff is your bacteria – treat them nicely!"

Biogas production is a biochemical process, i.e. based on the activity of bacteria, and will best perform in optimal conditions.
Biogas plant problems are often solved technically and mechanically, which means bigger drives and more energy-consuming technical equipment. It also results in higher O&M requirements.

The worst enemy of the bacteria can be the operator or the operation team. Eight identical plants with very similar feedstock can see their performance range from excellent to very poor because of the daily operation.

Make sure that the operation team is well trained and clearly understands the way bacteria work.

4

LIQUID BIOFUELS – THE ALCOHOLS

4.1 Introduction

Liquid fuels are the most portable of fuels; they are an efficient and affordable way to transport energy to distant areas. Liquid biofuels are produced from organic matter through one of several physical, biological or thermochemical processes, including fermentation, pyrolysis, gasification and catalytic conversion or direct extraction and transesterification. Liquid biofuels are also produced by anaerobic digestion and direct partial oxidation or gas synthesis. Fuels produced by the recombination of hydrogen and carbon are referred to as synthetic fuels or synfuels. The most developed liquid biofuels are ethanol, methanol and biodiesel.

Liquid biofuels are traded globally and have been historically used in transportation, lighting, heating, cooking and electricity generation. They lost currency with the rise of petroleum fuels and were displaced by kerosene, gasoline and diesel fuel. However, they have regained popularity for fuel blending and flex-fuel engines. For example, in Brazil and the United States, the production and use of bioethanol was supported by forward-looking policies, including the National Alcohol Program (ProAlcool) in Brazil, 1975, and the Renewable Fuel Standard (RFS) in the US, 2005.

Ethanol and methanol, the two simplest alcohols, have begun to emerge from under oil's dominance for compelling reasons.

These include their environmental benefits, such as their potential to be renewable and to recycle waste, the fact that they burn cleanly, are biodegradable, and are low-carbon fuels. Their socioeconomic benefits include their ability to be produced at low cost, through well-established pathways with relative ease, on a large or small scale. Liquid biofuels also have significant health benefits over other fuels, including wood and kerosene, as their use for cooking has been discouraged by the World Health Organization (WHO).

The three case studies presented next illustrate the opportunities created by bioethanol production and use. The focus on this liquid biofuel is based on its widespread application. It is produced in almost every country, including DCs and LDCs. In addition, the capital cost of very small plants is relatively low and competitive when compared with ethanol production costs in large plants. These smaller plants are micro distilleries, which are defined as producing up to 5,000 liters of ethanol per day. Ethanol is produced most easily from sugar and starch feedstocks, which are often by-products or wastes of other agro-industrial processes, such as sugar, food and beverage production.

4.2 Case Study #1: Tanzania bioethanol cooking program – a stove and fuel delivery facilitation project

Selling cook stoves at a local market. (Source: Project Gaia Inc.)

4.2.1 Project background

UNIDO, in collaboration with the Vice President's Office, Division of Environment, of the United Republic of Tanzania, is implementing a five-year GEF-funded project to promote the use of bio-ethanol as a clean, alternate fuel for cooking in Tanzania's largest city, Dar es Salaam. They are working together with partner institutions, including the TIB Development Bank. The project is spearheading an innovative approach, the Market Enabling Framework (MEF) – a private sector-driven market model with a target of 500,000 households adopting ethanol cookstoves by 2024, and to set up a fuel supply chain that sources, delivers and retails ethanol fuel to cookstoves in the Dar es Salaam market. The approach harnesses GEF and European Union funds to facilitate a rapid switch in cooking habits in households primarily reliant on charcoal and fuelwood for cooking. It also sets up, through the TIB Development Bank, a Private Sector Guarantee Fund (PSGF), to assist with financing infrastructure needed for an ethanol cooking fuel economy.

4.2.2 Supply and value chain

The MEF is a unique project design. The goal is to induce households to switch to a modern ethanol cook stove, priced competitively compared to traditional stoves.

The MEF assists the distributor to place a stove in the hands of the consumer at a competitive price. The distributor also sources and delivers the fuel. Thus, the MEF provides facilitation on the demand side, with a small subsidy on cook stoves. It also offers extensive business and technical support to the distributor. Moreover, the MEF seeks to build capacity within the policy and regulatory bodies of Tanzania and facilitate the adoption of standards, both for ethanol cooking fuel and ethanol stoves. It seeks to establish a supportive policy framework for the use of ethanol fuel. It also seeks to share knowledge with appropriate institutions engaged in research and development. UNIDO is working with the Tanzanian Bureau of Standards (TBS) and with private sector stakeholders, such as the Tanzanian Private Sector Foundation (TPSF), to support the collaborative process of developing standards. It is also working with the Sokoine University of Agriculture and the University of Dar es Salaam to build and share knowledge.

On the supply side, it offers financial support through the PSGF, which is designed to catalyze commercial lending for infrastructure development for producers by reducing lender's risk. The MEF team networks with sugar producers to encourage the use of molasses, an often-wasted by-product of sugar production, for distillation to ethanol fuel, thereby ensuring principles of circular economy.

Tanzania has 11 sugar factories around the country, large and small. Currently, the country produces just under 28 million liters of ethanol annually. Yet, based on its sugar production, it could be producing 365 million liters annually. Tanzania is a sugar-deficit country, importing sugar to meet its domestic needs. Therefore, it is likely that Tanzania's sugar sector will continue to expand. In addition, the UNIDO/GEF project also seeks to encourage the development of micro distilleries to process smaller agricultural waste streams. Examples of these are cashew apples, the sugary waste from cashew nut harvesting, and sisal boles, a waste in the sisal industry. Other agricultural feedstocks are of interest as well, most notably cassava. The MEF seeks to accomplish delivery through the private sector after years of planning, stakeholder consultations and a pilot study of 150 stoves from 2014 to 2015 in Zanzibar.

