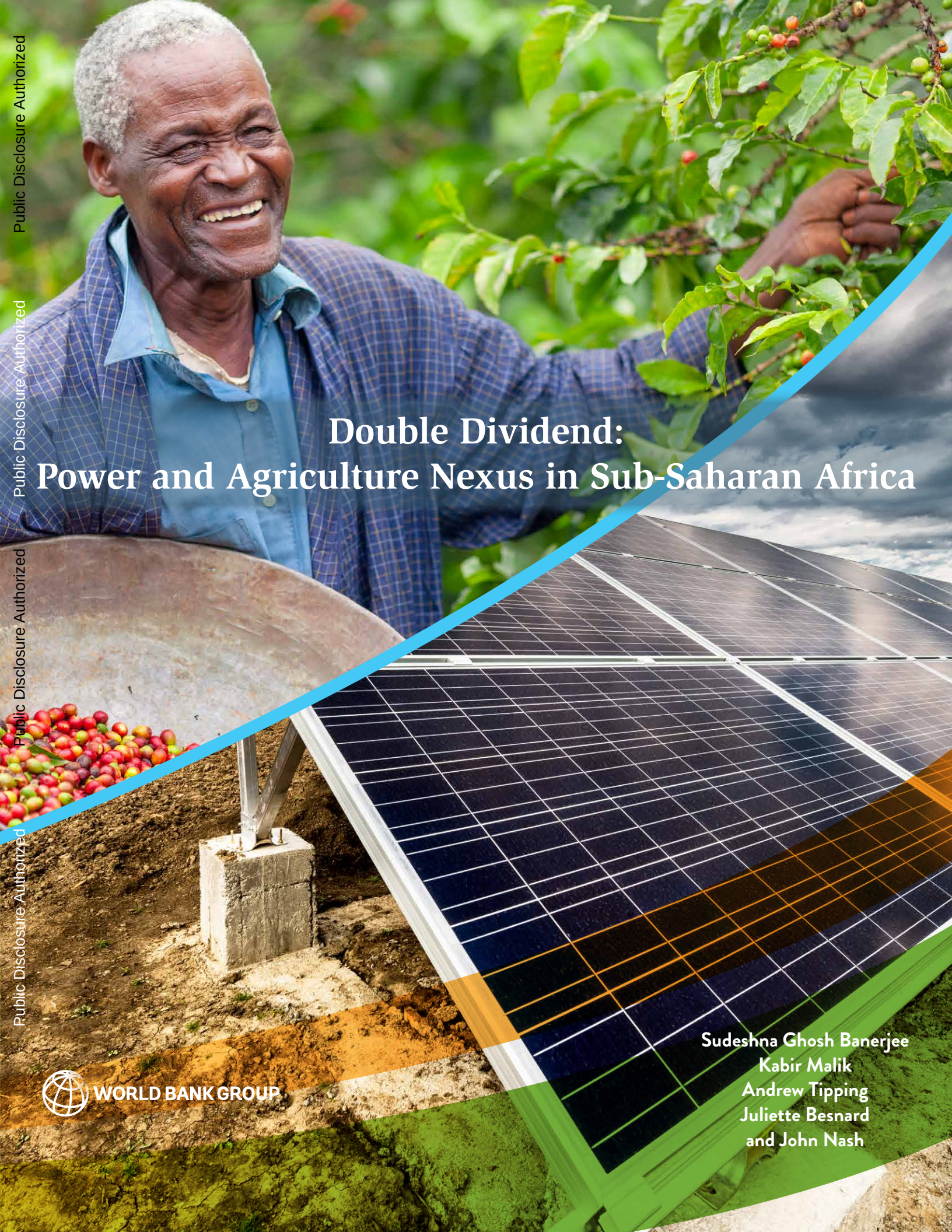

# Double Dividend: Power and Agriculture Nexus in Sub-Saharan Africa

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# Foreword

The greatest challenge to increasing electricity access in Sub-Saharan Africa is how to make electricity provision financially viable in low-demand rural households. The presence of commercially attractive customers—typically those that have relatively large and stable electricity demand for revenue generating purposes—can help reduce the barriers to accelerating grid and off-grid approaches to rural electrification. By aggregating anchor-load demand with that of households and businesses, it may be possible to extend the grid or create opportunities for mini-grids and other decentralized options.

African agriculture has tremendous potential to raise rural welfare through agricultural transformation. It is estimated that productivity growth in agriculture—which predominates the livelihoods of the subcontinent's rural poor—could be several times more effective than growth in other sectors in reducing rural poverty. Furthermore, there is a growing commitment among African governments toward sustainable and inclusive agricultural development.

Developing energy intensive agricultural processes, such as large-scale irrigation or milling activities, can not only increase agricultural productivity, but can also increase the commercial viability of electricity provision. The large-farm, agribusiness model practiced over the past 20 years has a continuing strategic role to play in promoting growth in Africa. At the same time, subsistence, smallholder farms, which account for most of Sub-Saharan Africa's agriculture, are key to stimulating the rural economy and uplifting the poor. Energy, along with investments in other complementary infrastructure and services (e.g., roads, transport links to markets, and access to finance), is a critical input for supporting Africa's agricultural transformation. Without access to affordable and reliable electricity, farmers will continue to face constraints to productivity growth and thus lag behind their counterparts in more prosperous regions of the developing world.

