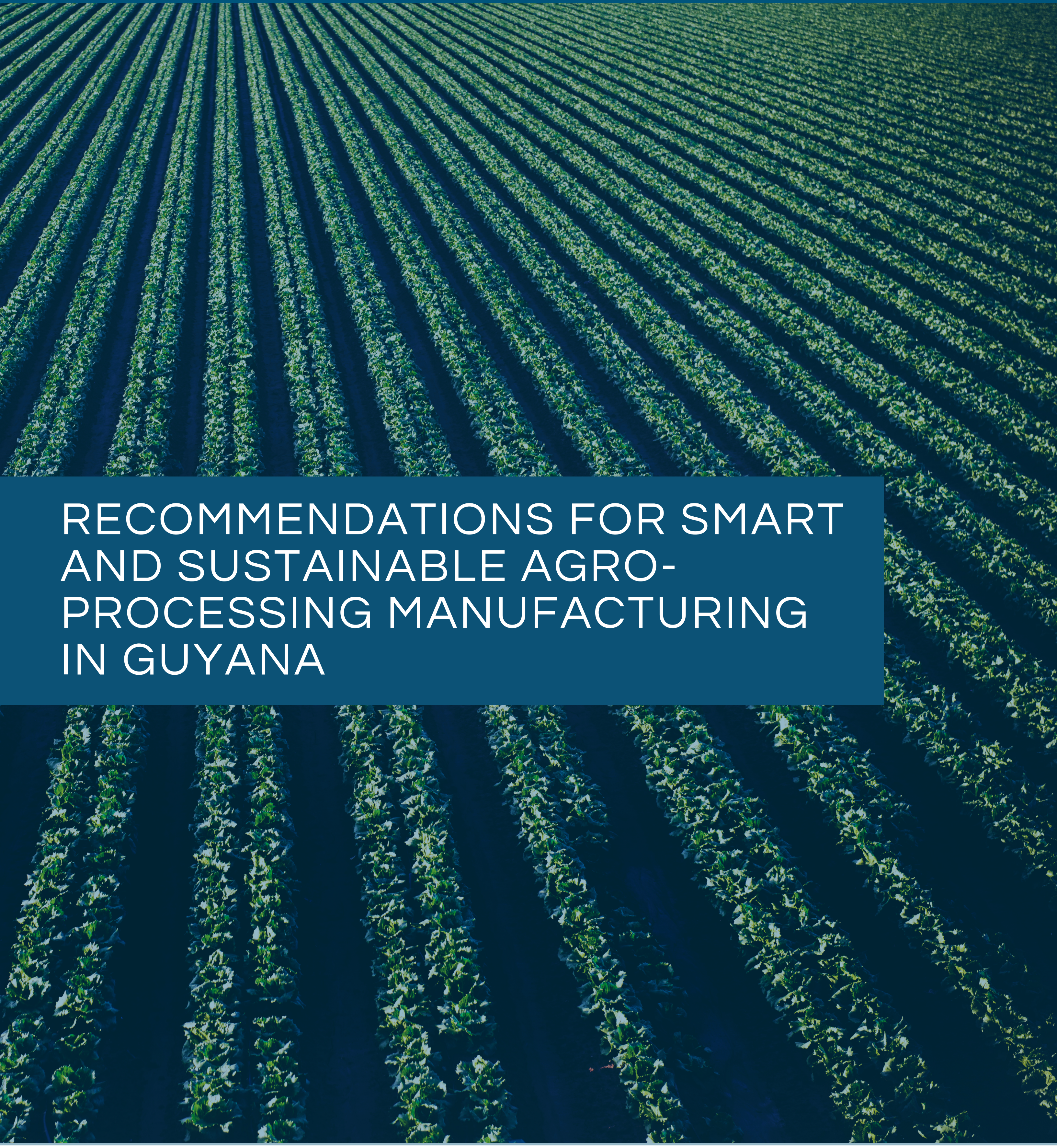


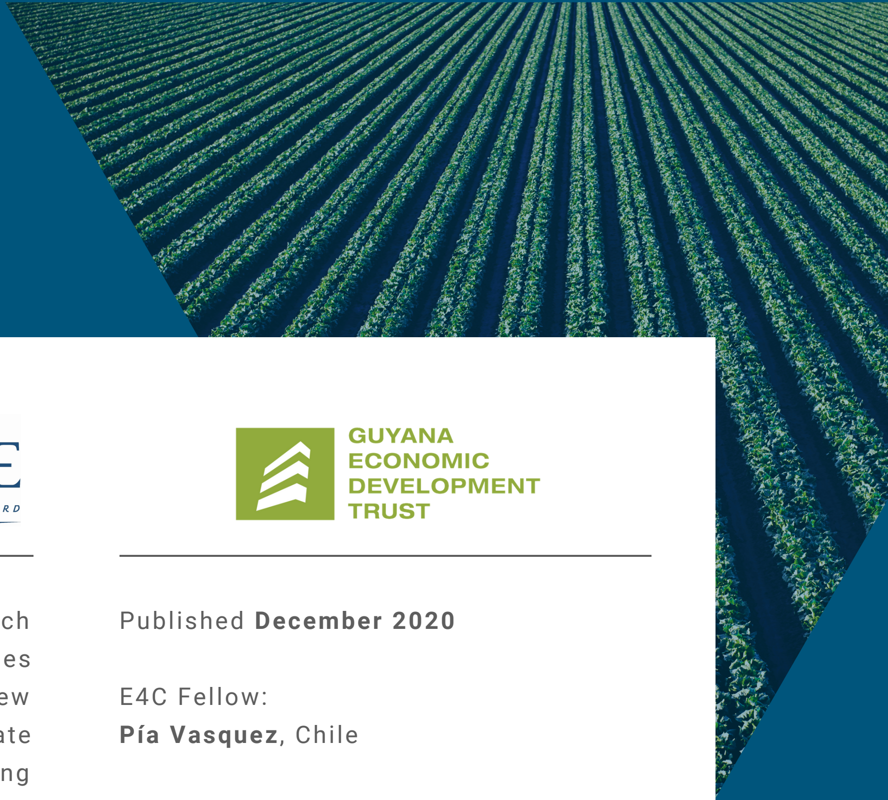
RECOMMENDATIONS FOR SMART AND SUSTAINABLE AGRO-PROCESSING MANUFACTURING IN GUYANA

ASME
SETTING THE STANDARD

engineering FOR CHANGE

A 2020 Engineering for Change

RESEARCH COLLABORATION



Engineering for Change (E4C) Research Collaborations cut across geographies and sectors to deliver an ecosystem view of technology for good. We investigate the relationship between engineering civil society impact, funding, and collective action. Through methods, such as participatory research and landscape mapping, we create actionable research for funders and international development organizations. Our targeted research is conducted by E4C staff and Research Fellows on behalf our partners and sponsors, and is delivered in the form of digestible reports that can be absorbed and implemented to address urgent global development challenges.

For more information, please visit:
www.engineeringforchange.org/research

To become a research partner, email:
partners@engineeringforchange.org

Published **December 2020**

E4C Fellow:
Pía Vasquez, Chile

Partner collaborator:
Oslene Carrington, Guyana Economic Development Trust
https://theguyanatrust.org/

E4C Editorial team:
Carolina Rojas, Expert Fellow
Grace Burleson, Research Manager
Mariela Machado, Program Manager

For more information about the E4C Fellowship, please visit:
www.engineeringforchange.org/e4c-fellowship/

Table of Contents

Introduction

The crucial role of agriculture, and agricultural-related activities in the economic development of emerging economies has been widely acknowledged.[1] According to the FAO, by 2009, the share of agriculture in GDP in emerging economies was higher than 30% in Africa, higher than 15% in Latin America, and even higher than 20% specifically within Guyana.[2] Even in developed countries, agriculture can be an important driver of growth, both in terms of income generation and employment opportunity.[3] There is also evidence that agricultural productivity is directly linked to industrialisation levels and the country's economic growth.[4]

The potential of the agricultural sector in boosting development not only resides on the economic aspects, but also the fact that it contributes to poverty reduction, food and nutrition security, and the sustainable use of natural resources. Historically, low and middle income countries often produce and export low value-added primary agricultural commodities.[5] However, during the last decades, governments and organizations in emerging economies have been promoting the industrialisation of the agricultural sector.[6] Agro-industries, which comprise all the post-harvest activities carried out for the transformation, preservation and preparation of agricultural production for intermediate or final consumption,[7] play a major role in economic growth and poverty reduction by the generation and enhancement of value chains starting from the agricultural primary produce.[8]

The aim of this Research Collaboration is to provide a general perspective of the current trends regarding sustainable development of agroindustries in emerging economies, with recommendations for applying these frameworks to the context of Guyana. This work, developed in partnership with the Guyana Economic Development Trust, explores in a broad manner the ecosystem of strategies and technologies available for supporting the growth of micro and small agro-processing entrepreneurs. The research is supported by detailed desk research on the agricultural sector, interviews with experts of varied backgrounds and interviews with micro and small entrepreneurs of the Guyanese agro-processing sector.

The structure of the report is as follows: First, the general structure of agricultural value chains is presented, highlighting the relevance of considering all the stakeholders involved from farm to fork in order to achieve high quality products, and an efficient allocation of primary resources and benefits for all the parts. Next, the role of energy supply and the need for adopting sustainable technologies for the agricultural sector throughout the entire value chain is discussed. Further, the relevance of food packaging and the main challenges faced by micro and small entrepreneurs regarding packaging of their products is discussed. Additionally, the current trends on packaging types together with the need for transitioning to more sustainable packaging technologies are also presented. Finally, inclusive strategies of packaging industries in order to address the micro and small entrepreneurs' needs, making use of R&D&I and technology transfer are shown, exemplified with case studies. Importantly, the Guyanese agro-processing environment is discussed and the application of strategies and technologies shown in previous sections is illustrated with a case study. A set of recommendations for the sustainable development of agro-processing industries in Guyana is given, together with a SWOT analysis considering the variables affecting the current Guyanese landscape.

---

1 Dethier, J. J., & Effenberger, A. (2011). *Agriculture and development: A brief review of the literature*. The World Bank.
2 FAO, Macroeconomy
3 Loizou, E., Karelakis, C., Galanopoulos, K., & Mattas, K. (2019). The role of agriculture as a development tool for a regional economy. *Agricultural Systems*, *173*, 482-490.
4 Gollin, D., Parente, S., & Rogerson, R. (2002). The role of agriculture in development. *American economic review*, *92*(2), 160-164.
5 FAO, External economic environment: Opportunities and challenges.
6 African Development Bank Group, Agro-industry Development.
7 Wilkinson, J., & Rocha, R. (2008, April). The agro-processing sector: Empirical overview, recent trends and development impacts. In *Global Agro-Industries Forum*.
8 United Nations Industrial Development Organization, Agro-value chain analysis and development, 2009

Sustainable development of small and medium agro-processing industries in emerging economies

Agricultural value chains

A generic agricultural value chain, as shown in Figure 1 starts with the raw materials, inputs and assets needed to grow the desired crops: Seeds, farming infrastructure, tractors, irrigation systems and fertilizers among others. The production stage requires the use of good crop management practices, such as appropriate planting and maintaining soil humidity at optimal levels, together with a correct use of soils and irrigation systems.[9] Effective post production activities are highly dependent on the availability of storage infrastructure, post-harvest equipment such as mills, threshers, graters, washing and disinfection equipment, together with safe and efficient transport services and connectivity between rural and urban environments. Agro-processing comprises all those processes of transformation and preparation, through mechanical or chemical processing, of value-added products from primary agricultural produce. Enhancing the agro-processing industry, in particular for small and medium entrepreneurs in emerging economies, demands switching from dispersed, non mechanized (or poorly mechanized) production frameworks to cooperative, technological, aggregated and diversified production schemes, fostering the development of economies of scale and scope, and improving the efficiency of processes and quality of the final produce. Packaging is also a very important stage of the value chain, providing the suitable conditions for the final products to be stored, transported, distributed and delivered to final customers.