The distributor chosen for the first phase of the project was Consumer's Choice Limited (CCL), a logistics and wholesale company with experience in buying and selling ethanol. They will distribute up to 110,000 stoves under the GEF-6 subsidy program in an assigned sales territory in Dar es Salaam. During phase two, two or three more distributors will be selected to create competition in the market.

One of the first things that CCL had to do once they were selected was to choose an ethanol stove supplier on an open tender. The winning bid was from CleanCook, a Swedish company with manufacturing facilities in Durban, South Africa. CCL's next move was to build its supply chain and secure financing from its banker to import the cook stoves. They built a fuel supply depot and a semi-automatic bottling plant at their industrial premises in Dar es Salaam to bottle fuel in one-, two-, and five-liter returnable HDPE containers. They secured contracts for supply of ethanol fuel from their suppliers. They signed an agreement with the stove company to assemble the stoves locally, with an eye to eventual local manufacture, and set up a stove assembly workshop adjacent to their fuel bottling plant. The first stove shipments arrived in October 2019. CCL leveraged approximately USD 282,000 with the bank to import the first 12,870 stoves and spent USD 775,000 to build and supply their fuel storage, handling, bottling and marketing operations. Thus, slightly over USD 1 million has been invested commercially so far in the project.

CCL began selling stoves in earnest in February 2020. To date, they have sold approximately 1,000 stoves in their assigned territory in Dar es Salaam. Just as sales volumes were on the rise, the COVID-19 pandemic hit Tanzania and Dar es Salaam went into quarantine. As a result of a government request, CCL quickly adapted to the situation to produce hand sanitizer. They joined Tanzania's largest ethanol producer, Kilombero Sugar, in donating pharmaceutical-grade ethanol to the effort. This was an opportunity for CCL to remind the public about clean cooking with ethanol, sharing the message: "Clean Hands, Clean Fuel, Clean Air."

Twin burner cook stove in Tanzania. (Source: Project Gaia Inc.)

4.2.3 Project assessment: benefits, success factors, challenges [12]

The program targets and indicators have a strong focus on women's empowerment, cleaner production, low-carbon technology, inclusive livelihoods, health, access to finance and social services, and innovative partnerships.

By developing a market for ethanol cooking fuel in Dar es Salaam, the project achieves the following:

1. demand in the agricultural sector to produce fuel from agricultural residues and wastes;
2. opportunity for value-add investment in the agricultural sector;
3. economic stimulus to the rural economy, encouraging jobs and the benefits that go with cash earnings, including an economic multiplier effect that will impact many aspects of daily life; and
4. response to a fundamental, unmet need in the city, namely clean and convenient cooking, and pollution-free homes.

One liter bioethanol bottles ready for distribution. (Source: Project Gaia Inc.)

These achievements directly improve the health and well-being of women and children. As the program expands, it is expected to have significant macro-economic benefits for Tanzania. Fuel imports represent the greatest demand on FOREX earnings and have a considerable impact on Gross Domestic Product (GDP). As more fuel is produced domestically and less is purchased from abroad, this will place greater financial resources within Tanzania, a critical requirement for growth.

The benefits realized (clean air, saved time, increased productivity) and money earned, contribute to the domestic economy. By injecting limited financial support where the financial obstacles are, this approach unlocks local investment and entrepreneurship and encourages conducive government fiscal and regulatory policy. This approach to development requires a lower investment from OECD countries and allows the investment to go much further.

Various financing issues were overcome during the project. Firstly, CCL was slow to obtain financing from its commercial bank to guarantee the Letters of Credit required to import stove parts from South Africa, resulting in an eight-month delay in the start of sales. The PSGF, to be seeded in capital from the Government of Tanzania, should be in place during Phase 2 of the project, to help reduce commercial capital risk. Secondly, despite a USD 7 subsidy to the consumer and a USD 3 success fee to the distributor, the stoves were still too expensive (USD 17) for households to buy without a consumer loan. Economic difficulties associated with the COVID-19 pandemic have only exacerbated the problem. As a remedy, the MEF will propose increasing the subsidy on the stoves by an additional USD 4 to bring them down to a cost of USD 13 for the consumer. It will do so by reducing the distributor's allotment of subsidized stoves from 110,000 to about 75,000 stoves.

While the MEF was designed in an adaptable way to address such problems, the following barriers point to possible improvements of the model: (1) a loan guarantee mechanism to help leverage the always risk-averse commercial capital and (2) consumer finance to help with the purchasing of stoves. The latter will also stimulate more rapid sales of stoves. A third barrier is the value added tax (VAT) on ethanol fuel. The fuels with which ethanol must compete, charcoal and LPG, are not subject to VAT. Removal of VAT on ethanol fuel will reduce its cost by 20% and position it as the cheapest cooking fuel in the marketplace. The MEF team, along with the distributor, will engage with the government to help shape conducive policies, of which VAT is one.

4.3 Case Study #2: Ethanol production from cassava in Thailand: a case of South-South Technology Transfer

Cassava field in Thailand. (Source: KMUTT)

4.3.1 Project background

In 2012, in response to a GEF call for climate change work, UNIDO and the National Science and Technology Development Agency (NSTDA) of Thailand, developed a proposal to share an innovative bioethanol technology developed at King Mongkut's University of Technology Thonburi (KMUTT) with neighboring countries, Vietnam and the Lao People's Democratic Republic (Lao PDR). UNIDO and KMUTT proposed a robust South-South Technology Transfer (SS-TT) process that involved demonstrations, pilot studies, trainings and workshops, capacity building with government and two knowledge hubs, one in Thailand and one in Vietnam, with an actively maintained website to make technical information and up-to-date research readily available[13].

The project was implemented between November 2013 and December 2018. The GEF grant for the project was USD 2,600,000, with co-financing commitments from all parties totaling USD 31,623,000 in cash, loans and in-kind payments.