Against this backdrop, this study explores opportunities for synergy between the goals of rural electrification and agricultural transformation in Sub-Saharan Africa. It shows that leveraging complementary investments in agriculture and electricity can yield double dividends in terms of poverty alleviation. Aligning electricity investments with agricultural development can maximize joint benefits from the expansion of rural electricity access and the increase in value added along the agricultural value chains, both of which are directly linked to improved quality of life and poverty alleviation in rural communities.

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# Abbreviations and Acronyms

| | |
|---|---|
| **ABC** | Anchor Business Community |
| **AMADER** | Malian Agency for Development of Household Energy and Rural Electrification |
| **CAADP** | Comprehensive Africa Agriculture Development Programme |
| **CAGR** | compound annual growth rate |
| **CHP** | combined heat and power |
| **CSR** | corporate social responsibility |
| **CTC** | cutting, tearing, and curling |
| **DRC** | Democratic Republic of the Congo |
| **ECA** | Economic Consulting Associates |
| **EEPCO** | Ethiopian Electric Power Corporation |
| **EFB** | empty fruit bunch |
| **ESC** | Ethiopian Sugar Corporation |
| **EWURA** | Energy and Water Utilities Regulatory Authority |
| **FFB** | fresh fruit bunch |
| **FiT** | feed-in tariff |
| **GDP** | gross domestic product |
| **GP** | global practice |
| **GTAP** | Global Trade Analysis Project |
| **IPP** | independent power producer |
| **IRR** | internal rate of return |
| **KPLC** | Kenya Power and Lighting Company |
| **KTDA** | Kenya Tea Development Agency |
| **LCOE** | levelized cost of electricity |
| **MSMEs** | micro-, small-, and medium-sized enterprises |
| **NPV** | net present value |
| **ODA** | official development assistance |
| **PV** | photovoltaic |
| **REA** | Rural Energy Agency (Tanzania) |
| **RVE** | Rift Valley Energy |
| **SAGCOT** | Southern Agricultural Growth Corridor of Tanzania |
| **SDG** | Sustainable Development Goal |
| **SE4ALL** | Sustainable Energy for All |
| **SHS** | solar home system |
| **SMEs** | small- and medium-sized enterprises |
| **SSA** | Sub-Saharan Africa |
| **TANESCO** | Tanzania Electric Supply Company Limited |
| **ZESCO** | Zambia Electricity Supply Corporation |

# Executive Summary

**Increasing access to modern electricity services in Sub-Saharan Africa is one of the main development challenges facing the world over the next two decades.** Inclusion of the target to "ensure access to affordable, reliable, sustainable, and modern energy for all" in the Sustainable Development Goals (goal 7) has brought a sharper focus to accelerating electricity access in the historically underserved regions of the world—most notably Sub-Saharan Africa. Two out of every three people in Sub-Saharan Africa live without electricity, a reality that is inconsistent with the modern world. The majority of this population without access to electricity is rural and poor. Rural electrification efforts in the region have not achieved sufficient progress in increasing electricity access as these areas are typically commercially unattractive, characterized by sparsely distributed customers with low electricity consumption and ability to pay, and a high cost of service to extend the grid. Rural enterprises and households thus must cope without electricity, relying instead on expensive, poor quality backups (e.g., diesel, kerosene or other oil-based sources), thereby stunting productivity, limiting development outcomes, and imposing harmful environmental impacts. The rural economies are overwhelmingly dependent on agriculture; in fact, agriculture and agribusiness comprise nearly half of Africa's gross domestic product (GDP). These enterprises require electricity to grow to their potential, while the expansion of rural energy services needs consumers with consistent power needs to serve as a reliable revenue source.

**Can agriculture and energy come together in Sub-Saharan Africa to offer a double dividend with benefits to enterprises, households, utilities, and private-sector service providers?** This is the central question of this study. That is, can energy intensive activities along the agriculture value chains provide significant revenues to the power utilities and increase the financial viability of rural electrification? Combining agricultural load with other household and commercial power demand could increase the feasibility of extending the grid or creating opportunities for independent power producers and mini-grid operators. Drawing on a suite of case studies, this study offers insights on what it would take to operationalize the opportunities and address the challenges for power-agriculture integration in Africa.

## WHAT IS THE SCALE OF OPPORTUNITY OF POWER DEMAND FROM AGRICULTURE?

**Historical performance of agriculture in Sub-Saharan Africa has been wanting.** The share of agriculture in GDP has declined from 20 percent in 2000 to 14 percent in 2013.[1] A very small percentage of Africa's agricultural production undergoes industrial processing.[2] In high-income countries, processing adds about US$180 of value per ton of agricultural produce, compared to only $40 in Sub-Saharan Africa; this disparity is aligned with the small size of Sub-Saharan Africa's agribusiness sector relative to on-farm agriculture. In addition, for more than four decades, the region's share in global agricultural export markets has been on the decline.