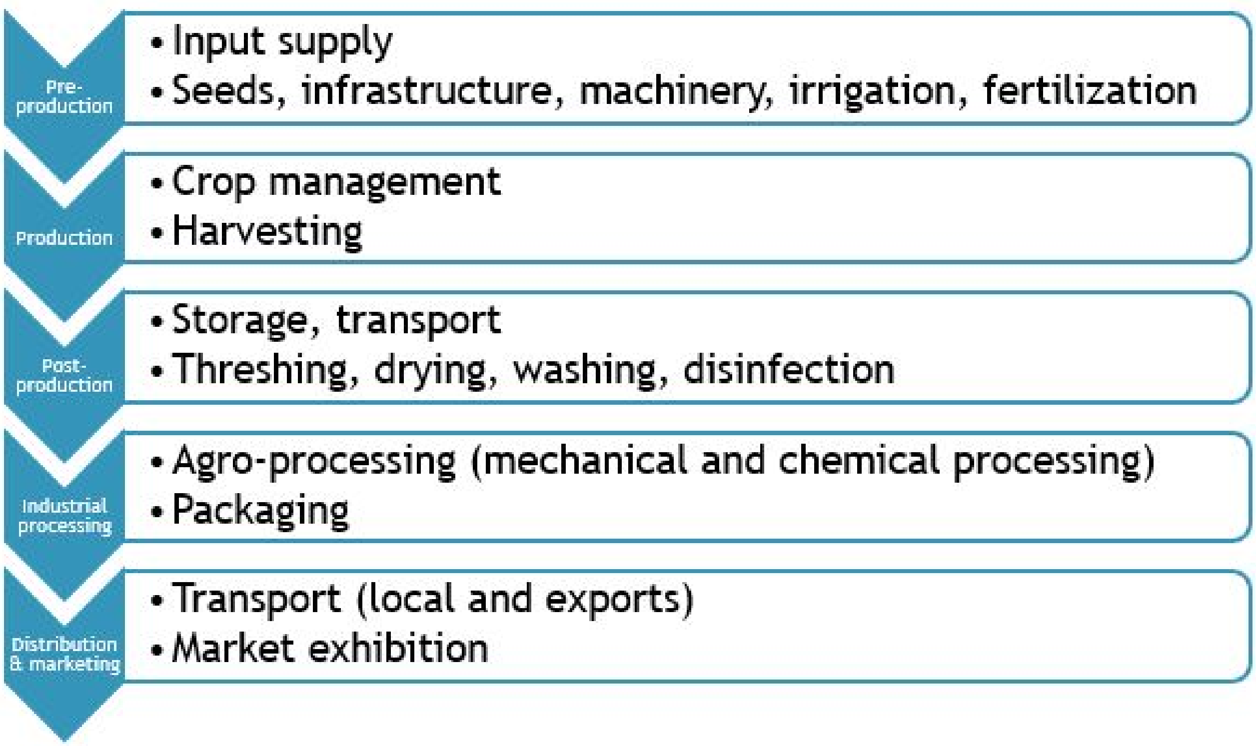


Figure 1: A generic agricultural value chain

Agricultural value chains are in need of more than just assets, infrastructure and technical capabilities to produce food. Supportive governments, enabling policy and economical environments are of crucial relevance for a sustainable development of the sector. It is also notable the addition of waste management and circular economy frameworks to the agricultural value chain, in order to address losses with the possibility of generating

[9] Sakadevan, K., & Nguyen, M. L. (2010). Extent, impact, and response to soil and water salinity in arid and semiarid regions. In *Advances in Agronomy* (Vol. 109, pp. 55-74). Academic Press.

byproducts such as fertilizers for the pre-production and production stages, and bio-energy for different processes throughout the chain. The conjunction of all the factors mentioned above, summarized in Figure 2, are critical determinants for an inclusive and sustainable development of agricultural value chains in emerging economies.

Figure 2: Factors influencing sustainable development of agricultural value chains in developing countries.

Challenges for sustainable development of agricultural value chains

Sustainable development of the industry sector in emerging economies is targeted within the Goal 9 of the Sustainable Development Goals (SDGs), adopted in 2015 by all United Nations member States.[10] Goal 9: "*Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation,*" concerns all activities which contribute with infrastructure development, raising of industry's share of employment, increase the access of small-scale industrial and enterprises to financial services, together with their integration to value chains. Additionally, the goal aims to enhance scientific research and the upgrade of technological capabilities across the globe.[11]

Emerging economies face many challenges pursuing sustainable industrialization of the agricultural sector.[12] These challenges can be categorized in three main types: Regulations and policy frameworks, Industry and business, and Agriculture/value chain, as shown in Figure 3. A critical task is to develop innovative and inclusive frameworks to overcome these challenges through collaborative methodologies involving government organizations, the private sector, investors, brokers and all scale ranges of agro-producers.

[10] United Nations, Sustainable Development Goals.
[11] United Nations, Decisions by topic: Industry.
[12] Innovations for infrastructure development and promote sustainable industrialization (2017), Global Expert Meeting on Agriculture and Agro-industries Development Towards Sustainable and Resilient Food Systems, New York.

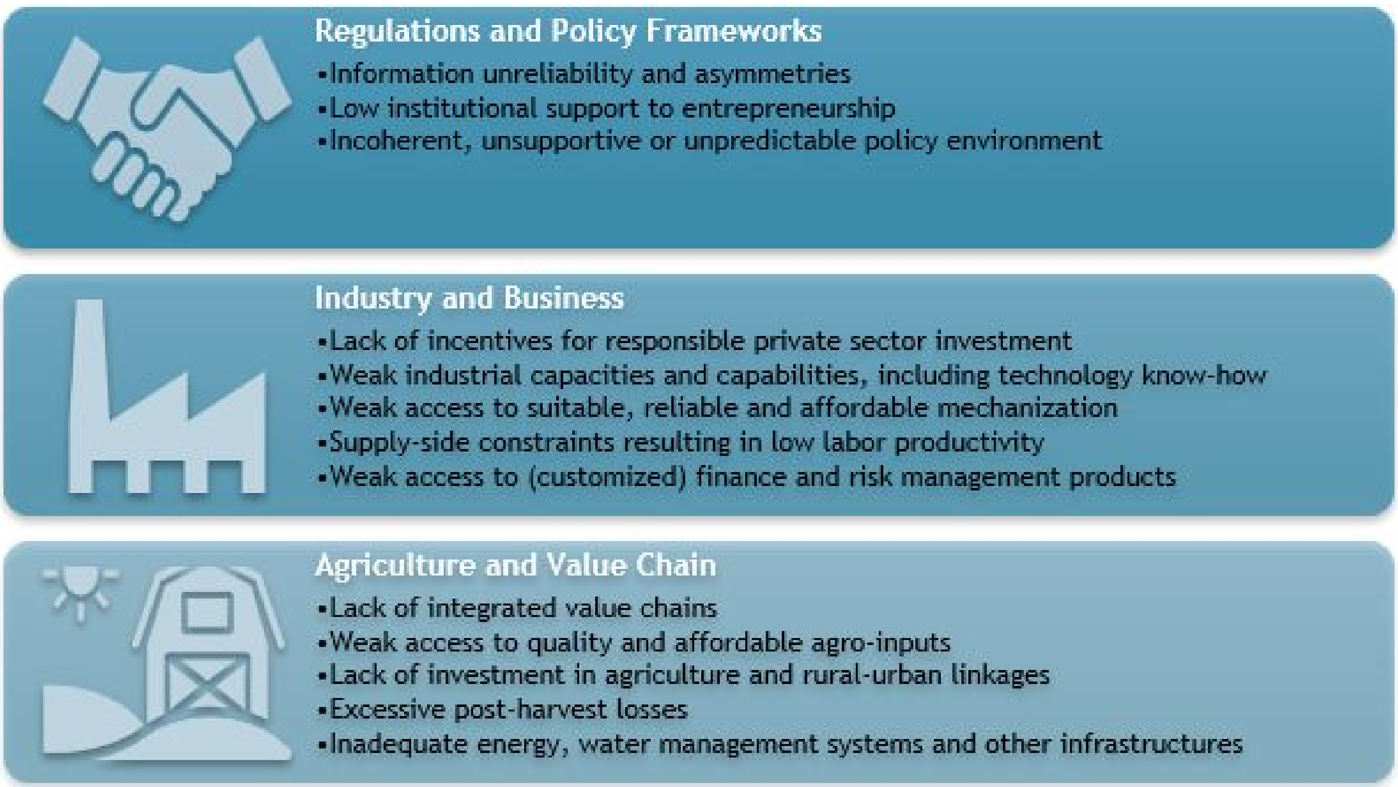


Figure 3: Challenges for achieving a sustainable development of agricultural value chains in emerging economies

Innovative approaches and best practices for development

Among the innovative approaches found in different resources and institutions, there are a variety of high-level programs implemented across Africa.[13,14] These initiatives are supported by UN programmes such as the Food and Agriculture Organization (FAO), the Industry Development Organization (UNIDO), the United Nations Development Programme (UNDP) and Value Chain Development Group (UN VCD). Additionally, Entrepreneurship Incubator Programs, driven by organizations such as the World Bank Group through infoDev, and the Netherlands-funded 2SCALE.[15] In Latin America, agricultural development is supported by the the International Fund for Agricultural Development (IFAD)[16] and the Economic Commission for Latin America and the Caribbean (ECLAC)[17] among other public and private organizations.

A holistic approach, considering the implementation of technologies, together with innovative and inclusive methodologies has demonstrated to successfully overcome the challenges and to promote sustainability and profitability to all parts involved in agri-businesses and agro-industries.[18] The development of inclusive value chains, considering the relevance and benefits of all the stakeholders from the farm to final consumption, has shown to promote better opportunities for smallholder farmers, small and medium agro-processing entrepreneurs, job creation, development of better quality and homogeneous products to the final consumer and fostering exports. Partnerships based on trust, transparency and information sharing, aggregation of producers

---

[13] FAO, African agribusiness and agro-industries development initiative (3ADI), 2010
[14] http://www.fao.org/3/i1587e/i1587e00.pdf
[15] 2scale.org
[16] https://www.ifad.org/en/topics
[17] https://www.cepal.org/en
[18] UNDP African Facility for Inclusive Markets, The roles and opportunities for the private sector in Arica's agro-food industry, 2012

for a better management of high volumes of produce, training, inclusion of women and youth, identification of markets and use of technology are highlighted among the key success factors, as shown in Figure 4. A brief description of each approach will be given below.

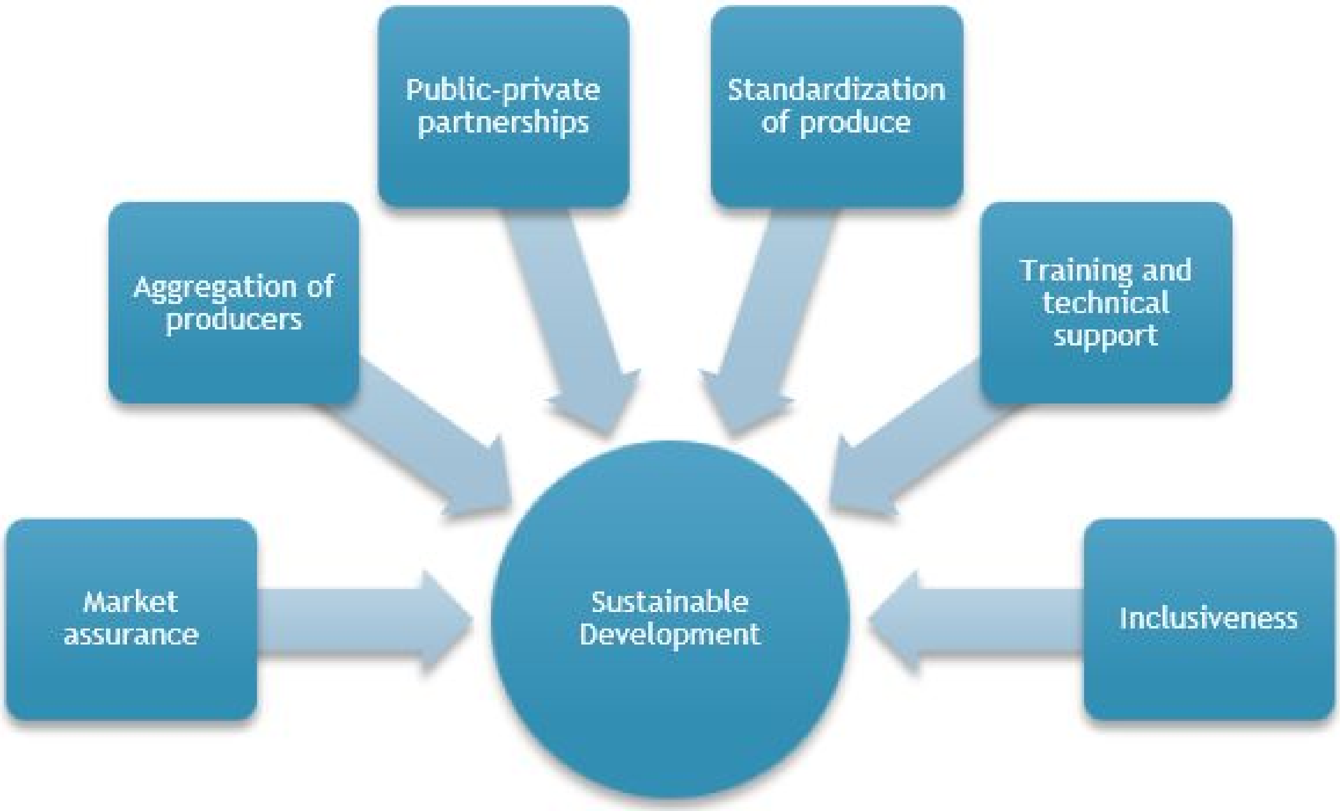


Figure 4: Best practices for achieving a sustainable development of agricultural value chains in emerging economies

Assurance of markets

Among the objectives of the distinct actors and stakeholders involved in agroindustry value chains, it is of their major interest to have ensured the access and participation in the target markets. This provides an efficient and reliable allocation of their production with the right amount of economic benefit, at the same time that enhances the integration of the value chain, generates jobs and new business opportunities. Market access and participation can be facilitated both by establishing the correct linkages and partnerships along the value chain, and designing a business that fits the market demand. According to the Principal Consultant of Farm2Market Agribusiness Consulting, Patrick Hanemman, it is imperative for agribusiness entrepreneurs, small startups and agro-processors worldwide to start designing their business with an early identification and complete characterization of their target market.[19] This implies a thorough understanding of the customer's needs and preferences, which can be successfully achieved by detailed and thorough market research, even before the launching of the business, budget delimitations and infrastructure/assets assessment.