Cassava in Asia is predominantly used for producing starch or dried chips for animal feed or for export. Therefore, cassava is a suitable candidate as a feedstock for ethanol production for fuel use, whether for cooking or for transportation. Research teams from KMUTT and the BIOTEC Cassava Starch Technology Research Laboratory developed improved feedstock and fermentation processes for producing bioethanol from cassava.

Their technology, referred to as Very High Gravity Simultaneous Saccharification and Fermentation (VHG-SSF), achieves higher yields, reduced energy and time during fermentation, and significant GHG savings. Thailand is now considered a world leader in this technology. Teaming up with UNIDO gave KMUTT the opportunity to transfer this knowledge to other cassava producers in the Association of Southeast Asian Nations (ASEAN).

4.3.2 Program objectives

The overall objective of the project was to transfer innovative ethanol technology from Thailand to neighboring countries in the Mekong region, especially to Lao PDR and Vietnam.

Specific objectives were threefold[14]:

1. to enable information dissemination of a new ethanol technology package within the Mekong region;
2. to create centers of excellence for bioethanol technology using fresh cassava roots in Thailand and Vietnam to implement and sustain project activities; and
3. to build associated capacity for both sending and receiving countries, including creating conducive policy and market environments, as well as removing existing barriers to facilitate the successful transfer of technologies while ensuring project sustainability through enhanced institutional and human capacity in Thailand and Vietnam.

4.3.3 Implementation and outcomes

The SS-TT methodology was based upon a holistic strategy. The idea was not just to transfer the VHG-SSF process and technology but also to build local capacity through training, demonstration, reaching commercial players and showing political leaders the broader economic issue of bioethanol fuel, its use and value to society, and how to create an enabling environment to support its use.

A series of capacity-building activities, supported by manuals, toolkits and training programs, were undertaken to facilitate the technology transfer. Training programs targeted farmers, entrepreneurs and technicians on cassava production. In the end, more than 150 farmers, 30 entrepreneurs and 30 technicians from ASEAN countries, and 40 scientists, engineers, and researchers, were trained on the technology. Additionally, training centers were established at KMUTT's 200 liters per day (lpd) pilot distillery in Thailand, and FIRI's 120 lpd plant in Vietnam. Four workshops were conducted at FIRI, training close to 150 participants.

The program also sought to build capacity at the institutional level. Consultations proceeded in the use of ethanol in gasoline, for the benefit of government leaders and policymakers. Training took place in Thailand in May 2018, which engaged 33 policymakers from Lao PDR, Myanmar, and Vietnam.

The results of and lessons learned from the program were disseminated at a regional event in Hanoi, Vietnam, for policymakers from Thailand, Lao PDR, and Vietnam. It included a site visit to the 120 lpd pilot plant at FIRI. The SS-TT program was presented at Conference of Parties (COP24) in Katowice, Poland.

The key outcomes of the program include (1) enhanced capacity at KMUTT, Thailand, and Food Industries Research Institute (FIRI), Vietnam, to lend strong and steady support to the region, (2) successful cross-border cooperation and technology sharing, and (3) progress toward a conducive environment to promote optimized bioethanol technology and its use for fuel, with the prospect of increasing opportunities for investment.

4.3.4 Lessons learned

The KMUTT VHG-SSF process offers the following benefits:
(a) Improved productivity of cassave root production:
- more than double productivity without changing the cassava variety,
- adoption of new soil conservation practice,
- mitigation of GHG emissions.

(b) Improved in-factory raw material management and pre-fermentation practices:
- increased flexibility for in-factory supply management,
- reduced water, energy and resource consumption,
- reduced transportation cost between farmers and factory,
- lowered average cost of bio-ethanol production.

(c) Improved fermentation process
- increased ethanol concentration using "Very High Gravity - Simultaneous Saccharification and Fermentation (VHG-SSF) technology (ethanol production increased by 165%),
- shortened process and fermentation time,
- reduced time and energy usage in distillation,
- mitigation of GHG emissions.

Based on a Life Cycle Analysis, KMUTT's bioethanol technology reduces 61,93 tonnes CO_2 per 100,000 liters produced compared with conventional bioethanol production from cassava chips[15]. The economic and environmental impacts of being able to displace gasoline, an imported fossil fuel, with locally produced renewable biofuel are important co-benefits of the program.

Procurement of equipment for FIRI's ethanol demonstration plant in Vietnam took longer than expected, due to the need for KMUTT to adjust its distillery design to local conditions and FIRI's due diligence procedures. Eventually the issues were resolved, and the distillery was built. In Myanmar, project activities were designed to support a 400,000 lpd cassava-to-ethanol project. Unfortunately, the cost and availability of commercial finance for the Myanmar project was so constrained that the focus had to be shifted to Lao PDR and Vietnam. In Thailand, the pilot plant for the KMUTT technology was to be built at the Liquor Distillery Organization Excise Department, located in Bang Khla District, Chachoengsao Province, Thailand. As the construction of this plant became delayed, the program's mid-term evaluators recommended moving the pilot plant to the Sapthip Company Ltd. distillery in Chaibadal, Lopburi.

4.4 Case Study #3: Demonstrating the feasibility of locally produced ethanol for household cooking in Addis Ababa, Ethiopia

Gelan Distillery in Ethiopia. (Source: Project Gaia Inc.)

4.4.1 Project background

The Gaia Association (now Gaia Clean Energy) and the Former Women Fuelwood Carriers' Association (FWFCA) identified an opportunity to produce ethanol on a small scale from locally available wastes and to sell it into a stove fuel market. With the support of Gaia, FWFCA developed a plan to sell and distribute stoves and fuel to their members and then to other consumers. They would sell ethanol produced in their own micro distillery and then supplement their supply with ethanol purchased from two government-owned distilleries.