**There are reasons to believe that agriculture productivity could turn the tide**. Trends in economic growth and urbanization fuel the demand for food, as do continuing improvements in infrastructure and the benefits of lower oil prices. The potential urban market for agricultural goods and commodities is projected to reach US$1 trillion by 2030. There are a number of underlying structural incentives to promote agriculture. The region has 45 percent of the world's total suitable land area for expanding sustainable agricultural production. Past gains in commercial crops (e.g., cashews, tea, and sesame seeds) indicate that the region can increase its agricultural productivity. But seizing this opportunity will require farmers and agribusinesses to ramp up production

**FIGURE ES.1:** ENERGY INTENSIVE ACTIVITIES ACROSS AGRICULTURE VALUE CHAINS

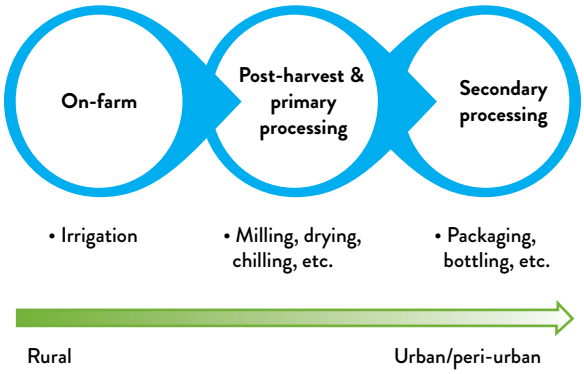
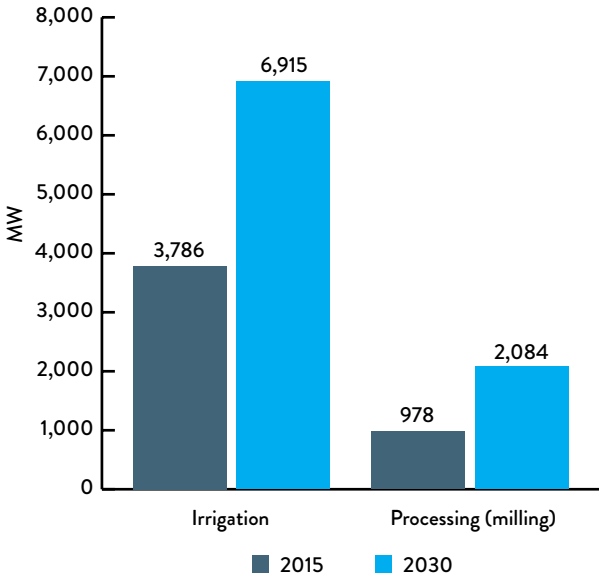



**FIGURE ES.2:** ESTIMATED POWER DEMAND FROM AGRICULTURE IN 2030




and develop agriculture value chains to enhance processing, logistics, market infrastructure, and retail networks.

**Electricity is an important enabler for the agriculture sector to realize its growth potential, especially for power intensive value chains.** The need for electricity is distributed across the life of the crop—from mechanized irrigation to processing for final consumption (figure ES.1). The power demand for irrigation primarily comes from (i) sourcing bulk water from a water body (e.g., a dam or river) and (ii) distributing it over the cultivated area. Bulk water pumping is typically the major source of demand and depends on the vertical and horizontal distances of the scheme from the water source. Demand from distribution systems varies by the types of irrigation system, which range in scale from manual to surface flooding and localized ones to center pivots. Post-harvest and primary processing (e.g., milling and drying) and secondary processing (e.g., packaging and bottling) represent a growth area. It is clear that milling is likely to increase significantly owing to the expected demand growth for such grains as maize, wheat, and rice. Similarly, such staples as cassava are expected to experience increased demand for processing due to their perishable nature and use as an industrial input in the manufacture of other products (e.g., glue in the case of cassava). Creating opportunities to piggyback viable rural electrification onto local agricultural development will depend on the scale and profitability of agricultural operations, crops, terrain, types of processing activity, and other site-specific local conditions.

**By 2030, the region's electricity demand from agriculture is estimated to double from its level today, to about 9 GW.** The estimated incremental demand between 2015 and 2030 is 4.2 GW (figure ES.2). Irrigation would provide about 75 percent of agriculture's demand, with the rest coming from agro-processing. The irrigation demand estimate assumes full exploitation of economically viable, potential areas for new or rehabilitated irrigation development, totaling nearly 6.8 million ha. This would be dominated by small-scale scheme development in the Gulf of Guinea and rehabilitation of existing schemes in the Sudano-Sahelian region. The agro-processing demand estimate is based on the electricity requirement for a typical processing activity (milling), and thus does not capture demand from the potential development of other processing activities or storage.

**For 13 major agriculture value chains, electricity demand could increase by 2 GW (from 3.9 GW in 2013 to 6 GW in 2030).** This represents nearly half of the 4.2 GW of potential increase in electricity demand from agriculture calculated for Sub-Saharan Africa. The 13 products are maize, rice, cassava, wheat, oilseed (soybean), horticulture (pineapple), sugarcane, oil palm, dairy, poultry, tea, floriculture (roses), and cotton (lint). These were selected on the basis of their nature and magnitude of power use for irrigation and processing, growth potential, and ability to serve as significant loads for electricity systems. Of the value chains studied, the per-hectare

electricity demand is largest for poultry, because the process is more intensive, using less land for a much larger yield. Other value chains with significant per-hectare demand are floriculture (roses), tea, and sugarcane. Together, maize, rice, and cassava add to about 83 percent of the total incremental demand in agriculture processing to 2030. For the 13 commodities analyzed, commercial-scale irrigated farming is the largest source of electricity demand. Commercial irrigated agriculture, which is highly mechanized, has the largest potential for developing large power loads across a range of farm sizes.