Aggregation of producers

According to the FAO, about two-thirds of the developing world's rural population live in about 475 million small farm households of less than 2 hectares, most of them performing subsistence activities, but still remaining food insecure and poor.[20] Smallholder farmers can benefit from supplying agricultural produce to the value chain either through local government or international programmes, or by association with agro-processors. While the

[19] Interview with Patrick Hanemman, Farm2Market Agribusiness Consultant
[20] http://www.fao.org/3/a-i5251e.pdf

former is mainly mediated by the intervening organizations, the latter composes a commercial agreement between the parts which can support the participation of the smallholders in the value chain, increasing their opportunities to grow. However, it is highly inefficient for the agro-processing industry to deal with a big amount of smallholder farmers, each with different commercial interests and heterogeneous produce in terms of quality and quantity.

The aggregation of small producers in agricultural cooperatives can address this issue, benefiting both smallholders and industry. On one hand, aggregation provides access of individual farmers to shared infrastructure and assets, shared services such as transport and storage that otherwise could not be affordable for them, benefits from economies of scale and bargaining power and access to technical support and training. This also contributes to the quality and homogeneity of the final product. On the other hand, the industry benefits with a reliable input of primary products, both in volume and quality. Cooperatives and producer organizations of smallholder farmers and primary producers are the most common, but there exist other schemes such as off-taker driven models, or intermediary-driven models.[21]

Public-Private Partnerships (PPPs)

PPPs are highly recommended in several successful case studies on agri-business and agro-industries development in emerging economies.[22] Rankin et al. (2016) suggest that there are four main reasons that make PPPs an attractive framework to enhance sustainable development of agribusiness in emerging economies: Their potential to leverage financing by provision of additional resources by private partners; risks sharing and incentives from enabling regulatory environments; Innovation and market access; and food security and smallholder inclusion.[23]

Standardization, Inclusiveness, Training and Technical Support

Following the frameworks presented above, standardization of produce is a requirement for achieving higher quality in the final products, integration to international markets, boosting the profitability of the sector and an overall sustainable development of the sector. Nevertheless, it is also a consequence of the appropriate adoption of inclusive frameworks such as aggregation of smallholder farmers, increased access to agricultural assets, training and technical support, partnerships between public and private stakeholders along the value chain.

[21] Grow Africa Smallholder Working Group (2015), How do off-takers and smallholder farmers use aggregation models to grow their businesses?
[22] UNDP (2012), The roles and opportunities for the private sector in Africa's agro-food industry.
[23] M. Rankin, et al (2016), Public-Private partnerships for agribusiness development: A review of international experiences, FAO, Rome, Italy.

Agribusiness incubators

Agribusiness incubation schemes can address many challenges encountered by startups and small entrepreneurs. According to infoDev, business incubation can be defined as *"a public and/or private, entrepreneurial, economic and social development process designed to nurture businesses from idea generation to start-up companies, and, through a comprehensive business support program, help them establish and accelerate their growth and success."* [24] The business incubator is the physical facility where these processes take place.

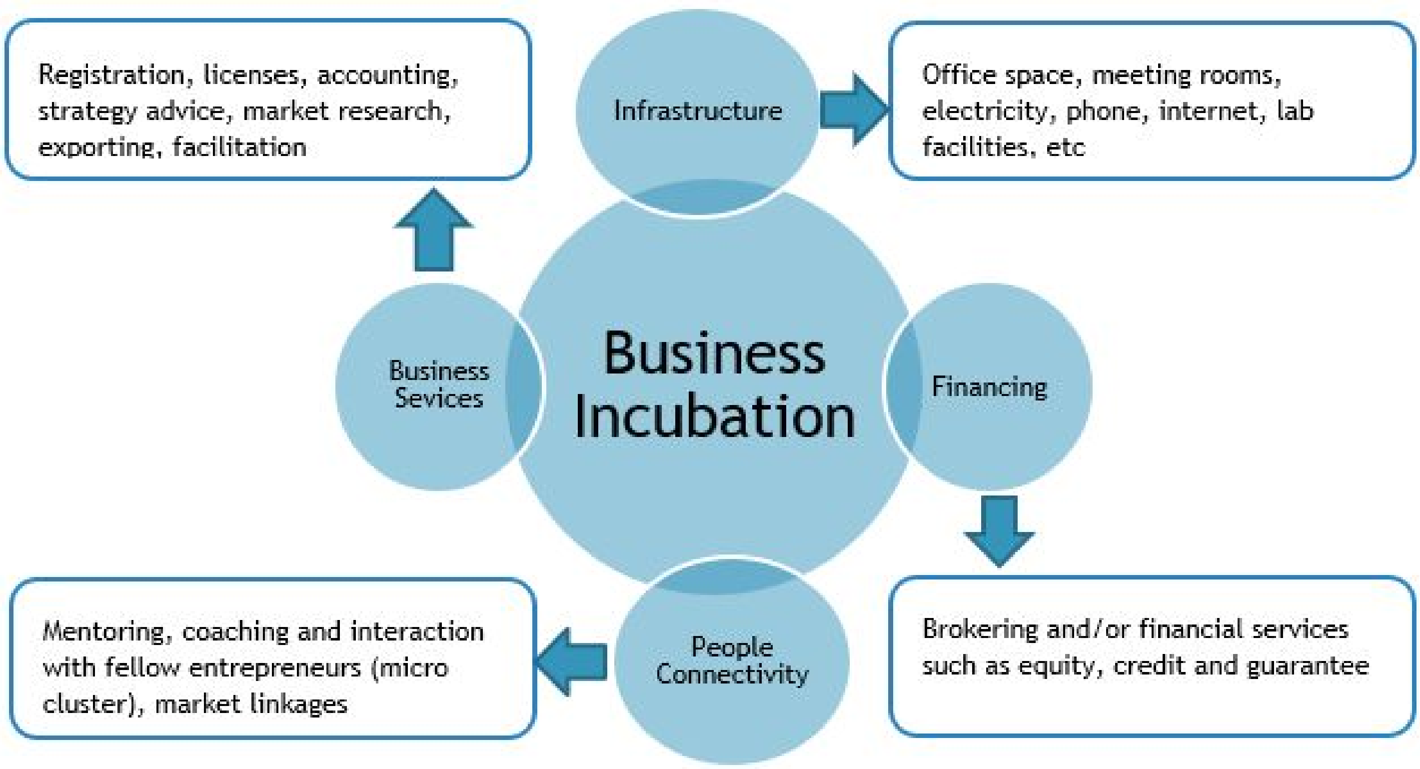


Figure 5: The four components of business incubation (schematics based on infoDev).

While the processes of agribusiness incubation generally comprise the same features as any other business incubation service, other aspects inherent to the agricultural sector make the agribusiness incubation process more complex.[25] In the first place, the variability associated with commodity prices, government policies, biological hazards, weather and climate change pose additional risks that must be compensated. In emerging economies, most small-scale farming is close to subsistence farming, and farmers with profit potential face a lot of challenges, such as financing options, food insecurity, healthcare and access to technical training and quality inputs.[26] Secondly, a very common barrier for smallholders is the lack of linkages between the primary productors and final consumers, which can be mediated by the Agribusiness Incubator. Another important role of the Agribusiness Incubators is to support the correct assessment of the product, forecasting its market share before performing intensive investment in infrastructure, technology and business advisory is critical.

Although business incubators are not decision-makers in policy issues, and are not necessarily involved in government environments, their practices may impact future regulations and policies. In emerging economies, Agribusiness incubators serve a social purpose, which is to increase the wealth of their community, helping local startups to become more competitive in the market. With this in mind, a well-established business incubator,

[24] infoDev, Business incubation definitions and principles
[25] infoDev, Agribusiness incubation trainee manual
[26] Fan, S., Brzeska, J., Keyzer, M., & Halsema, A. (2013). *From subsistence to profit: Transforming smallholder farms* (Vol. 26). Intl Food Policy Res Inst.

with networks, credibility and links can even advise policy makers with first-hand information about the issues that early stage entrepreneurs usually face.[27] Finally, Agribusiness incubators act as a link between the economies and business models found both in rural and urban environments, separated not only by distance but also by their basic organization, practices and cultural behavior.

Sustainable management of agricultural resources: The Water-Energy-Food Nexus

Agricultural activities and the generation of value added products make use of natural resources such as water and land, and it also requires energy inputs along the distinct stages of the value chain. Therefore, it is practically impossible to talk about sustainable development of the agriculture and agro-processing sectors without mentioning the Water-Energy-Food Nexus (WEF). The concept of WEF Nexus arises from the complex relationships observed when managing systems that make use of multiple resources in an interconnected way.[28] For instance, agricultural value chains make use of water and energy for irrigation, feedstock and crops management and agro-industrial activities for food production. In a review conducted in 2019,[29] the concept and implications of the WEF Nexus are discussed, acknowledging its relevance when optimizing the management of natural resources for ensuring water and food security for all human beings. However, it is also recognized the complexity of applying such a framework when each sector by itself faces already complex challenges, and the fact that by focusing on the global macro-scale resource security, local aspects such as livelihoods and the environment could not be properly addressed.

Water is a primary resource both for energy and food production, but it also is a limited and variable resource. In the present decade, scarcity already affects every continent.[30] Agriculture is responsible for 70% of water withdrawals, while consumes 30% of the total energy generated and produces 10% of the global greenhouse gas (GHG) emissions. Likewise, energy is needed both for food production and water management and treatment, while agriculture can be a source for generating energy from biomass. According to James Lomax, the Sustainable Food Systems and Agriculture Programme Officer in UN Environment's Division of Technology, in the Webinar: Ways to Walk the Water-Energy-Food Nexus: The Food Perspective (05/21/2020), it is necessary to rethinking agriculture in order to switch from the current schemes where main issues include deficient nutrition, bad soil management and exploitation and inexistent incentives for farmers and primary producers, to new paradigms promoting positive impacts in biodiversity, climate, pollution and human health, regenerative agriculture, reduced food losses and waste, plant-based diets and supporting good practices in agriculture.

---

[27] N. Ozor (2013), The role of agribusiness innovation incubation for Agrica's development, African Journal of Science, Technology, Innovation and Development.
[28] FAO (2014), The Water-Energy-Food Nexus: A new approach in support of food security and sustainable agriculture, Rome, Italy.
[29] G. Simpson and G. Jewitt (2019),The development of the water-energy-food nexus as a framework for achieving resource security: A review
[30] https://www.unwater.org/water-facts/scarcity/

Renewable energy in the agro-processing industry

Agricultural and agro-industrial processes require energy inputs throughout their entire value chain, including pumping and irrigation systems, preparation of land, transport, special requirements for storage such as moisture control and cooling facilities; agro-processing machinery, industrial machinery for preparation of processed food products, packaging equipment, etc. Rural electrification and access to energy for farmers is important, as the quality of final products depend directly on the quality of primary produce and producers' livelihoods.[31]

Powering the agricultural sector is relevant not only in terms of the amount of energy needed to ensure the required volumes and standards in food production, but also because of the undeniable relationship between the use of natural resources for different purposes with a common goal. As mentioned in the previous section, the WEF Nexus approach has critical relevance identifying the challenges associated with the use of freshwater for agriculture and hydropower generation, and the effects of GHG emissions from agriculture and the energy sector on climate change adaptation.[32] This, in turn, directly impacts on the water cycle and hydrological uncertainty, occurrence and extension of drought periods, climatic events such as hurricanes, typhoons and monsoon seasons, conditioning the agricultural outputs in the affected regions. Data presented in the COP25 Chile 2020 showed that 7 out of the 10 most affected countries by climate change are low- and middle-income countries,[33] whose GDP contribution from agriculture ranges from 7.45% (Sri Lanka) to 34.15% (Kenya).

Transitioning from fossil fuel-based energy resources to renewable energy resources is one relevant goal of the 21st century, specified in the 2nd target of the UN's Sustainable Development Goal (SDG) 7: Affordable and Clean Energy.[34] Although the share of renewables in the power systems worldwide has grown considerably, there still remain technical and economical challenges for implementing fully renewable power systems.[35] Technical challenges such as frequency control and voltage regulation, and variability of the natural resources such as water, wind and solar energy affect the feasibility of implementing 100% renewable power energy systems.[36] However, while transitioning to renewables for large-scale, fully integrated power systems may be challenging, localized applications in rural communities reliant in agricultural activities are a feasible option by the implementation of self-standing renewable mini grids, Solar Home Systems (SHS) and agricultural and agro-processing assets directly powered by solar energy.[37] Additionally, implementation of commercial or industrial size mini-grids for a wide variety of businesses and companies is also a growing trend, given the drop in prices of photovoltaic modules and energy storage systems. These powering schemes can offer sufficiency, service security and reliability in different degrees depending on the grid configuration, total generation and storage capacity, existence of backup generators and connection to the main grid.