In 2009, Gaia and the FWFCA obtained funding from the World Bank's (WB) Biomass Energy Initiative for Africa (BEIA) program to build a micro distillery in Addis Ababa[16]. In 2011, the Stockholm Environment Institute (SEI) joined the project. The team won additional funding from the Nordic Climate Facility to supplement the WB funding[17]. Research and study components were added to the project.

4.4.2 Project design

The project's main objective was to demonstrate the viability of ethanol micro distilleries (EMDs) in Ethiopia. Ethanol cook stove fuel is a promising market as the price of charcoal and fuelwood continues to increase in. Gaia held an open tender to choose a 1,000 lpd distillery. A thousand ethanol cook stoves were sourced from Domestic (now CleanCook) for the project. Gaia had tested these stoves and has used them in Ethiopian refugee camps since 2006.

Gaia worked with the selected contractor, Spectrum Technologies of Unity, Saskatchewan, Canada, to procure and install the distillery. The FWFCA women would set up and run the fuel and stove distribution business. Gaia engineers would operate the distillery, employing the FWFCA workforce. The FWFCA would take over running the distillery once trained, with Gaia providing support.

In the first phase of the project, the raw feedstock for manufacturing ethanol in the EMD would be molasses, purchased from Wonji Sugar Factory, close to Addis Ababa. Once the distillery was operational, the project would create a demonstration program for local businesses, for the Ethiopian government and for other governments coming to the African Union, situated in Addis Ababa. The city and governments would be encouraged to create an enabling environment to support biofuel production and use.

4.4.3 Implementation

The implementation of this project was divided into four components.

1. EMD bidding, installation and commissioning
The first project activity was to secure all permits, including project location. The original site proposed (owned by the FWFCA) was denied permits, and another site was selected, granted by the city's solid waste authority in Gelan.

Gaia then held an open tender in search of an EMD with a capacity of 1,000 lpd. 10 conforming bids were received from Brazil, Colombia, China, India, South Africa, Europe, the US, and Canada. Prices ranged widely, from USD 120,000 to USD 1.9 million. The bid price included planning and scoping, installation, commissioning, training, warranties and aftermarket support.

The bids were evaluated on six criteria: price, technical robustness, reliability and expertise of the manufacturer, energy and water saving measures, process simplicity, training and technical support, and suitability to the local environment. In the end, the second-lowest bid was selected (USD 168,000), the firm from Canada, Spectrum, with manufacturing in Mumbai, India.

Once the distillery vendor was selected, it took three years to complete the project, largely because of permitting issues and lengthy government approvals. The distillery was commissioned in October 2015.

2. FWFCA stove program and household socio-economic impact analysis
The SEI and Nordic Development Fund (NDF) entry added scope for studying the social and economic impact of biofuels in Ethiopia. Several studies were undertaken throughout implementation. This included a study of socioeconomic conditions in the FWFCA community and their use of stoves. SEI led the socioeconomic analyses using their Household Energy Economic Analysis (HHEA) methodology[18]. Gaia led indoor air quality (IAQ) measurements and analyses. Results confirmed that the ethanol fuel was effective in substantially reducing pollution, and that the ethanol fuel and stoves were accepted by the households.

3. Environmental impact and carbon finance analyses
The Ethiopian Environmental Protection Authority (EPA) required a full Environmental Impact Assessment (EIA) before approving the site. The NCF required energy efficiency and mass balance analyses on the distillery and wanted to see reduced wood fuel use in the boiler. Although the distillery had a solution for effluent treatment at the original FWFCA site, there was no room for treatment at the Gelan site. Initially, Gaia was forced to truck the distillery effluent to a disposal site, but eventually the city awarded Gaia land to construct settlement ponds. Gaia believes the real solution is to build a biogas plant on site to process the effluent and produce biogas for the boiler. It is estimated that enough biogas would be generated to replace 40% of the boiler fuel.

With a soft loan from the UNFCCC, later converted into a grant, Gaia developed a Program Design Document for carbon finance for ethanol stoves. The Project Gaia Program of Activities was approved by COP in 2014[19].

4. Policy outreach and results dissemination
Both Gaia and SEI invested considerable time into policy outreach activities, with the aim of creating an enabling environment for replication and use of ethanol for cooking. SEI and Gaia produced several briefing papers and reports. These include the SEI Discussion Brief-Ethanol: towards a viable alternative for domestic cooking in Ethiopia[20]. Additional funding was received from the KPMG Strategic Climate Institutions Program, funded by the U.K. Department for International Development, to produce a national strategy for ethanol cooking fuel production and use in Ethiopia.

4.4.4 Replicability

The FWFCA EMD is an inexpensive, simple distillery design that produces quality fuel and is both easy and efficient to operate. The cost of the EMD was under USD 200,000. The cost of the entire construction project, with add-ons (civil works, buildings, effluent treatment, etc.), was around USD 300,000. Currently, Gaia is assisting a commercial business to build Ethiopia's second fuel EMD.

4.4.5 Lessons learned

This project was the first of its kind in Sub-Saharan Africa (SSA). It demonstrates the feasibility of microscale, distributed ethanol production for cooking fuel use.

The EMD and its supply chain are a model for microscale urban and rural enterprises that create employment (approximately 50 direct jobs), including for women. The project also provides additional health, socio-economic and environmental benefits. Ethanol has displaced the use of dirty fuels in up to 1,000 households, reducing reliance on charcoal, kerosene, fuelwood, and dung. Women save a substantial amount of time each day both in cooking and fuel management.

Based on conservative estimates, baseline documentation and ongoing ethanol stove monitoring and evaluation, the project mitigates up to 6,000 tonnes of CO_2 per year. This will be sold as carbon credits once the program reaches critical mass and is validated, i.e. once 10,000 stoves are in use in Addis Ababa.