## WHAT ARE THE CASE STUDY LESSONS ON ECONOMIC AND FINANCIAL VIABILITY?

**This study analyzes eight case studies—six actual and two simulated—in five countries of Sub-Saharan Africa; these provide important lessons on the benefits and risks of large power loads, supply options, and viability.** In **Tanzania**, the first case study is the Sumbawanga Agriculture Cluster, a concept-stage project located in the country's Southern Agricultural Growth Corridor of Tanzania (SAGCOT). The second case in Tanzania is the successful Mwenga Mini-Hydro Mini-Grid Project, which supplies the Mufindi tea estate and surrounding households in the country's Southern Highlands. In **Zambia**, the first case is a grid extension to the ongoing Mkushi Farming Block Project, stretching over 176,000 ha of land in the country's Central Province. The second case study in Zambia is the Mwomboshi Irrigation Development and Support Project (IDSP), which is developing integrated irrigation agriculture based around a recently built water storage dam on the Mwomboshi River. In **Kenya**, the first case examines floriculture development by the Oserian Development Company Limited (ODCL), a pioneer in using heat from geothermal wells for internal power generation and consumption. The second case in Kenya focuses on the Kenya Tea Development Agency (KTDA) mini-hydro mini-grids. The two simulated case studies are in Ethiopia and Mali. The **Ethiopia** study centers on a sugar estate with self-generated power from bagasse and the opportunity of selling the power surplus to the main grid. The **Mali** study analyzes capacity expansion of an existing hybrid mini-grid (diesel-solar PV) to serve productive users (tables ES.1 and ES.2).

**Irrigation is typically the largest source of power demand, along with processing activities in specific instances.** Irrigation usually has a larger load requirement than agro-processing activities, especially in cases of supply to a given area (e.g., Tanzania's Mufindi Tea Estate). Irrigation development and electrification can significantly help increase the viability of rural electrification. Taken alone, the smaller loads of agro-processing activities (e.g., milling and extrusion) may not be sufficient to justify rural electrification investments, except when they provide a viable source of electricity generation (e.g., sugar) or have a large and consistent load requirement (e.g., tea). If the volumes of produce can benefit from powered irrigation, supplemented by economies of scale, the load from the production could be significantly larger.

**Irrigation and processing are often linked.** In many instances, increase in yields from irrigation is an important prerequisite for the development of large-scale processing activities (as seen in Zambia). This cause-and-effect relationship between irrigation and processing was also observed in the cluster concept (e.g., SAGCOT in Tanzania). Increase in the scale of processing activity could lead to a significant increase in the power demand.

**Successful integration of agriculture and power system development requires physical and market infrastructure, which facilitate market access for inputs and produce.** Viable rural electrification relies on a healthy and profitable agriculture sector. Better infrastructure and market access improve agriculture revenues, spurring further expansion in production and associated electricity demand. In Zambia, for example, the strategic location of the Mkushi farming block along a major international highway (T2 Highway and Tazara Railway, which connects Lusaka and the Copperbelt in Zambia to the port at Dar es Salaam) has improved its development viability. The location of the farming block allows access to markets for both inputs and produce. In Tanzania, the Sumbawanga agriculture cluster benefits from access to shared infrastructure and services, including market access. This helped increase the viability of the agriculture sector as a creditable customer for electricity suppliers.

**The seasonality of power demand from the agriculture sector can be a significant constraint**

**TABLE ES.1:** SUMMARY OF ONGOING OR PLANNED CASES OF POWER-AGRICULTURE INTEGRATION

| Project | Tanzania | Tanzania | Zambia | Zambia | Kenya | Kenya |
|---|---|---|---|---|---|---|
| Name | Sumbawanga Agriculture Cluster | Mwenga Mini-Hydro Mini-Grid | Mkushi Farming Block | Mwomboshi Irrigation Development and Support Project (IDSP) | Oserian Flowers and Geothermal Power | Tea Development Agency Holdings Mini-Hydro Mini-Grids |
| Overview | Expansion of electricity supply to support the development of an agriculture cluster and surrounding households through main power grid extension. | A 4 MW hydro mini-grid connected to the main grid. Main local anchor load is Mufindi Tea Estates and Coffee Limited; 1,300 households connected in surrounding communities. | Extending a transmission line into a farming area with significant agricultural potential. | Grid upgrade and grid extension to support irrigation development and household electrification. | Expansion of the estate's geothermal generation capacity and distribution network to power the farm's operations and distribution within the estate. | Development of hydropower plants powering tea factories and staff housing and selling surplus power to the grid. |
| Commodities | Maize, sunflower, finger millet, paddy, sorghum | Coffee, tea | Wheat, soybean, tobacco, soya, vegetables, coffee | Tobacco, wheat, poultry, maize, sunflower, horticulture (tomatoes, onions, bananas) | Floriculture | Tea |
| Financial Viability | The project is marginally financially unviable as a stand-alone project. | The financial viability of the project depends critically on the ability to sell excess power to the main grid. Despite financial viability, capital subsidies were provided to keep local electricity tariffs low. | From a purely financial point of view and as a stand-alone project, grid extension to Mkushi was profitable for the farmers but not for the utility; sharing of capital costs was however an appropriate and successful approach to project financing. | Positive financial NPV, estimated at US$1.1 million. | With a positive financial NPV, the planned expansion project of 0.4 MW and electrification of 2,000 households is financially viable. | Evaluation of a sample project, North Mathioya, shows that the project is financially viable, with a NPV of US$3.3 million; revenues accrue from the sale of power to the grid and cost savings by tea factories. |