Traditional fossil fuel energization of agricultural processes

As many other sectors, agricultural value chains have been widely reliant on fossil fuels utilization, including product transport, fertilizer production, irrigation, to food production and packaging machinery.[38] Fossil fuel consumption is unsustainable both from the perspectives of reserves depletion and environmental concerns.

[31] Asian Development Bank, Improving agricultural productivity and rural livelihoods, 2011
[32] Mpandeli, S., Naidoo, D., Mabhaudhi, T., Nhemachena, C., Nhamo, L., Liphadzi, S., ... & Modi, A. T. (2018). Climate change adaptation through the water-energy-food nexus in southern Africa. *International journal of environmental research and public health*, *15*(10), 2306.
[33] Iberdrola, Which countries are most threatened by and vulnerable to climate change?, 2020
[34] United Nations, Sustainable Development Goal 7: Affordable and Clean Energy.
[35] Nyambuu, U., & Semmler, W. (2017). The challenges in the transition from fossil fuel to renewable energy. In *Industry 4.0* (pp. 157-181). Springer, Cham.
[36] Hung, D. Q., Shah, M. R., & Mithulananthan, N. (2016). Technical challenges, security and risk in grid integration of renewable energy. In *Smart power systems and renewable energy system integration* (pp. 99-118). Springer, Cham.
[37] Alliance for Rural Electrification, Rural electrification with renewable energy.
[38] J. Tomczak, Implications of fossil fuel dependence for the food system, 2006

Additionally, the use of fossil fuel-based agricultural and agro-processing equipment becomes obsolete while new technologies based in renewable generation are being increasingly adopted, and national grids are moving towards renewable generation at utility scale.

Renewable energy mini-grids

Although there is not a standard definition for mini-grids, for rural electrification applications the term can be referred to "small-scale electricity generation (from 10 kW to 10 MW), distributed to a limited number of customers, through a distribution system which can operate in isolation from the main grid and support relatively concentrated settlements with grid quality levels."[39] Mini-grid schemes have been widely adopted because of the system's inherent modularity and scalability. They are also a viable alternative for isolated rural communities, mines or astronomical observatories when it's cheaper to set up an isolated power system than conducting expensive grid extensions to these remote locations. In the case of rural mini-grids, this type of system offers the possibility of satisfying modern domestic needs at households level, public services such as medical care centers and schools, and also boost economical activities related to communication services and agriculture. A rural mini-grid installed by Black Star Energy, a subsidiary of the American Startup Energicity in Daban, Ghana, is shown in Figure 6. Renewable mini-grids can be based in a wide variety of technologies, such as solar photovoltaic modules, wind turbines, small hydropower or biogas systems, mixed with gensets (generally diesel) and battery storage systems for backup purposes or supplying energy demands when availability of renewable resources is low. It is common that mini-grid systems are composed by mixed technologies.[40]

Figure 6: Daban (Ghana) PV mini-grid. Facilitated by Black Star Energy, a subsidiary of Energicity in Ghana, allowed the access to refrigeration systems for cold water and vaccine storage, and household electrification for rural people.[41] Image from energicitycorp.com.

[39] Alliance for Rural Electrification, Mini-grid Policy Toolkit
[40] International Renewable Energy Agency (IRENA), Innovation outlook, renewable mini-grids, 2016
[41] The New Yorker, The race to solar-power Africa,2017

In contrast, the reasons for adoption of mini-grid energization schemes for commercial and industrial purposes can be either related to improving service security, long-term cost savings and alignment with environmental targets of reducing GHG emissions.[42] Hybrid systems composed by solar photovoltaic generation, batteries and diesel units are the most common,[43,44] but other configurations based on wind, biogas and small-hydro are also recommended as they offer additional reliability, generation during periods of low availability in solar resources and the use of resources otherwise wasted, such as manure and agro-processing organic residues.[45] According to Sims et al (2015), the opportunities of the agri-food sector for adopting renewable energy in their farming and industrial activities are promissory, both due to the availability of suitable technologies for every link in the value chain, economic feasibility and small land extensions required to install renewable projects.[46]

Photovoltaic (PV) mini-grids are being widely adopted due to their technology maturity, decreasing costs, modularity for scaling-up as the energy requirements increase, and the possibility of installing the modules in places otherwise idle, such as roofs. However, the variable nature of the solar resource and the complete absence of solar generation during night make it necessary to complement this technology with storage systems or gensets. Lead-acid or lithium batteries are a common option for storage while diesel and small Combined Heat and Power (CHP) based on natural gas or biogas can be used as main generation sources,[47] backup or complementary generation for PV. According to Joe Phillip, Vice-President of Engineering and Co-founder of Energicity, a company that provides mini-grid services for rural off-grid communities in Africa, since prices of solar and batteries have gone down, off-grid renewable mini-grids are currently a cheaper alternative than grid extensions in developing countries, especially in countries where the main grid is unreliable or insufficient. In the case of industries, which operate mainly during the day, replacing night-time diesel generation by batteries, in order to keep small assets such as security lights or alarms can be very cost effective. However, in agro-processing industries, seasonality is a relevant consideration, in order to avoid idle equipment and facilities during certain periods of the year, together with the adjustment of production schedules to sunlight for maximizing PV generation and lower reliance on complementary systems. Stewart Craine, Managing Director of Village Infrastructure Angels (VIA), a company that provides Project Development and Consulting Services for village infrastructure projects in emerging economies, highlights the importance of achieving interconnected environments throughout the entire value chain of food systems. In developing countries, where rural zones are usually distant from urban centers and lack access to the national electricity grids, providing access to clean energy both for livelihoods and productive use assets (particularly for agricultural activities) through leasing schemes and Pay-As-You-Go (PAYG) technologies integrated with mini-grids, Solar Home Systems or community assets has shown effective results.[48]

For agro-industrial activities, namely food-processing and packaging, the design of Hybrid PV mini-grid power systems requires several considerations. First of all, the type of activities will determine the type of assets to be powered: refrigerators, air conditioning and cooling systems, moisture control systems, agro-processing equipment (dryers, mills, grinders, hullers), production lines, packaging machinery, among others. Determination of base and variable loads and schedules, solar resource availability in the place where facilities are located,

---

[42] Microgrids for commercial and industrial companies: Delivering increased power reliability, lower energy costs and lower emissions, World Business Council for Sustainable Development (2017)
[43] Energypedia, Mini Grids.
[44] Johannsen, R. M., Østergaard, P. A., & Hanlin, R. (2020). Hybrid photovoltaic and wind mini-grids in Kenya: Techno-economic assessment and barriers to diffusion. *Energy for Sustainable Development*, *54*, 111-126.
[45] Mugodo, K., Magama, P. P., & Dhavu, K. (2017). Biogas production potential from agricultural and agro-processing waste in South Africa. *Waste and Biomass Valorization*, *8*(7), 2383-2392.
[46] Sims, R., Flammini, A., Puri, M., & Bracco, S. (2015). Opportunities for agri-food chains to become energy-smart. *FAO USAID*.
[47] P. S. Varbanov and J. J. Klemes (2011), Small and micro combined heat and power (CHP) systems for the food and beverage processing industries, Advanced Design, Performance, Materials and Applications, Woodhead Publishing Series in Energy, 9.395-426.
[48] SIINC, Case Studies LATAM, Village Infrastructure Angels, 2017

price per kWh of solar capacity relative to grid prices, space availability for modules accommodation, storage and backup systems sizing and the type of installation (roof- or ground-mounted, flat or tilted, stationary or MPPT) are critical both for a technical and economic perspectives[49], which will finally determine the size (electrical and physical) of the installation.

Productive Use Leveraging Solar Energy (PULSE) in the agro-processing sector

The development and commercialization of technology for productive activities in the agricultural sector started more than 20 years ago with rural electrification efforts, solar water pumping, solar home systems, electric fences and many other assets.[50] Since then, with the advances in solar modules technologies, a wide range of equipment based in DC solar power has also been developed and improved for diverse agricultural and agro-processing activities, including feedstock breeding, irrigation and water pumping, food processing, food storage and cooling and food preparation.[51]

Figure 7: Solar refrigeration systems. On the left, a Youmma 100L DC fridge manufactured by Embraco, available in Kenya and Uganda by M-KOPA Solar. On the right, the DC solar fridge Steca PF 166L, manufactured and implemented by Phaesun in Africa.

The concept of Productive Use Leveraging Solar Energy (PULSE) encompases appliances developed for off-grid applications further than providing energy for household lightning and consumption needs, but also powering productive, income generating activities. PULSE appliances have increased their market share in emerging economies in Africa,[52] the Pacific Islands and some regions of Central America, but still with capacity limited to small applications (< 1.5 kW). However, as the target markets of PULSE technology manufacturers are mainly rural, off-grid communities in emerging economies, the profitability of the sector is limited by the cost of assets (rural clients are often unable to pay for these appliances). Leasing schemes and PAYG technologies have been implemented by companies to address this issue, such as VIA, AgSol, Youmma and LORENTZ. Other frameworks based in the acquisition of shared appliances for farmers or agro-processing cooperatives have also been implemented and recommended.

According to Lighting Global, the use cases of PULSE appliances is heavily dependent on the activity, energy intensity and scale. Irrigation systems, shown in Figure 8, are the most mature technologies showing high market readiness for scales up to 5 Ha of irrigation. Cooling systems, shown in Figure 7, and agro-processing

[49] Mo, J. P. (2016). Design of solar energy system in food manufacturing environment. *Cogent Engineering*, *3*(1), 1233613.
[50] B. van Campen, D. Guidi, G Best (2000), Solar photovoltaics for sustainable agriculture and rural development, FAO.
[51] GIZ, Photovoltaics for Productive Use Applications, 2016
[52] Lighting Global, The market opportunity for productive use leveraging solar energy (PULSE) in Sub-Saharan Africa, 2019.

machinery, also shown in Figure 7 are still in early stages of development, being usually suitable for large commercial applications or small/medium agro-processing activities.

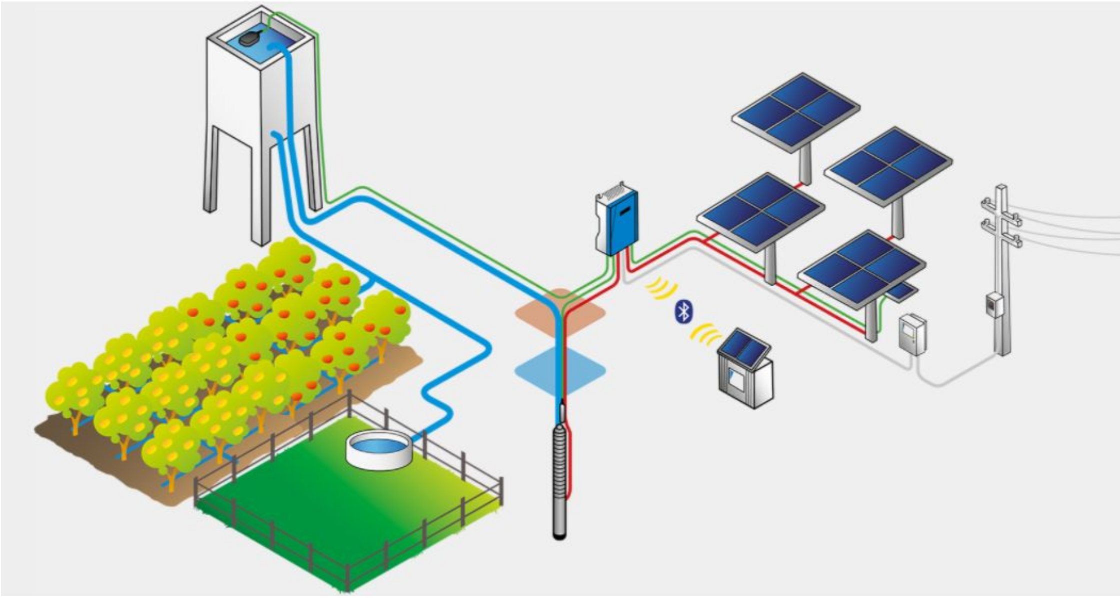


Figure 8: Solar water pumping system designed and manufactured by Lorentz. The model shown is the PS2, comprising a specialized solar pump controller, water pumps and smart sensors to optimize the efficiency of the system.

Case study: The Agrigrid Project

The Agrigrid Project, an initiative founded by Anka Madagascar and Amanhã Ventures, aims to foster rural development through a business model that combines commercial opportunities in rural electrification with food and agricultural value chain development. The Agrigrid operator (see Figure 9) performs the following commercial activities:

1. Management and sales of mini-grid energy services to the rural community.
2. Development of an agricultural strategy, and purchasing of raw food and agricultural products from the community.
3. Agro-processing and sales of value added products to external markets.
4. Profit-sharing agreement between Agrigrid operator and the community.

The Agrigrid initiative is based on the premise that, increasing the profit of the agro-processing and food commercialization sector requires reinforcing all the links of the agricultural value chain. Minimization of the negative outcomes (food losses, high seasonality, high barriers in market access and pricing power) by implementing sustainable technology and energy services can address the issues of the rural poor smallholder farmers. Intervening all the stages and processes associated with food production in the agricultural value chain in a sustainable way needs to be addressed using a community framework.