The most difficult obstacle to overcome was the loss of the FWFCA's original building site. The new site was less suitable due to its size, location, soil structure and lack of an all-weather road. The Ethiopian Electric Power Company was slow to serve the site. Additionally, due to its location on the border of the Addis Ababa administrative state and the Oromia Regional State, the distillery was damaged during political unrest in 2019. Gaia and the FWFCA are currently making plans to move the distillery to a new location, where it can be safely re-erected, maintained and operated.

Some of the women from the Former Women Fuelwood Carrier Association (FWFCA).
In the background (top left), the ethanol storage tank in the FWFCA compound. (Source: Project Gaia Inc.)

4.5 Liquid biofuels and the Sustainable Development Goals

Clean burning and renewable ethanol displaces charcoal, wood and liquid or gaseous fossil fuels (SDG 7). Reduced consumption of woody biomass supports the sustainable management of forests and resources (SDG 12). There is less deforestation, biodiversity loss and habitat fragmentation (SDG 15). This is important as forest cover prevents erosion, preserves surface and ground water supplies and combats desertification (SDG 6 and 15). By replacing liquid fossil fuels, bioethanol also reduces exposure to smoke, particulate aerosols, and carbon monoxide. This contributes to cleaner urban air quality for healthy and sustainable cities (SDG 3 and 11). The reduced production of GHG, along with the retention of soil and biomass carbon, contributes to climate change mitigation (SDG 13). There is significant market creation for bioethanol production and value is added to the agricultural industry (SDG 9). Bioethanol projects also generate employment (SDG 8), including an increase in employment and pay of women (SDG 5). By creating livelihoods, improving access to affordable energy and improving living standards, these projects can indirectly address poverty, hunger and well-being (SDG 1, 2 and 3). In case studies focused on cooking fuel, projects also reduce women's labor inside and outside the household (SDG 5). Financial and time savings allow more focus and resources for education, particularly for girls (SDG 4 and 5). Another key aspect of some of these projects is the sharing of knowledge, expertise, resources and technology from one country to another, allowing projects to be replicated and partnerships to form around the world (SDG 17). This is particularly the case for SS-TTs, which bridge the gap between countries (SDG 10).

Table 4 shows the way liquid biofuels address the SDGs.

4.6 Success factors and challenges

In Tanzania and Ethiopia, a strategy for market creation using ethanol produced in the sugar industry was developed and implemented, which could be scaled-up from excess molasses, a by-product of sugar manufacturing. In Thailand and its neighboring countries, Vietnam, Lao PDR, Myanmar and Cambodia, innovation took place in the cassava agricultural industry to boost production and processing efficiency. In this case, cassava is grown as a source of starch for fuel production or export.

4.6.1 Large and small plants – a diversity of feedstocks

A typical sugar factory distillery in SSA might be sized from 10 to 30 million liters per year, which, by international standards, is a small plant. Farmers, cooperatives, small businesses, and business associations could rely on micro distilleries, producing from 300,000 to 1,5 million ltd. These plants could bring value to localized, undervalued feedstocks. The approach of embracing both larger and smaller industrial solutions creates opportunities for a wide range of stakeholders, from established industries to individual farmers and small agro-processors.

In the case of the KMUTT micro distillery in Thailand, and its replication at FIRI in Vietnam, the purpose was to demonstrate to larger distillers an improved process that could produce higher ethanol yields. In the case of the FWFCA micro distillery in Ethiopia, the purpose was to demonstrate a strategy for national scale-up of ethanol production, relying not only on the state sugar industry but also on private businesses. In Tanzania, the market creation for ethanol fuel, through an ambitious stove and fuel distribution business in Dar es Salaam, encourages the sugar industry to build its ethanol production capacity. At the same time, the market creation is meant to create value in wasted feedstocks, which can be processed in smaller distilleries sized to fit the feedstock supply.

An output of the Ethiopia project was a national strategy for scale-up, using both larger and smaller distilleries and considering a diversity of feedstocks. This national strategy could serve as a model for Tanzania, as well as for other SSA countries.

4.6.2 Growing to scale

Whether DCs and LDCs can succeed at scaling-up ethanol, so that it becomes a viable replacement for biomass and petroleum fuels is still to be seen. There is great interest in doing so, and the challenge seems less a resource and technology problem than a management problem. It requires (a) an enacting policy and law to codify biofuels and allow them to compete with other fuels, and (b) securing finance to build production plants and distribution infrastructure.

Ethanol production in Thailand has grown by 350% in the past decade and its growth is influencing biofuel development in the region. Ethanol production in Southeast Asia and Africa is growing rapidly, and the potential for growth is still enormous.

SUSTAINABLE DEVELOPMENT GOALS (SDGs)	CASE #1: TANZANIA ETHANOL COOKING PROGRAM	CASE #2: ETHANOL PRODUCTION FROM CASSAVA IN THAILAND	CASE #3: ETHANOL FOR HOUSEHOLD COOKING IN ETHIOPIA
1	✓	✓	✓
2	✓	✓	✓
3	✓	✓	✓
4	✓	✓	✓
5	✓	✓	✓
6	✓	✓	✓
7	✓	✓	✓
8	✓	✓	✓
9	✓	✓	✓
10		✓	
11	✓	✓	✓
12	✓	✓	✓
13	✓	✓	✓
15	✓	✓	✓
17	✓	✓	✓

Table 4: Liquid biofuels and the SDGs

4.6.3 Sustainability

A frequent concern expressed about biofuels is that they will take land away from food production. The FAO has put this concern into perspective, emphasizing the opportunity of "food and fuel" over "food or fuel". In order to be viable and sustainable, agriculture needs reliable markets to sell farmers' products. Gaining access to a new market in biofuels offers farmers the opportunity to produce a reliable cash crop. Sending that crop off for biofuel production at a local distillery may return to the farmer valuable by-products such as animal feed, fertilizer, compost, and even electricity. Other products, such as food grade protein and CO_2, chemicals, flavorings, bio-oils for biodiesel production, and bioethanol, are sold forward to industry.