| Project | Tanzania | Tanzania | Zambia | Zambia | Kenya | Kenya |
|---|---|---|---|---|---|---|
| Economic Viability | Economic benefits would be significant (US$134 million), justifying the project; they come mainly from households' cost savings, small-scale irrigation benefits, and margin uplift from market access. | Economic benefits are positive (US$9 million); they come from households' energy cost savings, reduced reliance on diesel backup for the tea estate, and job creation from newly electrified businesses. | Thanks to households' energy cost savings, increased yields from irrigation on small-scale farms, and job creation; the project's economic NPV was positive (US$46 million). | Positive economic NPV was estimated at US$2 million for the power line extension, mainly from greater irrigated tomato and maize production. | Positive economic benefits were estimated at US$2.5 million; the main economic benefit is based on increased household electrification and thus savings due to lower energy consumption costs (e.g., less use of kerosene and no more payment for cell phone charging services and disposable batteries). | The same project is evaluated as economically viable, with a NPV of US$10 million; direct and indirect rural electrification impacts include electrification of staff housing, reduced connection costs for surrounding households, and development of stand-alone home systems. About 30,000 households will benefit from electricity connections. |

**to viability.** Large seasonal differences in electricity dependent agricultural activities will impact the cost recovery of electricity supply investments. In such cases, it is important to consider ways to mitigate the impact of a variable load. One option, especially in the case of mini-grid or captive generation, is the ability to sell excess power to the grid (e.g., Mwenga mini-hydro in Tanzania and KTDA mini-hydro development in Kenya).[3] During the post-harvest season, an increase in the post-harvest processing activity may complement electricity demand from irrigation. In addition, irrigation itself may reduce seasonality in agricultural production and thus electricity demand by allowing for multi-cropping (e.g., Mkushi in Zambia).

**When considering agricultural anchor loads, it is more risky for the investment to depend on a single large customer since any negative shock to the customer would negatively affect operating revenues of the electricity supplier.** As such, agricultural clusters (e.g., Sumbawanga in Tanzania) can increase the viability of rural electrification. Cluster development has load diversity by design and thus is less risky than relying on a single anchor load. If there is a private electricity supplier and private off-takers, any such risk will be priced into the supply contract, thus increasing the price of electricity for all customers. In such cases, diversified cluster development can also help reduce the price of electricity. In some such instances, the public sector can also help mitigate this risk through a grid connection and a feed-in tariff (FiT), subsidies to increase the customer base, or guarantee/insurance instruments.

**Large-scale development of irrigation-based agriculture and sugar estates with excess generation can justify a main grid connection on a purely financial basis.** Requirements for this—not all of which are readily available in Sub-Saharan Africa—include relatively clear and empty land with good quality soils, a reliable

**TABLE ES.2:** SUMMARY OF SIMULATED CASES OF POWER-AGRICULTURE INTEGRATION

| Project | Ethiopia: Power Generation from Sugar Estates | Mali: Mini-Grid Expansion for Productive Uses |
|---|---|---|
| Overview | Self-generation of power from bagasse and sale of power surplus to the main grid. | Capacity expansion of an existing hybrid mini-grid (diesel-solar PV) to serve productive users. |
| Commodity | Sugar | Agro-industrial activities |
| Financial Viability | From the utility's perspective, extending the grid to the sugar estate is not financially viable since the net present value (NPV) is negative—because it does not benefit from sales to the estate, which self-supplies; however, from the standpoint of the sugar estate, it is highly profitable (US$139 million). | From the perspective of Yeelen Kura, the current financial situation of the Koury mini-grid is fragile; however, the capacity expansion project is profitable thanks to a higher payment rate, additional revenues, and proportionally low capital expenditure and operating expense (NPV of €103,000). |
| Economic Viability | The economic NPV for the whole period is positive (US$367 million), thus justifying project development. | The economic NPV for the expansion project is slightly negative (−€18,000) as no significant savings are expected from agro-industrial customers (currently using individual diesel generators); however, it could become economically viable if other economic, environmental, and social benefits are considered (e.g., reduction in $CO_2$ emissions, reduced reliance on imported fuels, and reduced exposure to price fluctuations). |

supply of sufficient water, and high quality physical and market infrastructure. Suitable commodities include those typically cultivated on large-scale farms: maize, wheat, sugar, rice, soybeans, and barley.

**The main grid has certain fundamental advantages that may make it the most viable option, even in cases where it is located at a distance.** The multiple generation sources connected to the main grid help mitigate the risk of power failure and enable the utility to minimize costs by balancing supply profiles to match demand. In contrast, a smaller isolated system based on a single generation source may not be amenable to different load profiles and is at a greater risk of failure due to shutdowns of the sole generation facility. In addition, due to economies of scale in generation and the ability to spread fixed costs over a wider set of consumers, electricity from the main grid tends to be cheaper than that from a smaller system. At the same time, the size of electricity load required to ensure viability of grid extension increases with the capital costs incurred for the extension, which, in turn, is related to distance. The Sumbawanga cluster (Tanzania) and the Mkushi farming block (Zambia) cases show that grid extension is the more viable option.