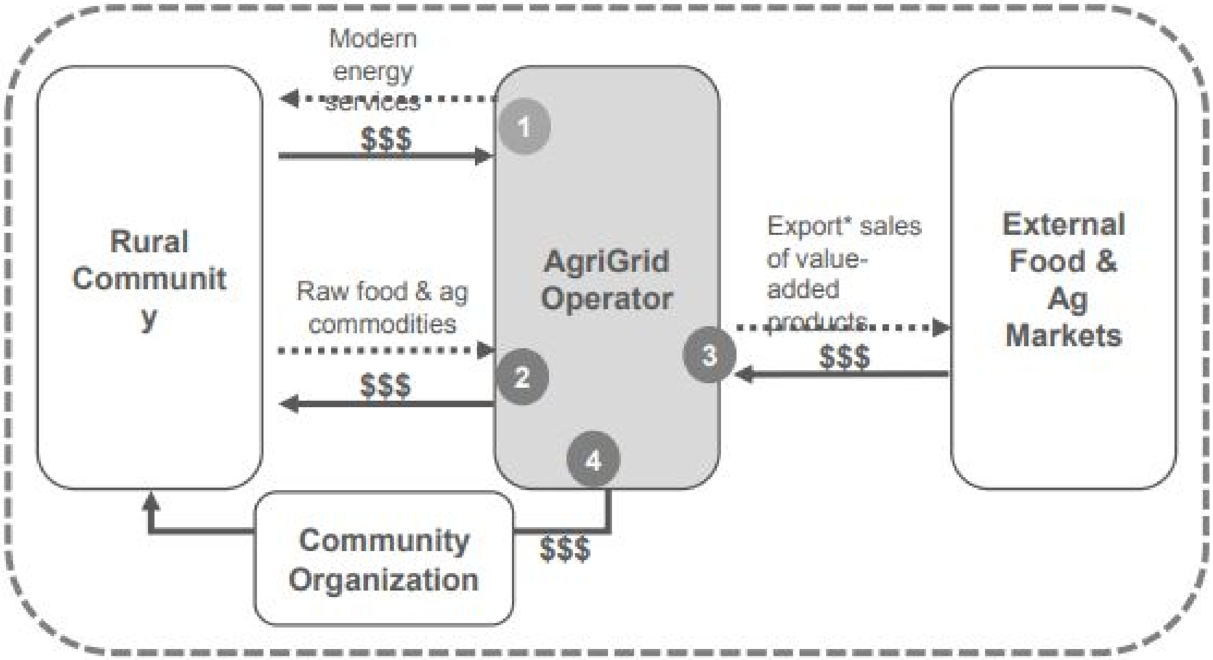


Figure 9: The Agrigrid business model.[53]

The implementation of Agrigrids in Africa left several lessons learnt. In the first place, the constraint of seasonality requires the model to be applied to different agricultural activities, in order to take advantage of productive use of energy throughout the entire year. Additionally, combinating activities which provide inputs between each other aids in fostering a circular economy. Distributing the agro-processing of certain products throughout the year can contribute to price stabilization. Being aware that a precise feasibility study is difficult and the fact that in many cases data can be ambiguous. It is also recommended to find support in an agronomic expert. Finally, considering the implementation of an Agrigrid in sites with or without previous electrification system requires detailed assessment in order to forecast the profit of the business in an adequate manner.[54]

Case Study 2: Solar Agro-processing Power Stations

In many emerging economies, rural activities related to agro-processing are conducted by hand, resulting in high time-consuming and low-efficiency work, and producing low-quality products. Additionally, in most places agro-processing activities are conducted by women and girls, spending in total 250 million hours only for household and community feeding purposes.[55] This makes it difficult for poor farmers and underserved communities to generate value added products and raise income from their primary production. Moreover, low availability of agro-processing machinery such as mills, grinders, graters or dryers in off-grid, rural communities forces people to move several kilometers from their farms to access diesel-powered agro-processing equipment. Doing this by cars or trucks adds costs of fuel which can be several times higher than the benefits of mechanized agro-processing. Besides, the processing capacity of most agro-processing machinery is higher than the need of small agro-processors in rural locations.[56]

To address this issue, the Project Development and Consulting Services Company Village Infrastructure Angels (VIA), designed and implemented a strategy based in 3-5 year lease agreements with local communities or intermediary partners in locations such as Vanuatu, Indonesia and Honduras, with the aim of facilitating access to rural electrification, Solar Home Systems (5-10 W per household) and communitary low power solar

[53] AgriGrid, A business model concept for next-generation mini-grids in Africa, 2020
[54] Agri-Grid, Lessons Learned, 2020
[55] Sustainable Energy for All, AgSol's solar powered mills promote universal energy access, 2019
[56] Technology Case Study: Clean Energy Agro-processing, Powering Agriculture (2020)

agro-processing assets (125-500 W).[57] VIA, in partnership with the DC solar powered agro-processing machinery manufacturer Project Support Services (PSS) have deployed a varied set of solar agro-processing units: Rice huller, rice polisher, hammer mill, corn huller, cassava grater, coconut scraper, maize mill, maize thresher and mincer. According to the Manager Director of VIA, Stewart Craine, the main advantages of solar systems and solar powered agro-processing machinery is that solar equipment can be deployed nearly everywhere, in contrast with other cheap alternatives such as mini-hydro. Additionally, the dropping prices and the advancements in DC post-harvest equipment allowed poor farmers to access productive use technology to foster the local economy and save time.

The agro-processing units are run by a central power platform (see Figure 10), controlled by a Smart Solar Control Box, which allows connecting multiple machines, Solar Home Systems, phone charging and water supply. The system's capacity can be easily grown by adding more solar modules and batteries. With its business model, VIA has supported underserved communities in several emerging economies, in partnership with PSS, IRENA, Rotary Melbourne, GIZ, USAID and other organizations and angel investors.

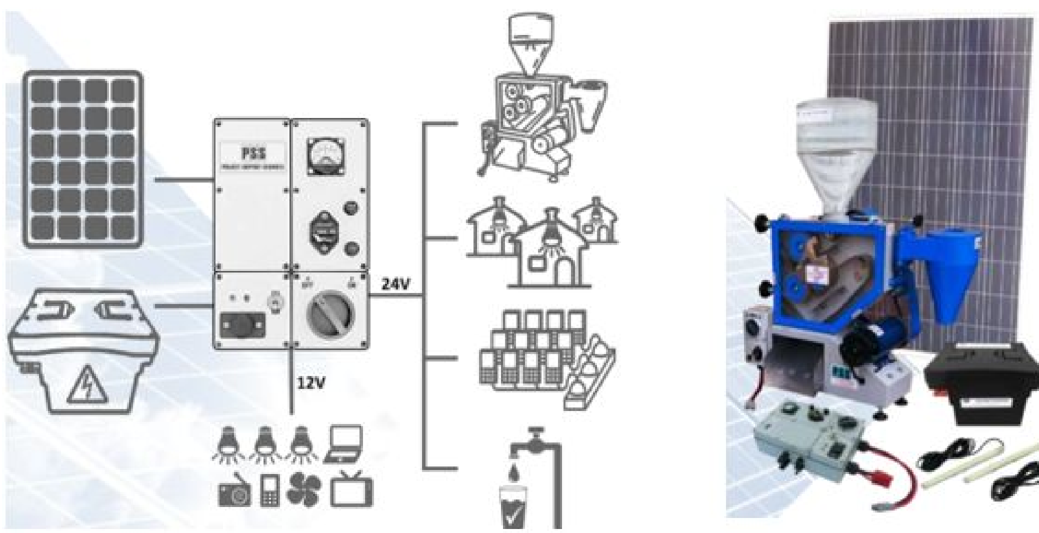


Figure 10: Schematics of the PSS Power Platform (left). Solar powered rice huller (right).

[57] Village Infrastructure Angels, About page

Food packaging

Without properly packaging, agricultural produce and processed food items have a reduced shelf life and high probabilities of contamination with external agents such as bacteria, soil, fungus and others which can be potentially harmful for human health. Packaging materials for food applications are varied: Paper board and cartons, metal cans, plastics, glass, and woods. However, while necessary to address food losses and health issues, the environmental costs derived from the use of plastic packaging materials can be high. Most food packaging is designed for single use, non-recyclable and requires intensive energy and water inputs for manufacturing.[58] According to Food Packaging Forum, 37% of the packaging market share is dominated by plastics,[59] but 91% of plastic waste worldwide isn't recycled.[60]

Sustainability Practices in Food Packaging

Decomposition and final disintegration of packaging materials is varied given their composition and disposal conditions. Paper products under adequate conditions can degrade between 6-8 weeks,[61] but this time can extend up to decades with additional GHG emissions under landfill disposal conditions.[62] Glass products are the most stable existing packaging types, taking up to 1 million years to fully decompose. However, as most commercial glasses are basically a mixture of natural materials: silica (sand), soda and lime, slass is a 100% closed loop-recyclable material (it can be recycled over and over without losing its properties or quality),[63] just like metal cans.[64] Plastic bags and bottles are estimated to take up to 1000 years to finally decompose but, as plastic composition is not based in organic compounds, it virtually lasts forever, only breaking down in smaller pieces of the same material.[65]

Apart from recycling, in order to address environmental stress due to packaging waste, innovative solutions have been developed. Some of these solutions are coatings for fresh produce preservation based in organic compounds (starches, gums and proteins),[66] biodegradable plastics,[67] and compostable plastics.[68] While these technologies show growing market share trends[69,70] and consumers show more awareness and interest in sustainability practices around packaging,[71] lower correct disposal rates have been observed for bio-based packaging materials than those for regular fuel-based materials.[72]

The successful implementation of sustainability practices for food packaging depends not only on the availability of technology or the public awareness about environmental concerns. While the packaging industry is highly driven by consumer preferences, willingness to pay and sustainability practices at social level such as

[58] Food Print, The environmental impact of food packaging, 2019
[59] Jane Muncke, Market share of packaging material, 2012
[60] National Geographic, A whooping 91% of plastics isn't recycled, 2017
[61] Rob Wreglesworth, How long does your garbage take to decompose or break down?
[62] Ximenes, F. (2010). The decomposition of paper products in landfills. In *64th Appita Annual Conference and Exhibition, Melbourne 18-21 April 2010: Conference Technical Papers* (p. 237). Appita Inc.
[63] Glass packaging institute, Glass recycling facts.
[64] Santa Barbara County Resource Recovery & Waste Management Division, Metal cans.
[65] Plastic Soup Foundation, Plastic breakdown.
[66] Embuscado, M. E., & Huber, K. C. (2009). *Edible films and coatings for food applications* (Vol. 222). New York: Springer.
[67] Plastics Europe, Biodegradable plastics.
[68] Plastic Soup Foundation, Compostable plastics.
[69] Bio-based News, Green Dot Blog: What growth in bioplastics industry means for investors and the economy, 2017.
[70] Business Wire, Global fruits and vegetables coatings market 2019-2023, 2019 https://www.businesswire.com/news/home/20190913005314/en/Global-Fruits-Vegetables-Coatings-Market-2019-2023-7
[71] Packaging Digest, Study: Consumers see value in biodegradable food packaging, 2017
[72] Taufik, D., Reinders, M. J., Molenveld, K., & Onwezen, M. C. (2020). The paradox between the environmental appeal of bio-based plastic packaging for consumers and their disposal behaviour. *Science of the Total Environment*, *705*, 135820.

recycling,[73] additional aspects need to be considered. Adequate infrastructure, such as composting facilities, and enabling policies are needed to support these practices, such as taxes or penalties that foster recycling.[74]

In developing countries, additional challenges must be faced in order to achieve sustainability in the packaging industry. According to the study Appropriate Food Packaging Solutions for Developing Countries, conducted for the International Congress Save Food in 2011, the local packaging industry in emerging economies still fails at meeting international market requirements, and there are low incentives for increasing investment for developing higher quality solutions. However, increasing needs for packaging local products, mainly from the agricultural sector, create opportunities to set up local packaging facilities which could aid on addressing food losses.

Sustainable Packaging Case Study: TIPA Sustainable Packaging Technology

Looking to respond to a growing demand for packaging but avoiding the negative consequences of using single-use flexible plastics, TIPA-Corp, a compostable packaging company was founded in 2010 in Israel. The aim of the company is to create flexible packaging for supplying the food and fashion industries, but using technology 100% compostable with zero residue for the environment just like natural organic plant peels.[75] TIPA-Corp has developed a wide variety of packaging solutions for dry goods and fresh products, including film sheets, laminates, lidding laminates, oppen and pillow bags, zipper bags, bar wrappers, sachet bags, pouchess and tea bags. Examples of these packaging types are shown in Figure 11. Packaging reels are also available in three varieties (transparent, metalized and coloured films and laminates) which fully degrade within six months in a compost environment.