In many developing countries, only a fraction of arable land is farmed, often because of the lack of markets for what is grown. When markets for export crops such as rubber, cotton, tobacco, cocoa, soya and groundnuts disappear, the land may be left idle. In this condition, it degrades. If farmers have access to markets, they will cultivate the land and care for the soil. Profitable agriculture sustainably managed will return jobs and livelihoods to rural communities. Many of these will belong to women.

Several African countries are refocusing their national economic development plans back to agriculture. Their agricultural sector is a major contributor to GDP and in most instances is the major employer. A leading strategy in agricultural growth and development is a value addition. This is one of the reasons why there is so much interest in biofuels.

Agriculture and biofuels feature prominently in national Climate Resilient and Green Growth plans and the Nationally Determined Contributions. Therefore, biofuels not only provide domestic production of fuel, the opportunity for import substitution and saving of hard currency, but also a pathway to a climate-resilient economy.

4.6.4 Biofuels and the SDGs – guide for future work

A detailed Monitoring, Evaluation and Learning (MEL) tool was developed for the Tanzania project that may be used as a guide for designing and executing future projects. As discussed in Case Study #1, the replicability of the project, which recommends to expand to 20 additional high impact countries, is predicated on a funding plan called PSGF and the Clean Cooking Social Facility, which provides donors and investors with the opportunity to invest in measurable progress in addressing the SDGs. Because clean energy and biofuels address so many of the SDGs, these projects lend themselves well to the MEL strategy. This provides the ideal guide for future work.

Gelan distillery boiler is able to burn low-grade biomass such as sawdust and coffee husk. (Source: Project Gaia Inc.)

5

CHALLENGES IN IMPLEMENTING BIOENERGY PROJECTS

During an Expert Group Meeting held in Vienna from 3-5 December 2019, some 15 bioenergy projects implemented by UNIDO in DCs or LDCs in Africa, Asia and Latin America, with financing from GEF, were presented. According to the panel and working group discussions that took place during the meeting and the case studies presented by the bioenergy experts in chapters 2 to 4 of this document, the problems faced during the development and implementation of some of these projects were exposed and discussed. Lessons learned were then drawn and some key recommendations formulated.

5.1 Policy and regulatory framework

5.1.1 Problems faced

Bioenergy projects implemented in DCs or LDCs often face a lack of appropriate regulatory frameworks and conducive policies. Policymakers may not have a clear understanding of the bioenergy technologies and their economic, social and environmental benefits. Some national policies still focus on traditional mainstream activities and are still indirectly supporting the use of fossils fuels. Bioenergy is regularly left behind. Biofuels, such as bioethanol, biodiesel and biogas, face unfair competition from subsidized kerosene, diesel and LPG.

As biomass has been the most commonly used form of energy in households for cooking and/or heating and in some wood and agro-industries for covering their energy needs (power and/or heat), some governments do not feel that it is necessary to develop laws and regulations to support bioenergy. However, there is a need to support the implementation of more modern, higher efficiency systems, allowing a better conversion of biomass energy. Many countries do not have a proper regulatory framework in place for these effective industries to sell their excess green power to the grid and, if some do, the FITs are not attractive enough to justify the upgrade of the existing low efficiency power plants.

Other issues mentioned during the EGM included: (a) the discontinuity of some policies due to government changes and the setting of new priorities; (b) the mismatch between policies and implementation where bioenergy producers/developers were unable to secure licences to produce electricity.

5.1.2 Lessons learned

National and local governments have a key role to play in supporting the implementation of bioenergy projects. Most DCs have at least one ministry in charge of alternative energy that covers bioenergy. Some have developed appropriate policy instruments, while some are still in the process of developing action plans. The latter can benefit from the experience of countries which have already developed their own effective mechanisms, such as RE targets, FITs for power projects, financial and fiscal incentives, carbon tax for fossil fuel use, etc.

Practically, a conducive policy and regulatory framework should include:

- realistic and achievable targets for bioenergy adoption and development;
- attractive tariffs along the supply chain;
- suitable financial support mechanisms (subsidies, grants, soft loans) for bioenergy projects, including micro-financing for community-based projects;

- appropriate fiscal incentives to bioenergy projects, such as a reduction of VAT, corporate income tax, and an exemption of import duty and tax;
- simplified and transparent licensing and permitting procedures;
- facilitated grid connection for bioenergy projects;
- mandatory requirements (technical standards, quota obligation for biomass electricity, renewable portfolio standards);
- penalties for non-respect of regulations and a carbon tax for fossil fuels; and
- gender mainstreaming in bioenergy activities along the whole value chain.

The legislation must be adapted to include equipment quality and efficiency requirements. Therefore, it is recommended to establish and implement a quality control system, with an incentive program, a monitoring system and the necessary infrastructure, including testing, certification, accreditation and mechanisms for market surveillance. The regulatory framework should include the adoption of international standards for bioenergy equipment and encourage technology transfer.

Pellet presses in Portugal. (Source: Futerra Fuels)

5.2 Economics and finance

5.2.1 Problems faced

One of the major obstacles to the implementation of bioenergy projects in DCs and LDCs is the high level of investment cost. As local manufacturing of bioenergy equipment is limited, a large part of, if not all, the equipment needs to be imported, generating additional costs for freight, custom duties, import taxes and local transportation to the project site. Additional costs can also come from the hiring of a foreign team for erection, commissioning and first months of operation of the plant.

The lead time between the conceptualization and the commissioning of the project is much longer than usual. It was reported that four years were often not enough to get a biomass power generation project in place. Additional delays are common and often induce price increases. This additional capital cost affects the ROI of the project, to the point that it may become unviable. It affects the confidence of investors and financial institutions to get involved in similar projects.

Moreover, financiers are not familiar with these “unconventional” bioenergy projects and are reluctant to fund them. Hence, investors are requested to provide more equity and guarantees than normal.