**Despite the advantages of the main grid, mini-grids may still offer the least cost solution to reach unserved consumers, overcome grid unreliability, and leverage private-sector funds to accelerate rural electrification.** Case studies in mini-hydro mini-grids developed under the Mwenga (Tanzania) and KTDA (Kenya) projects show how unreliable grid supplies have led to the development of alternative generation sources. However, the more typical case is establishing mini-grids in greenfield areas and access-deficit countries setting up policies and regulations to create a level playing field and mitigate uncertainties for private-sector, mini-grid operators. The two main concerns are (i) the ability to be financially sound, either through charging cost recovery tariffs or receiving government subsidies and (ii) having regulations that specify what happens when the large grid reaches the mini-grid areas.

**A number of options exist to make projects financially viable.** First, to benefit from economies of scale, the local generation capacity can be increased beyond the level of local demand, and surplus power can be sold to the grid. This option is particularly relevant in countries that have introduced FiT programs set above the utility's avoided costs. Selling excess power makes it possible to lower the per megawatt cost, but relies on the ability to sell excess generated power. For example, the capacity of Tanzania's Mwenga mini-hydro mini-grid is greater than what the tea estate requires; therefore, the surplus is sold to the utility and nearby rural customers. Another option, as is done for the main grid extension projects in Zambia (i.e., Mkushi and Mwomboshi), is to require beneficiaries to partially finance projects and share the development costs with major customers. Farmers partially contribute to capital costs in exchange for receiving power. A further option is load balancing across beneficiary categories, which enables the spread of fixed costs, especially capital costs, across a larger pool of customers with diverse peak-load profiles.

**The role of subsidies to cover some costs should be highlighted.** All of the distributed schemes have received subsidy payments to decrease the level of cost recovery through retail tariffs. This contributes toward ensuring maximum capacity development, increasing the project's net present value (NPV), improving tariff affordability for customers, and attracting private-sector participation. Subsidies are particularly necessary for most privately developed, small-scale projects under 5 MW. By subsidizing household connections, which also tend to be financially unviable, developers can be encouraged to expand their customer base to capture additional subsidies, prioritizing smaller customers close to each other rather than larger ones.

**National policy targets based on economic net benefits, rather than financial viability, drive investments in rural electrification.** For all the cases studied, the estimated economic viability was high. Power for agricultural use enables the development of previously unviable activities, which increases yields and lowers production costs. The benefits to households and businesses include savings on energy expenditures, better health, and improved educational outcomes. Wider benefits accrue from higher incomes and improved quality of life. However, subsidies are needed to make the schemes financially viable. All of the distributed schemes analyzed received subsidies to bridge the gap between actual retail tariffs and the levels required for full cost recovery.

## HOW CAN COMPLEMENTARITIES IN POWER AND AGRICULTURE BE HARNESSED?

**To realize the full potential of agriculture-power integration in Sub-Saharan Africa, the region's policy makers and power companies must think about demand creation.** Governments should coordinate strategies in the power sector with complementary strategies on rural development and agricultural extension. The experience of agriculture corridors, clusters, and growth poles should be analyzed and applied on a wider scale. In addition, power companies should coordinate with other related agencies and institutions to maximize complementarities. Electricity can be prioritized in areas with large irrigation potential, combined with access to markets for agricultural goods. The sale of agricultural machinery, including irrigation pumps and small threshers, can be promoted as part of a package to encourage electricity use in agriculture. In the process of developing expansion plans, power companies should account for the electricity needs of, and benefits to, both smallholder and commercial scale farmers.

**Leveraging complementarities in rural development across sectors would likely result in higher revenues for the utility companies and deliver greater economic benefits to rural areas.** While power companies can prioritize regions with existing or potentially high levels of agricultural production, rural development or agricultural agencies can target areas that are able to take advantage of the many productive use benefits of electricity. The utilities can create internal units responsible for encouraging the productive and efficient use of electricity. Productive use units can be responsible for promoting electric machinery in agriculture, from irrigation to harvest and post-harvest. Banks and other financial institutions should be incentivized to set up credit lines for farmers and agricultural entrepreneurs to purchase agricultural machinery. Given the high expense of using diesel powered engines for grain processing, campaigns by local government could be developed to promote electricity as a substitute for diesel engines among farmers in areas just gaining access to electricity.

**Coordinated planning encompassing geospatial efforts and multi-agency inputs is necessary.** A geospatial map with information about future developments of the national grid, as well as layered data on agriculture and other rural infrastructure, is important to understand where the load clusters are. These are the areas where feasibility studies of mini-grid developments could be carried out for potential future tendering. Clarity in site identification and the regulatory environment is also useful for mini-grid developers and concessioners to allay fears on what happens when the grid arrives. Such integrated maps, possibly housed in a national institution, can also support more transparent decision making on infrastructure expansion and integrated rural development approaches.