Figure 11: Three varieties of fully compostable packaging offered by TIPA: Open bag-reel, tea bags and zipper laminates. Images taken from tipa-corp.com

Replacing conventional polymeric plastics by compostable packaging is not a straightforward task. The market success of this type of technology is highly dependent on the availability of composting infrastructure, cultural behaviour and economic capabilities of the population in the target countries. According to Avishag Seligman, Marketing Manager at TIPA-Corp, to evaluate the feasibility of implementing this kind of packaging technologies, it is of major relevance to consider the structure of the packaging value chain in the target country. Fully integrated value chains are less likely to introduce new packaging technology from an external company, while in fully disintegrated value chains new incumbents only need to be competitive. To introduce a fully compostable packaging in a country or region, we need to figure out several aspects: Market awareness, infrastructure, affordability and regulations. Developed economies have increased the market readiness for this type of packaging, but emerging economies are still weak in many of these aspects. Although market awareness is

[73] Boz, Z., Korhonen, V., & Koelsch Sand, C. (2020). Consumer considerations for the implementation of sustainable packaging: A review. *Sustainability*, *12*(6), 2192.
[74] Independent Commodity Intelligence Services (ICIS), EU agrees tax on plastic packaging waste, 2020
[75] https://tipa-corp.com/about/overview/

increasing in some regions of Asia and Africa, poor infrastructure and lower income still are considerable barriers to the development of these markets.

Contract Packaging (Co-packing)

For micro, small and medium entrepreneurs in emerging economies, purchasing their own packaging machinery can be expensive and inefficient. Placing a product on the market requires not only for it to be within a package, but also to accomplish safety regulations, labeling and nutrition facts, and in many cases to have an attractive design for consumers. Additionally, the market share of packaging machinery manufacturers is dominated by European countries (Germany, Italy, Switzerland), USA, Japan and China, with subsidiaries in some countries such as Argentina, Brazil or India. Therefore, accessing technical support and replacement components can be complicated for individual entrepreneurs. An efficient framework to address these issues is contract packaging (co-packaging). Services offered by co-packers can range all the processes needed for assembling a product into its final form which will be released to final customers. The importance of packaging lies both on the marketing aspects (customers buy what they see), but also in the preservation, protection and safety of the packed goods, in particular for food products. Co-packaging enterprises offer a wide range of services including: Design of the product's packaging, Inventory management and control of products, printing and component production, plastic/thermoform packaging production, packaging assembly and fulfillment, and warehousing and distribution.

The benefits derived from co-packaging for micro, small and medium enterprises are numerous, from avoiding investment in warehousing infrastructure, packaging equipment, specialized staff and acquiring of materials. Specialization of packaging companies in this area increases the efficiency, cost-effectiveness and speed in the processes of packaging, labeling and management of the products. Additionally, co-packaging companies can also be involved in the design aspects of a product's packaging, saving time and providing professional design skills to the product's owner. Co-packaging facilities are usually equipped with a diversified set of packaging appliances, available to address any short- or long-term needs of the contractor, increasing the efficiency and cost-effectiveness of the goods production.

Co-packing Case Study: Philippines Packaging Technology Division

The Packaging Technology Division (PTD), founded in 1999 by the Department of Science and Technology (DOST) of Philippines, aims to provide packaging services to Small and Medium Enterprises (SMEs), in order to promote national brands, develop packaging for ethnic foods, enhance regional packaging capabilities, and develop packaging for emergency/disaster relief ready-to-eat foods.[76] The packaging complex, shown in Figure 12, is equipped with laboratories for R&D and testing of packaging technologies, packaging design, library and data resource information and a pilot plant for selected packaging technology. The services offered include: package development, shelf life testing, technical supervision/evaluation for in-plant production, transport packaging, nutrition labeling, label design, use of facilities packaging facilities and package testing, with prices ranging from 2.00 PHP (0.041 USD, converted in August 2020) per square inch of mock-up labels printing, to 19,930 PHP (406.33 USD, converted in August 2020) for low-acid canned foods shelf life testing.

[76] Packaging Technology Division Profile, Philippines

Figure 12: PTD facilities (left). Packaging solution for local product's needs (right).

Apart from offering packaging services to SMEs, the PTD complex is an active center of R&D with the aim of improving the existing packaging technologies and methods, enhancing the technology transfer in benefit of the agro-processing sector and its workers (which represent nearly 30% of the country's workforce). From 2013 to 2017 the novel "Project for enhancing the competitiveness of fresh and semi-processed agricultural products through the application of appropriate and sustainable packaging technology in the Republic of the Philippines" was developed by the DOST together with the Japan International Cooperation Agency (JICA) within the PDT laboratories, with the aim of evaluating and developing sustainable packaging solutions (technology and transport) for eight selected agricultural products from different regions of the Philippines.

The implementation of this project has left several lessons learned. In the first place, research and development in packaging technologies can address the problem of high food loss rates currently existing in emerging economies. However, challenges for the penetration of the technology within the earliest links of the value chain (farmers and primary agro-processors) can be found, mainly economic and logistics. Nevertheless, this project demonstrated that the adoption of technology produces economic benefits that can overcome by far the implementation costs. Technology transfer played a major role in the development of this project.

The Guyanese Environment

Overview

Guyana is a country located in the northernmost region of South America, limiting to the North with the Atlantic Ocean, to west with Venezuela, to the South with Brazil and to the East with Suriname. Within its 196,849 km^2 of land and an estimated population of nearly 780,000 inhabitants,[77] Guyana has a great potential for growing economic development through the sustainable exploitation of natural resources and enhancing the industry sector.[78] Administratively, the country is divided in ten regions. The vast majority of the total population is concentrated in region 1 with 42% (Demerara-Mahaica) where the capital city is located. Together with regions 3 (Essequibo Islands-West Demerara), 5 (Mahaica Berbice) and 6 (East Berbice-Corentyne), almost 80% of the total population is located in the coast-based regions, as shown in Figure 5.1. The coastal plains make up only 5% of the total Guyanese territory, where the majority of crops, while the hinterlands are mainly populated by indigenous villages.

Figure 13: Guyana administrative division (left), 56% of the country's population resides in regions 3 and 4.

During the past decade Guyana has experienced considerable increases in its Gross Domestic Product (GDP). By 2018, the GDP per capita reached 4,965.97 USD,[79] which, according to the World Bank income classification for countries, is considered as an upper-middle income economy.[80] Furthermore, due to the recent findings of oil deposits in the Guyana offshore, the country is expected to have the highest GDP growth in the world, reaching 85.6% in 2020.[81]

Nevertheless, the oil findings and sudden wealth increase have generated controversy within the country. The lack of regulatory schemes to oversee the oil exploitations,[82] but also concerning border disputes with neighboring countries,[83] political corruption,[84] and distribution of wealth[85] has arisen social and political tension during the last years. Despite these issues, there is a general consensus that part of this increasing wealthiness should be destined to support economic resilience, through diversification of industry in different sectors, modernization of public institutions and regulation, and built-out of domestic infrastructure.[86]

---

[77] The World Bank, Population, total - Guyana.
[78] Barrow-Giles, C., & Marshall, D. D. (Eds.). (2003). *Living at the borderlines: issues in Caribbean sovereignty and development*. Ian Randle Publishers.
[79] Trading Economics, Guyana GDP per capita.
[80] The World Bank, Classifying countries by income, 2019.
[81] Dylan Baddour, Massive Guyana oil find continues to grow with fresh Exxon discovery, 2020.
[82] Kevin Crowley, Guyana may not be ready for its pending oil riches, but ExxonMobil is, 2019
[83] Anthony R. Cummins, How Guyana's oil discovery rekindled a border controversy, 2018
[84] Trading Economics, Guyana Corruption Rank.
[85] Business Human Rights Resource Centre, Guyana: Concerns raised over the discovery of large oil reserves in America's second poorest nation, 2019
[86] Wood Mackenzie, Guyana: Global oil's new king of the heap, 2020

The Micro and Small Agro-processing Sector in Guyana

Development of the agro-processing industry in emerging economies can contribute to reducing poverty by increasing the demand of agricultural products, but also by generating employment for poor farmers.[87] However, two critical issues for developing the industry are the technological upgrade and the construction of suitable facilities. Additionally, the productivity of factories is linked directly to a reliable power supply. Power outages can have a negative and significant effect on productivity, particularly in small firms.[88] The Guyanese power energy grid is fragile, with users suffering frequent power outages. Therefore, much of the commercial and manufacturing sectors are either off-grid or use the grid only as a backup, relying on expensive and pollutant diesel gensets.[89] Although there has been observed a general interest in transitioning to solar power[90] and other renewable generation technologies, but the current upper limit of 100 kW in distributed generation may discourage investment in private solar power plants. According to data from Global Solar Atlas the specific photovoltaic power output in Georgetown can reach 1,546 kWh/kWp per year, making it a suitable location to take advantage of solar energy. Additionally, one of the targets of the Green State Development Strategy (GSDS) contemplates the transition to 100% renewable energy generation by 2040 in Guyana.[91]

Agriculture and agro-processing is of special interest for the economy of Guyana. This country has been historically reliant on agriculture and extractive industries.[92] By 2018, the contribution of the agriculture sector to the total GDP of the country reached 12.73%,[93] and this sector is responsible for the largest share of private employment, indirectly impacting close to 200,000 households in all ten regions.[94] As shown in Figure 14, the main agricultural goods produced in Guyana are sugar and rice, but other fruits and vegetables production has increased since 1990. With the higher availability of raw products, an increased production of prepared food items has been observed in Guyana, driven by micro, small and medium single- or family-owned companies.

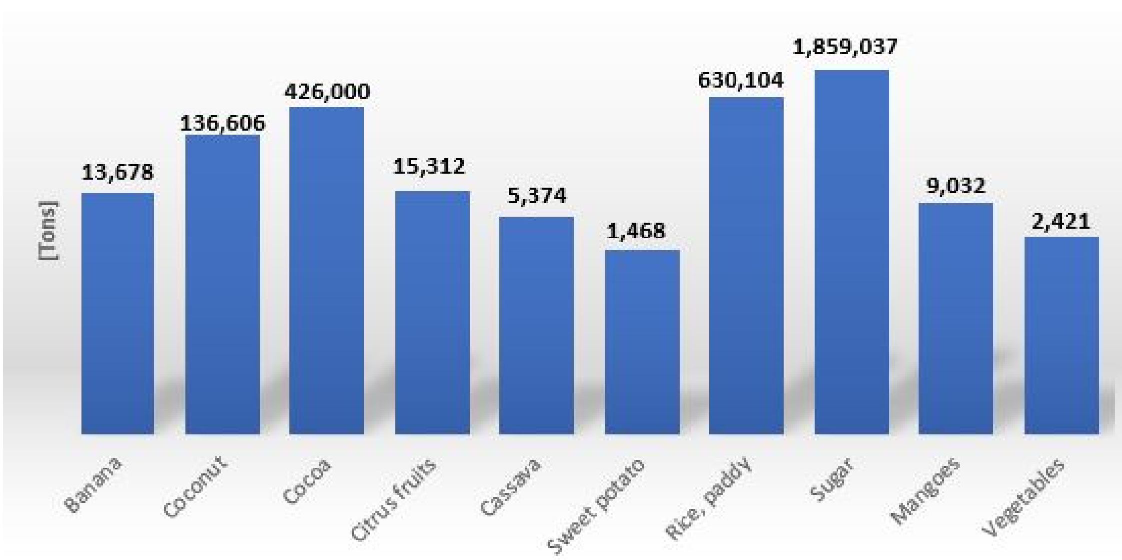


Figure 14: Agricultural produce of Guyana (tons, log scale) produced in Guyana in 2017. Data obtained from tilasto.com.

87 Watanabe, M., Jinji, N., & Kurihara, M. (2009). Is the development of the agro-processing industry pro-poor?: The case of Thailand. *Journal of Asian Economics*, *20*(4), 443-455.
88 Moyo, B. (2012). Do power cuts affect productivity? A case study of Nigerian manufacturing firms. *International Business & Economics Research Journal (IBER)*, *11*(10), 1163-1174.
89 Global Green Growth Institute, Guyana's private sector-led transition, 2018.
90 Guyana Energy Agency, Solar energy.
91 Green State Development Strategy: Vision 2040, 2019.
92 Index mundi, Guyana economy profile 2019
93 The Global Economy, Guyana: GDP share of agriculture, 2019.
94 Oil Now, If oil triggers loss of agriculture, Guyana could face social, economic upheaval, 2017.

Enhancing the development of industries based on agricultural produce is of great importance in emerging economies, especially for the so-called "non-traditional" food products for exports.[95] In Guyana, which has been traditionally reliant on rice and sugar production, considerable growth in the non-traditional agricultural export has been observed. In 2017, the New Guyana Marketing Corporation (New GMC) reported a 25% increase in non-traditional exports compared to 2016, valued at GY $3.6 billion, equivalent to $17 million USD.[96] Furthermore, agro-processing adds extra benefits to agricultural products and the overall sector. Economic benefits from the reduction of post-harvest losses, increasing the nutritional value of food and increasing food security, through reductions on food spoilage and wastage, added to the price stability of processed food in the international markets, employment generation, fostering enterprise development, among others.[97]

In Guyana, non-traditional agricultural products are promoted to great extent through the New GMC, whose mission is "Facilitating and coordinating the development of quality non-traditional agricultural produce for export."[98] The GMC offers several services such as advisory, agro-business development, cold storage facilities, packaging facilities, refrigeration trucks among other services, together with the promotion of products from engaged agro-producers, and a marketplace to offer their products, located in the capital city. However, specialized agro-processing facilities aimed to provide services for micro and small agro-processing entrepreneurs are practically nonexistent within the country. Additionally, the existing transport, storage and packaging services give priority of use to those exporters to countries under the protocol arrangement.[99] Therefore, local companies and small exporters to other countries may not have the same opportunities for using these facilities.