5.2.2 Lessons learned

A bioenergy project feasibility study provides a good estimation of its economics and of the expected financial conditions. However, the reliability of its outcome in terms of ROI, pay-back period and net present value highly depends on the reliability of the input data.

As mentioned, bioenergy plants require large investments, especially when the technology and equipment need to be imported. This is often the case for the implementation of such projects in DCs and LDCs. There is a high risk associated with investing in the cheapest equipment, which may not be reliable, may necessitate regular repairs and generate abnormally high maintenance costs.

Another key operation cost for bioenergy plants comes from the feedstock. This can be the trickiest parameter, as it can broadly fluctuate. From very cheap, or even free, when the investment decision is made, its cost can rise gradually as competing markets develop, not only in the bioenergy sector itself, but also in other sectors. Consequently, a highly profitable plant today might not be economically viable tomorrow and might need to be shut down. A very critical feedstock availability study must be carried out separately, which should include a sensitivity analysis of the feedstock cost showing the limit of profitability of the bioenergy project.

Another factor that needs to be taken into consideration, is the fact that bioenergy is often facing unfair competition from subsidized fossil fuels. This is particularly the case for biogas-based power generation projects and for bioethanol use in the transport sector.

Securing a proper O&M of the plant and covering its related costs is of critical importance and, therefore, should never be overlooked or underestimated, particularly when projects are implemented in DCs and LDCs. Proper training must be organized for local operators during the final stages of the implementation and during the commissioning of the bioenergy plant. As O&M is crucial for the sustainable operation of the plant, it must, in all cases, be covered by the project revenues.

Depending on the type of bioenergy plant, revenues can come from the sales of biomass products (briquettes, pellets), biogas, liquid biofuels, heat and/or electricity. These revenues need to be properly assessed and some sensitivity analyses must also be carried out. For projects including electricity sales to the grid, firm, long-term contracts (10-20 years) with the utility are needed as they will condition the long-term viability of the project and its bankability.

Additional revenues can sometimes come from the sales of bioenergy plant by-products, like biogas plant residues that can be sold as fertilizers.

In some cases, savings can be generated from the avoidance of the biomass residues, disposal cost and from the fact that there is no need to rely anymore on fossil fuel and/or grid electricity to cover the plant energy requirements.

Banks and financial institutions are not inclined to finance bioenergy projects. They prefer to finance more conventional projects which they are familiar with, and which are faster to implement. However, it has been reported that banks in some countries like Brazil and Thailand have been less reluctant to finance new bioenergy projects as specific seminars had been organized to “educate” them on these new technologies. Naturally, it became easier for subsequent projects to get financial support, especially if they were developed by reputable agro-industrial investors whose core business generates the feedstock for the bioenergy plants and whose excess electricity can be sold to the grid. For the very first projects, corporate financing was preferred with an equity/loan ratio around 1, but afterwards, project financing became more common with the equity/loan ratio down to 0.5 or even below.

The above relates to private sector investments, but the situation is different for community projects that mainly rely on public funds from national/regional/local budgets or from international organizations. These projects require a large portion of grants, as loan reimbursement and provision of loan guarantees are more complicated.

5.3 Feedstock supply, process and technology

5.3.1 Problems faced

Projects implemented in DCs and LDCs are sometimes pilot projects, i.e. experimental, rather than fully proven demonstration projects. Some technologies are unknown by the recipient countries, meaning that there are no local skills to operate them. The lack of technical capacity in DCs and LDCs is often the main reason for project failure.

The appropriateness and full reliability of some technologies have not been properly checked in the preparation phase, leading to the implementation of unproven technologies. One of the reasons for such failures is that some projects are not necessarily country demand-driven and do not address specific local needs. Some promising, simple technologies like biomass gasification seem appropriate, but their operation often causes problems. Some projects require some re-engineering and adjustments, which cause additional cost and alter the confidence in the technology. In some cases, the equipment is supposed to accommodate different kinds of biofuels but, in the end, shows much less flexibility than expected.

The actual availability of bio-residues is often overlooked. Their supply can fluctuate throughout the year because of crop seasonality. Moreover, some bio-residues have competing uses that have not been properly assessed.

5.3.2 Lessons learned

The first and most important factor to be checked is the feedstock production and supply to make sure that the bioenergy plant can be operated throughout its lifetime and, in the case of biomass energy plants, be able to continuously cover the demand for energy (heat and/or power). Those projects can easily find private sector investors, including banks. The first study to be carried out before deciding to invest in a bioenergy project is a comprehensive feedstock availability study. Competing uses for the raw material of a bioenergy plant and the price paid for these alternative uses must be carefully studied. If a continuous supply of raw material cannot be secured at a competitive price for the lifetime of the project, it would be a waste of time to carry out any project feasibility study.

The continuous supply of feedstock requires a close collaboration and a relation of trust with local farmers or traders. They should be provided with a fair and attractive price. Some raw materials also require some logistics, such as collection, transport, conditioning, storage and conveying.

The most attractive and secured projects are those implemented within an industrial facility producing its own process residues as they minimize the risk of raw material shortage.

The size of the project must be carefully studied. As a new plant is often expected to become a demonstration project, its size should be in line with the energy demand and with the feedstock availability. Oversized plants will not be good showcases as they will not perform in an optimal way. It is advisable to start with a plant of small capacity, modular if possible, that can easily be scaled-up when the energy demand increases.

The level of sophistication of the technology must also be carefully looked at. As the technology is often meant to be replicated in the recipient country, it should be easily operated and maintained. Part of the plant manufacturing, if not all, should be transferred, so that spare parts would be easily available and repairs readily made, preventing long plant stoppages. This delocalization of the equipment production to DCs should not mean a reduction in quality; it should always be based on international technical standards.