**Policy makers can support a stable regulatory environment for electricity suppliers.** To succeed, projects must be implemented within a stable legal environment that imposes requirements and provides protection. Light-handed regulation of small-scale electricity systems is generally more favorable to developers and operators. For example, Tanzania's small power producer (SPP) framework allows private operators to function as power distributors and retailers, charging fully cost-reflective tariffs. This type of regulation should tackle the economic barriers of unaffordability and uneconomic supply. Regulation must also extend beyond the power sector to tackle interactions with related sectors. Tanzania's Mwenga Mini-Hydro Mini-Grid Project, one of the first projects of its kind, encountered significant delays when negotiating regulations over water rights, land access, import laws, and building permits. Also, information about future developments of the national grid and concession protection is crucial for dispelling developers' reluctance and avoiding potential friction from tariff differences between customers.

**Supporting the financial health of key sector institutions, central to the World Bank policy dialogue in the electricity sector, is important for this agenda as well.** The weak financial status of the utilities prevents them from being able to develop financially viable projects without external support. Furthermore, their constrained cash flows increase the risk of non-payment for the power supplied by private developers, which negatively impacts project costs and tariffs and, as a result, power affordability. If FiTs are not capped at the utility's avoided costs, this situation could worsen, further deteriorating the utility's viability. From the perspective of power sector regulators, the extra cost and delays resulting from inexperience in negotiating various supply arrangements may be a hindrance to developing private-sector power generation, distribution, and supply.

**Finally, rapid changes over the last few years in small-scale generation and distribution technology, especially solar PV, have created opportunities to test new models for viable rural electrification and power-agriculture integration.** Recent technological advancements and reduction in small-scale generation costs have led to heightened interest in viable isolated mini-grid development models, such as those based on shared solar PV systems and DC distribution lines. Compatible product development (e.g., TVs, refrigerators, solar pumps, and grain mills) is enabling increased productive use of electricity and increased aggregate electricity demand from such mini-grids to further improve their viability. While there is limited experience of such mini-grids in operation (which thus explains why they are not reflected in our findings), this is a dynamic space with tremendous current interest and significant future potential to spur greater opportunities for power-agriculture integration.

## ENDNOTES

1. Authors' calculation from the World Development Indicators (WDI) database.

2. Korwama (2011) estimates that 30 percent of agricultural produce in Sub-Saharan Africa is processed, compared to nearly 98 percent in some developed countries.

3. Apart from the mitigating impact of seasonal variation, the ability to sell excess power to the grid also helps to invest in large generation capacity and reduce costs due to economies of scale in generation.

# Agriculture and Power Nexus

## CHAPTER 1

Agriculture predominates the livelihoods of the rural poor in Sub-Saharan Africa; thus, higher growth in the agriculture sector, especially through increased productivity, is instrumental in reducing the incidence of extreme poverty in the region. Diao et al. (2012) estimate that the decline in national poverty rates is up to four times higher for agriculture-led growth, compared to growth led by nonagricultural sectors (e.g., 4.3 times higher for Kenya, 3.1 for Rwanda, 1.6 for Nigeria, and 1.3 for Ethiopia). Similarly, ongoing research using the Global Trade Analysis Project (GTAP) model of world trade finds that productivity growth in agriculture, compared to growth in other sectors, is nearly three times as effective in reducing poverty.

Agriculture and agribusiness comprise most income generating activities in Sub-Saharan Africa's largely rural economies (box 1.1), together accounting for nearly half of its gross domestic product (GDP) (figure 1.1). Agricultural production is the most important sector, averaging 24 percent of the region's GDP. Agribusiness input supply, processing, marketing, and retailing contribute another 20 percent (World Bank 2013). Thus, transformation of the agriculture sector through improved productivity and incomes can simultaneously help achieve both robust economic growth and poverty reduction. In other developing regions, agricultural transformation has resulted in declining numbers of the poor. Thus, for Sub-Saharan Africa, where poverty rates have remained stubbornly high, utilizing agricultural transformation to tackle poverty in rural areas—where more than 70 percent of the region's poor live—is a critical part of any poverty reduction strategy.

For both agricultural and nonagricultural households, electricity is needed to raise living standards,[1] as well as enable broader economic development. Lack of access to reliable and affordable electricity in Sub-Saharan Africa constrains development of on-farm and off-farm economic activities, as it does for other manufacturing and services firms. Rural electrification can raise productivity and income when farmers switch from manual to electricity powered inputs and small industries begin using electric tools and machinery. Access to reliable electricity supply can increase productivity along the agriculture value chains and enable increased production and income generation for the farm sector and the rural economy as a whole.

### BOX 1.1: TERMINOLOGY CLARIFICATION: AGRICULTURE AND AGRIBUSINESS

**Agriculture** refers to on-farm production. It includes crops and livestock but not floriculture, fisheries, or forestry. Although much agriculture in Africa is oriented to sustaining livelihoods, this study focuses on commercial farming, recognizing that commercial farmers in Sub-Saharan Africa are overwhelmingly small and medium in scale.

**Agribusiness** denotes organized firms—from small- and medium-sized enterprises to multinational corporations—involved in input supply or downstream transformation. It includes commercial agriculture involving some transformation activities (even if they are basic). It includes smallholders and microenterprises in food processing and retail to the extent that they are market oriented. Indeed, these producers and enterprises comprise the bulk of agribusiness activity in Africa today.

*Source:* World Bank 2013.