Sustainable development of the agro-processing sector depends not only on the availability of agricultural products and the enthusiasm of entrepreneurs. Government support in terms of import and export taxes, loans and supportive policies to establish businesses; provision of infrastructure such as rural roads, agro-processing and packaging facilities, rural electrification and agricultural machinery; supporting academic research and technology transfer; facilitating the participation of private investment and enhanced marked access are critical. During the last decade, government efforts to enhance the agriculture sector in Guyana have been guided through the National Strategy for Agriculture 2013-2020, whose main targets are focused on food and nutrition security. A central objective of this Agenda is to provide opportunities for entrepreneurs, and create and sustain employment, livelihoods and wealth generation for people.[100] Additionally, participation in international markets is also searched, by improving quality of the food products within the entire value chain. Other aspects such as technology transfer, the development and facilitation of agricultural infrastructure and improvement of farm-to-market roads are also mentioned. Furthermore, the country's electrification has also been improved since 2010, reaching 92% of the total Guyanese population accessing electrification by 2018, and 90% of rural people, according to data of the World Bank.[101] Regarding technology transfer, the Guyana School of Agriculture and the University of Guyana have strong academic programmes with potential to develop innovative food products and agricultural businesses. Two small agro-processing entrepreneurs interviewed for this research started developing their products in the Guyana School of Agriculture.[102]

---

[95] Wilkinson, J., & Rocha, R. (2008, April). The agro-processing sector: Empirical overview, recent trends and development impacts. In *Global Agro-Industries Forum*.
[96] Guyana Office for Investment, Agriculture/Agro-processing sector.
[97] Owoo, N. S., & Lambon-Quayefio, M. P. (2017). The agro-processing industry and its potential for structural transformation of the Ghanaian economy. *Industries without Smokestacks*, 191.
[98] New Guyana Marketing Corporation, Company profile.
[99] New Guyana Marketing Corporation, Packaging facilities.
[100] Ministry of Agriculture, A national strategy for agriculture in Guyana 2013-2020.
[101] The World Bank, Guyana Access to electricity, rural (% of rural population).
[102] Interview with Guyanese small agro-processing entrepreneurs, July 2020.

Despite the government efforts, Guyanese small agro-processing entrepreneurs, claim facing several challenges for scaling up their businesses.[103] In the first place, the price variability and difficulties in acquisition of raw materials during certain periods can impact negatively on their final product's price and sales. Secondly, the lack of specialized agro-processing machinery impacts directly on the quantity of items that can be produced by hand processing, or with minimal mechanized assets. They claim that a "DIY scheme" predominates within the sector, and the lack of support in terms of investment, taxes, access to mechanization and packaging machinery highly prevent their growth. Although there exist companies that offer packaging and labeling services in the country, these are not attractive for small entrepreneurs from an economic perspective. And finally, difficulties in placing their products on the market at competitive prices are also a setback for these companies to grow. The interviewees said that, although the New GMC offers marketing support and the possibility of exhibiting their products in the supermarket, this support is highly constrained by limited budget. The entrepreneurs also think that the government could be more involved in fostering the micro and small agro-processing companies, given their potential to generate income both in local and international markets. One of the interviewees has achieved to export her products to the UK by private request with successful results, but limited capacity for growing without external support.

Case Study: Sweet Potato Flour Value Chain in Guyana

In this example, we explore the value chain of a Guyanese sweet potato flour, according to data provided by an anonymous local entrepreneur. We describe the current process for manufacturing this product, proposing feasible alternatives to increase yields, processing times and costs, analyzing the benefits of implementing smart and sustainable agro-processing manufacturing technology. Special attention is put on the agro-processing stages. As shown in Figure 15, the general value chain of sweet potato flour is composed by six steps: Land preparation for crops; Sweet potato cultivation, harvesting and post-harvesting management; acquisition of the raw sweet potato by the agro-processor, transportation and storage; agro-processing for flour production; packaging of the prepared product; and final storage, transportation and distribution to the final consumers.

Through each step of the value chain of a product there are requirements of energy and water in order to perform the transformation processes to achieve the final product from the primary inputs. In the case of sweet potato flour, the very first step of the value chain starts with the land preparation, site selection, ploughing, planting, irrigation, fertility management and pests control. In Guyana, sweet potato crops can be found mainly in regions 3, 4 and 9, and to a less extent in regions 2, 5 and 6.[104] While most of these regions are located in the coast near the Capital City, these territories can be prone to excessive rain and floods.[105] In contrast, as region 9 (the most extensive area for cultivation) is located in the hinterlands, where remoteness and poor road connectivity can affect the interchange of inputs, machinery and produce between rural-hinterland and urbanized-coastal areas.[106] In this aspect, the Guyanese government is leading efforts to improve road connectivity.[107]

[103] Interview with Guyanese small agro-processing entrepreneurs of non-traditional food products, August 2020.
[104] Guyana Chronicle, What you need to know about sweet potatoes - Part 1, 2018
[105] The World Bank, Guyana: Agricultural insurance component, 2018
[106] FAO, Sector Studies: Guyana rural sector note, 2005
[107] DPI Guyana, Hinterland slated to receive improved road connectivity in 2019, 2019.

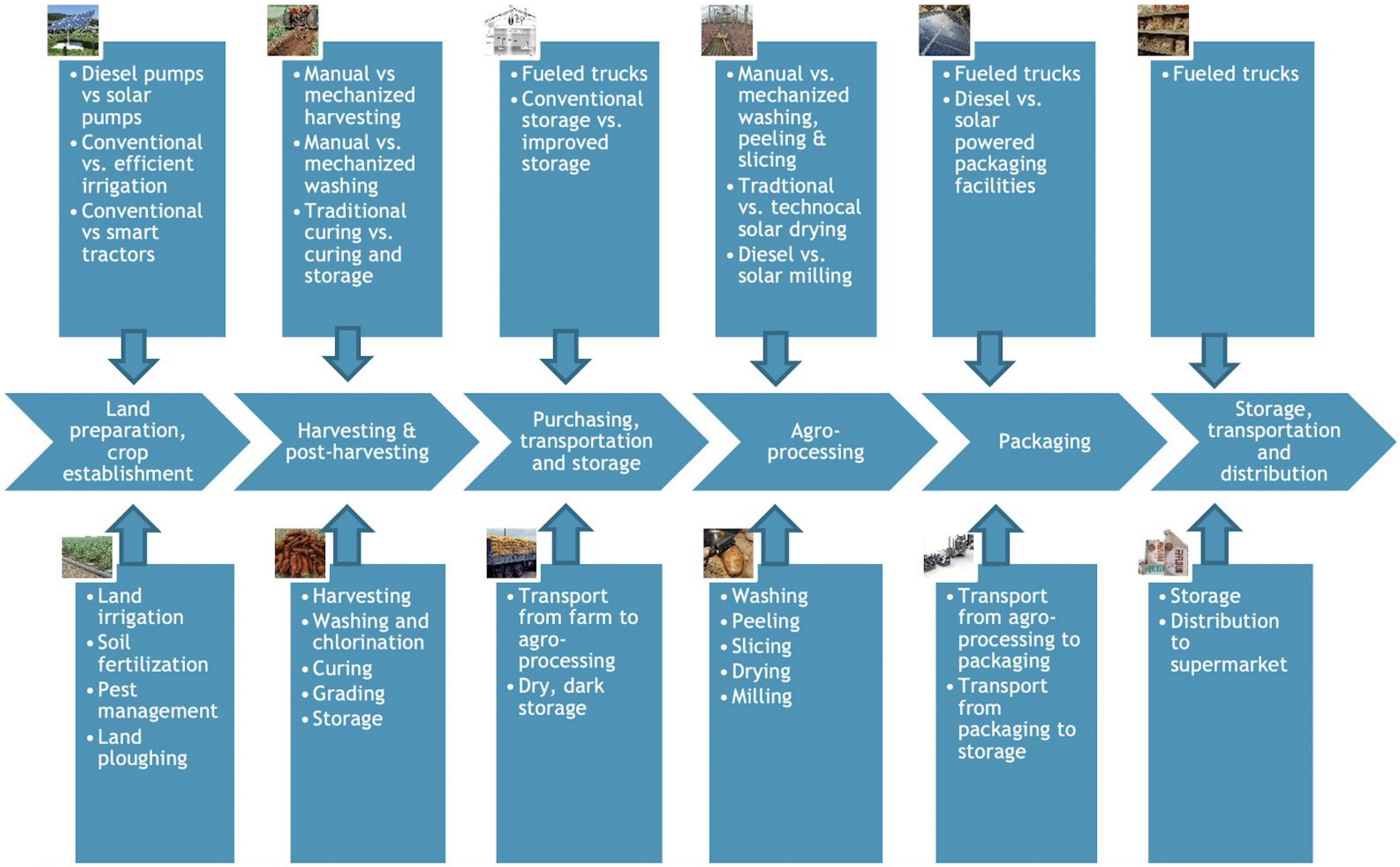


Figure 15: Sweet potato flour value chain, with different energy, water and fuel input requirements (upper boxes) for the different production and processing stages (lower boxes).

Ploughing land for crop preparation can be done manually, with intensive labor or using a tractor, with fuel consumption (generally diesel). For small farmers, a feasible alternative is to use the Smart Tractors (describe Smart tractors business). In Guyana, producers of sweet potatoes are mostly smallholder farmers, which could take advantage of these kinds of technologies.

Fertilization of sweet potato crops requires nitrogen, phosphorus, potassium and small quantities of boron, calcium and magnesium.[108] Chemical or organic fertilizers can be used, but organic compost-based fertilizers have shown to improve sweet potato yield compared to chemical fertilizers.[109] Pest management can also be done either using chemical or organic products.

Land irrigation requires water input and energy to power the water pumps. Traditionally, water pumping has been done using diesel pumps, but solar irrigation pumps are currently a feasible alternative, avoiding GHG emissions and purchasing expensive fuel.

Harvesting can be done either manually or mechanically, but using this last method the vegetables are prone to be damaged. After harvesting, which can occur between 3-8 months after planting, sweet potatoes must be washed thoroughly to remove soil, which can also be done by hand using a sponge or using a washing machine. In this step, water is mixed with small amounts of chlorine to avoid spoilage. Next, sweet potatoes are graded and sorted according to their size for further commercialization, and prepared for curing. Curing can be done using traditional methods (describe), or using modern infrastructure with specialized room conditions

---

[108] CARDI Root and Tuber Commodity Group, Sweet potato technical manual, 2010.
[109] Novianantya, A. C., Fardany, N. K., & Nuraini, Y. (2017). Improvement of sweet potato yield using mixtures of ground fish bone and plant residues. *Journal of Degraded and Mining Lands Management*, *4*(2), 759.

(temperature and humidity), where sweet potatoes can also be stored by extended periods, increasing the lifetime of the produce and reducing food losses.

At this point of the value chain, the agro-processor purchases the sweet potatoes for the primary producers. Fueled transport from the farm storage to the agro-processing storage is needed. Storage of the sweet potatoes on the preprocessing stage needs to be done within a dark, dry room. The temperature required for storage depends on whether the potatoes need to be cured (29 °C) or just stored (13 °C) when curing has been successfully done in the farm stages. Under the current storage conditions of the case study Sweet Potato Flour, sweet potatoes can be stored for up to one week. A suitable technique to accomplish these constraints and extend the storage time is the Negative Horizontal Ventilation (NHV) System. Properly storage sweet potatoes can last for up to 13 months. This could allow the company to purchase greater volumes of raw material at lower prices, or even purchasing the sweet potatoes prior to curing, ensuring the desired quality and homogeneity of the final product.

The agro-processing stages for preparing the Sweet Potato Flour are: Washing, peeling, chipping, drying and milling. The total processing time for 100 (45.4 kg) pounds of raw sweet potatoes is 7 days by doing the processing manually. Currently, the strategy of the agro-processor of this product is as follows: Manual washing, peeling and chipping 50 pounds (22.7 kg) are done in one day. Dehydration of this half of the total volume is done by traditional solar drying which takes three days. Within this time, processing of the other half is done. The total time after drying is six days. On the seventh day, all the produce is taken to the agro-processing facility for mechanical milling. Following this step, the grinded flour is taken back to storage for further mixing with the other ingredients that compose the final product. After this step, the mix is stored for the final processes of bagging and boxing for commercialization of the finished product.