FIRI distillery in Ho Chi Minh City. (Source: KMUTT)

5.4 Capacity building and communication

5.4.1 Problems faced

Many projects implemented in DCs or LDCs have failed because of insufficient capacity-building programs. There is a lack of in-depth understanding of bioenergy technologies by all stakeholders along the value chain. Investors do not understand the importance of a secured feedstock supply. Operators are not familiar with the implemented equipment and have not received any appropriate training for O&M of the plant. Policymakers and financial institutions have not been exposed to similar types of projects. New technologies are not part of academic or research and development programs.

5.4.2 Lessons learned

The transfer of technologies or just the implementation of a new type of equipment requires comprehensive training programs. They should include all key stakeholders, i.e. biomass producers (farmers), bioenergy investors, banks and financial institutions, policymakers, as well as researchers and academics. Policymakers and financial institutions need to have a good understanding of the technology, of the best international standards, and of current international best practices in terms of policy, regulatory framework, and bioenergy project financial support.

Broad communication should be in place to raise awareness. Before the rather broad UNIDO/GEF project in Albania, there was little public awareness on the production and possible uses of pellets as fuels. The organization of site visits and workshops to reference projects helped raise awareness.

The training of operators must take into consideration the existing local knowledge and skills and be customized accordingly. It is an ideal case when the operators are already familiar with the technology, and if that technology is already perceived as appropriate and is well accepted. They will then better benefit from the capacity-building activities on a new, more performant version of the technology.

Capacity building shall also take place at research and development level through cooperation between research institutions from the exporting and the recipient countries. This should also be combined with academic activities and knowledge exchange between universities.

6

CONCLUSIONS AND RECOMMENDATIONS

Bioenergy has a very promising future as only a very small fraction of its potential has been exploited so far. That potential can easily be achieved without tapping into the crops and experiencing competition with food production. Indeed, there are still huge quantities of unused bio-residues around the world that can be converted into bioenergy.

Bioenergy is a strong catalyst towards the development of local and regional circular bioeconomy. It helps strengthen the agriculture sector by opening new avenues for the use of their products and/or by-products and develop new industrial activities such as the production of biofuels for the transportation sector. Bioenergy leads to a reduction of the dependence of DCs and LDCs on imported fuels and towards the achievement of most of the SDGs.

Here are some key conclusions and recommendations from the case studies presented in this document:

Bioenergy has a very promising future as only a very small fraction of its potential has been exploited so far. That potential can easily be achieved without tapping into the crops and experiencing competition with food production. Indeed, there are still huge quantities of unused bio-residues around the world that can be converted into bioenergy.

Bioenergy is a strong catalyst towards the development of local and regional circular bioeconomy. It helps strengthen the agriculture sector by opening new avenues for the use of their products and/or by-products and develop new industrial activities such as the production of biofuels for the transportation sector. Bioenergy leads to a reduction of the dependence of DCs and LDCs on imported fuels and towards the achievement of most of the SDGs.

Here are some key conclusions and recommendations from the case studies presented in this document:

- Proven and reliable **technologies** do exist from a small to large scale and are able to provide solutions at household, community, and industrial levels. When it comes to the implementation of bioenergy projects, the type of technology should be carefully selected so that it can convert the locally available resources and cover the local requirements. Therefore, the **size** of the equipment is a key parameter for a successful bioenergy project. It must be selected according to the **feedstock availability** and to the market for the final product (solid fuels, biogas, bioethanol, electricity) over the project lifetime. The technology often has strict requirements regarding the **quality** of the feedstock. To be operated in an optimal way, bioenergy plants require a feedstock of constant quality, in sufficient quantity and at a reasonable and reliable cost.

- The management and organization of the whole **supply chain** is key. It goes from the production and collection of sufficient raw material, its purchase at a fair price, to its conversion into a final product that is attractive enough to be sold in a competitive market. This fair balance between the buying price of feedstock and the selling price of end product can have a significant impact on the economic, social and environmental well-being of local populations.

- Another key factor is the ways **plants** are **operated and maintained.** When implementing a new plant in a DC or LDC, a comprehensive in-depth training of the operators must be organized to make sure that it will be properly operated and maintained.

- The transfer of a new technology to DCs and LDCs also means **building capacity** at other levels than just plant O&M. It shall include other stakeholders such as farmers, biomass growers, policymakers, potential investors, and financiers. The involvement of academic institutions in technology transfer is essential for the absorption of the technology by the country.

  Capacity building shall be combined with **public awareness** campaigns and, whenever possible, include workshops and site visits to existing reference projects which have been successfully operated for a few years.

- A critical barrier to the deployment of bioenergy technologies is their rather **high investment** cost when compared to conventional technologies. It makes it difficult to finance bioenergy projects as their ROI is often low compared to the perceived risks. Without proper support from the local authorities, investors and banks would tend to give up and get back to technologies they feel more comfortable with and ready to invest in.

- New bioenergy technologies often face a lack of **policy support**, as local governments are not aware of their economic, social and environmental benefits. They even face some unfair competition in relation to technologies using subsidized fossil fuels. It is recommended to carefully check whether local policies are in place before introducing a new technology in a country. Otherwise, it is highly recommended to work hand in hand with the local authorities and help them elaborate conducive policies based on the successful policy experience of other countries. That includes fiscal and financial incentives, simplified registration procedures, attractive FITs and prioritized access to the grid for projects generating excess electricity.

- The **preparation phase** of a bioenergy project is crucial. A preliminary study must include a thorough analysis of the sustainability of the whole value chain, i.e. from feedstock production to the demand of the final product (biomass fuel, biogas, bioethanol, heat, electricity, etc.). This analysis must encompass many key factors such as the feedstock production and supply, the reliability and appropriateness of the bioenergy conversion technology, the economic viability and bankability of the project, the policy, the legal and regulatory frameworks of the country or region of implementation, the awareness, the familiarity of all stakeholders with this type of technology and equipment, the capacity and skills of the local operators, and the environmental friendliness and sustainability of the project.

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