The current equipment and facilities are mainly naturally ventilated, manual and traditional techniques, which can be improved with suitably conditioned, technically upgraded and not-necessarily expensive equipment. While a proper storage facility such as the NHV is recommended for long-term storage of sweet potatoes and the possibility of performing curing, the cost of such a facility remains low as the main equipment consists of fans and dampers, together with the constructive form of the building. The amount of sweet potatoes capable of storing can vary from 130 to 2,000 tons. General guidelines for the construction of sweet potato curing and storage facilities are given in.[110]

Manual washing and peeling can consume a lot of human energy, time and water. Depending on the volume of produce to be washed and peeled, several models of sweet potato washing & peeling machines can be easily found online. The smallest models are capable of handling between 400 to 700 kg/h, with power consumption of about 1 kW and prices ranging from 2,000 to 7,000 USD. These machines are usually available to be used to wash and peel similar products, such as potatoes, carrots, kiwi among others, which make them suitable to implement in a diversified agro-processing industry or a cooperative. Most manufacturers claim to offer water saving and pollution-free products, designed to reduce the reliance on workforce and manual processing.

Manual chipping of sweet potatoes can be replaced by mechanized chipping with capacities ranging 600-800 kg/hr. Just like the other assets, chippers can also be used for other products such as cassava, yam, lotus root and radish, using 0.75 kW of power.[111]

Technical solar drying equipment can vary from slight modifications to traditional solar open-sun drying techniques, such as greenhouse dryers, hybrid solar dryers, tunnel dryers and black-box dryers. In general, solar dryers can be classified according to their mechanisms for air movement and mode of heat transfer between passive, active and hybrid solar dryers. Drying times depending on the technology, but also on the product to be

[110] B. Edmunds et al (2013), Postharvest handling of sweet potatoes, N. C. State University.
[111] High Efficiency Sweet Potato Chips Cutting Machine With Four Holes

dried. Usual drying times range between 2 to 6 days. Different technical solar dryers are available with prices ranging from 200 USD with 5kg capacity, to 3,000 USD with 270 kg capacity.

For milling, diesel and electric mills are available on the market, with prices ranging from 300 to 2,000 USD, capacities ranging from 10 to 1000 kg/hr and power consumption ranging from 2.2 to 22 kW.[112] Turnkey systems integrating all the assets needed for sweet potato flour are also available from 85,000 to 450,000 USD.[113] DC solar powered mills are available from 3,000 to 5,000 USD, with hourly outputs of 25 - 200 kg/hr, and power consumption of 0.75-1 kW. Manufacturers of solar mills are Project Support Services, Phaesun, AgSol and SeineTech.

After the milling and storing (if necessary) stages, the flour is ready for packaging. Packaging machinery is available from a varied range of manufacturers worldwide. The current situation in Guyana is to acquire services from companies within the country or to import packaging machinery from abroad.[114] Offering both agro-processing and contract packaging services specialized for small and medium entrepreneurs, with access to business and technical support, shelf life testing and labeling, among other services can be a feasible option given the diversity of small food producers with potential to grow their businesses.

An important aspect to consider is about quality standards for packaged food. While packaging standards vary from one country to another, this gains relevance when exports are a target of the entrepreneur. As many countries, Guyana follows the guidelines of the Codex Alimentarius,[115] through the National Bureau of Standards (GNBS).[116] Regarding packaging, as Guyana integrates the Caribbean Community (CARICOM),[117] food producers of pre-packaged items should follow the guidelines of the CARICOM Regional Standard, Specification for pre-packaged food.[118] According to Bezalel Adainoo, BSc. in Nutrition and Food Science from University of Ghana, and Consultant at PreScout, for countries that hold the Codex Alimentarius it is a good baseline to start looking at export markets such as US, UK, UE or Canada. However, it is also important to consider additional restrictions imposed by each country.

Discussion and Recommendations for Agro-Processing in Guyana

Development of agribusinesses and agro-industries in emerging economies need a holistic approach considering the complete value chain of agricultural products: farm activities, storage and transport, agro-processing and packaging, distribution and commercialization. This is because weak links on the value chain (poor farmers for instance) can affect the overall supply, availability, quality and final price of the products, reducing the net profit of the sector. Additionally, addressing the issue of food losses in emerging economies can contribute to reducing poverty, malnourishing and poor health, improving food security and nutrition security.

Enhancement of the value chain can be done primarily by ensuring the right access to basic services and resources by each link of the chain. For farmers and primary producers, accessing irrigation systems, tractors, proper storage conditions among others can ensure the production of more homogeneous, high quality agricultural goods, reducing losses and increasing availability of the products throughout the year, in order of delivering better products for the further links on the value chain. The successful case of the Agrigrids is a good example of rural development with the creation of business.

---

[112] Small electric mill sweet potato flour making machine
[113] Zhengzhou Sida Agriculture Equipment, Ltd.
[114] Interview with anonymous small entrepreneur
[115] FAO, Codex Alimentarius
[116] Guyana National Bureau of Standards, Codex Contact Point
[117] CARICOM, Guyana
[118] CROSQ, CARICOM Regional Standard: Labelling of Foods – Pre-Packaged Foods, 2018

All these aforementioned considerations need to be addressed by multiple stakeholders: the government, banks, international organizations, NGOs, privates and rural communities. In this sense, public-private-partnerships have shown successful international implementation, therefore their implementation is highly recommended in Guyana.

Regarding the agro-processing and packaging industries, sustainable development requires both infrastructure, agro-processing and packaging assets, and a reliable power supply. As the national electricity grid of Guyana is sometimes unreliable and with high losses (contributing to high prices). Thus, private power mini-grids, mainly fuel based, are a common option for industries and businesses. However, the competitive prices of solar technologies make it feasible to consider adoption of solar powered-industrial mini-grids, easily scalable and customizable according to the investor’s needs and budget. In contrast, the use of PULSE appliances can also be an attractive option, depending on the volumes of produce, but they offer reliable, clean and independent power supply. Furthermore, improvements on roads connecting rural and urban locations is critical for achieving fluid transport of goods, particularly in Guyana where there is high potential for developing agriculture in the hinterlands, which are very far from the urban centers, all located in the coast.

Additional considerations such as waste management and energy generation from agricultural and agro-processing waste can also be an attractive option. Packaging is an important stage of the food industry and current packaging technologies are not sustainable given that the industry is highly dominated by plastics. Sustainable packaging such as biodegradable, compostable or recyclable packaging are feasible alternatives. Although these can be several times more expensive than traditional packaging, they help to address land and sea pollution, of which more and more people are getting aware. Also, since the final consumer choices and preferences is of critical concern for food producers. Attractive packaging designs, organic origin, sustainable packaging, “produced with renewable energy” can be strong allies on the market penetration of a product. In the same line, it is highly recommended for the agro-processors to have a clear identification and thorough knowledge of their target markets.

In Guyana, many small entrepreneurs lack economic and technical support to grow their businesses. An open facility providing rental agro-processing and complete packaging services, together with business incubation and professional advice is recommended. Other schemes such as the rental or PAYG of agro-processing appliances could also be suitable. Strong support for small entrepreneurs on accomplishing international food standards such as the Codex Alimentarius is highly recommended. Additionally, specific standards required by the target markets should also be considered for exports.

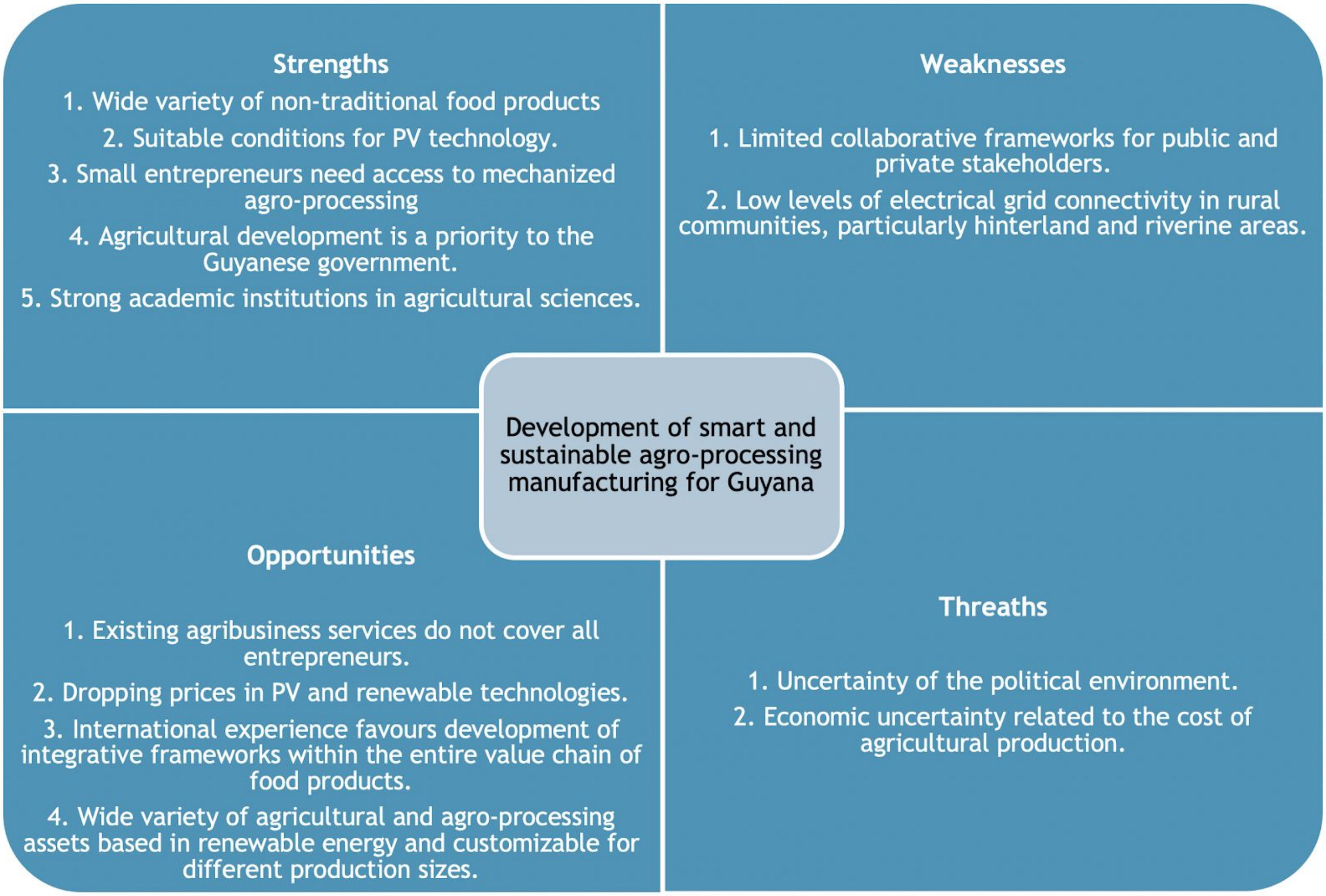


Figure 16: SWOT analysis for developing sustainable agribusiness and agro-processing manufacturing in Guyana.

Conclusions

Sustainable development of agro-processing industries in emerging economies need to consider the complete value chain of products, from raw materials to the final customers, and from governments to smallholder farmers. Since emerging economies have historically produced low value added commodities for export, transitioning to higher value added products based on non-traditional goods involves an efficient use of the natural resources, enabling environments regarding policies and regulatory frameworks, and a close collaboration between the different actors of the value chain. Inclusive development strategies, involving rural electrification, provision of agricultural and agro-processing assets for smallholder farmers and primary producers, agro-processing cooperatives, agribusiness incubation schemes and public-private-partnerships have shown promising results in achieving higher quality products and increased income. The undeniable nexus between water, energy and food production highlights the relevance of adopting renewable energy, and circular economy frameworks such as recycling, sustainable packaging and waste management practices within the agricultural value chain. As packaging plays an important role both in the preservation and marketing of food products, continuous R&D&I and sustainable frameworks available for micro, small and medium entrepreneurs is also relevant. In Guyana, the implementation of technology and inclusive frameworks for sustainable agro-processing is recommended. Fostering an enabling environment for sustainable technology integration is expected to help Guyanese micro and small agro-processing entrepreneurs facilitate their growth, and potentially penetrate international markets. For example, increased support in terms of legal advisory, technical capacity and infrastructure to small entrepreneurs within Guyana from private and public institutions is recommended. The individual acquisition of machinery is expensive, inefficient and risky, and the need of several appliances per agro-processor make the placement of a common facility with shared equipment an attractive solution for small-business owners. The access to infrastructure and specialized assets could contribute to increase the market share of non-traditional goods both in local and international markets.

E4C was founded by ASME as part of the Society's mission to advance engineering for the benefit of humanity. Engineering for Change (E4C) is powered by the American Society of Mechanical Engineers (ASME).

E4C's mission is to prepare, educate and activate the international engineering workforce to improve the quality of life of underserved communities around the world. We are a Knowledge organization with global community of 1,000,000+ that believes engineering can change the world. Founded in 2009 by ASME, IEEE and EWB-USA.

Access our platform: **https://www.engineeringforchange.org/**

- Global community of 1 million+ engineers, technologists and development practitionersCodified data on 1000+ essential technologies.
- Engineering insights about latest developments, best practices, opportunities and expert insights in EGD.
- Access research studies and field insights

Read full reports at:
https://www.engineeringforchange.org/research/

Read more about our Fellowship and Research Fellows:
https://www.engineeringforchange.org/e4c-fellowship/

To become a research partner, email:
partners@engineeringforchange.org

To learn more, email:
mariela@engineeringforchange.org

engineering FOR CHANGE

**BY ENGINEERS,
FOR EVERYONE.**