The United Nations Sustainable Development Goals (SDGs), adopted in September 2015, set a target for universal access to affordable, reliable, and modern energy services by 2030 (SDG 7). The acknowledgment of modern energy access as a development goal builds on the momentum created by the Sustainable Energy for All (SE4ALL) initiative, which has galvanized the international community into action to achieve concrete energy related targets.[2] Under SE4ALL, the three goals to be achieved by 2030 are: (i) universal access to modern energy services, (ii) doubling the share of renewables in the global energy mix, and (iii) doubling the growth rate of energy efficiency.

## HIGH POTENTIAL FOR AGRICULTURAL TRANSFORMATION

Historically, agriculture in Sub-Saharan Africa has underperformed despite the region's comparative advantage stemming from abundant land and water resources. However, recent developments have created more favorable conditions for an agricultural transformation. Today there is an expectation that well-informed policies and investments can put agriculture on a higher growth path to achieve its vast potential and raise rural welfare.

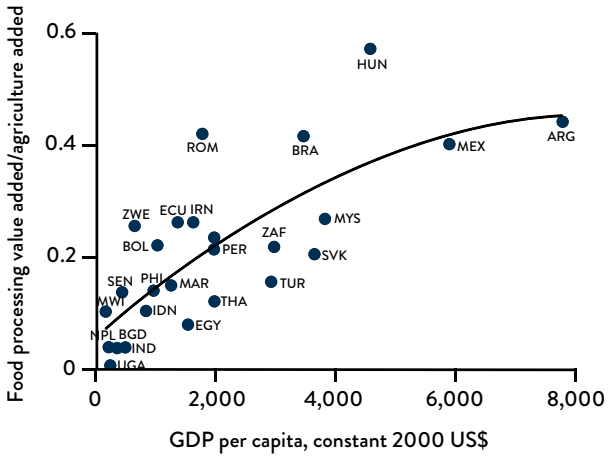
### *PAST PERFORMANCE: A MISSED OPPORTUNITY*

Agricultural growth has typically lagged behind that of other sectors in Sub-Saharan Africa. Vulnerability to weather shocks, limited use of modern tools and inputs, low levels of processing, poor development of rural financial markets, and market access barriers have all hindered agricultural growth and kept agricultural productivity and incomes low. Between 2000 and 2013, the share of agriculture in GDP declined by 6 percentage points (from 20 percent to 14 percent).[3]

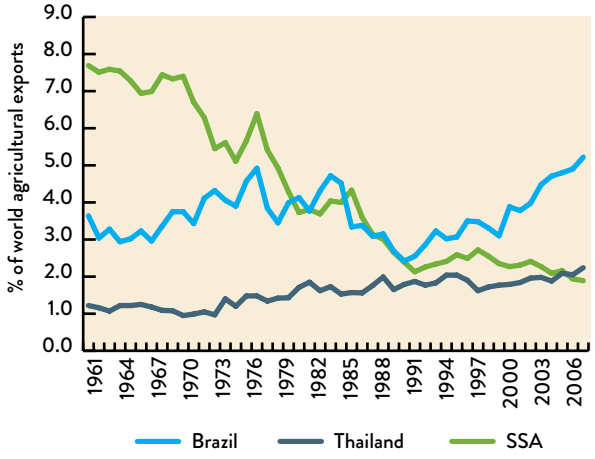
Only a small percentage of the region's agricultural production undergoes industrial processing.[4] For the world's high-income countries, processing adds about US$180 of value per ton of agricultural produce, compared to only $40 for Sub-Saharan Africa. This is related to the small size of the agribusiness sector compared to on-farm agriculture in Sub-Saharan Africa relative to other regions. For developing countries, including those in Sub-Saharan Africa, the ratio of value added in agribusiness to that of farming is typically 0.6. This ratio increases to 2.0 for transforming countries (mainly in Asia), 3.3 for urbanized countries (mostly in Latin America), and 13.0 for the United States, indicating significantly more value created in the downstream agribusiness sector than on-farm production for countries outside Africa. These comparisons reflect the positive correlation between the relative importance of agribusiness and economic growth: both per capita GDP growth (figure 1.1a) and human development indices (da Silva et al. 2009).

**FIGURE 1.1:** HISTORICAL PERFORMANCE IN AGRICULTURE

a. Ratio of food processing to agricultural value added




b. Market share of global exports




*Sources:* World Bank 2008, 2013.

*Note:* In figure 1.1a, three-letter codes represent the following countries: ARG = Argentina, BGD = Bangladesh, BOL = Bolivia, BRA = Brazil, ECU = Ecuador, EGY = Egypt, HUN = Hungary, IDN = Indonesia, IND = India, IRN = Iran, MAR = Morocco, MEX = Mexico, MWI = Malawi, MYS = Malaysia, NPL = Nepal, PER = Peru, PHI = Philippines, ROM = Romania, SEN = Senegal, SVK = Slovak Republic, THA = Thailand, TUR = Turkey, UGA = Uganda, ZAF = South Africa, ZWE = Zimbabwe.

For more than four decades, Sub-Saharan Africa's share in global agricultural export markets has been on the decline. By the early 1990s, the region's share had fallen to about 2 percent, 5–6 percentage points lower than in the 1960s. Meanwhile, other important agricultural exporters, including Brazil and Thailand, have seized market share despite having a tiny fraction of Africa's land area, especially in the case of Thailand (figure 1.1b).

African imports of agricultural products have skyrocketed due to the gap between regional demand and supply. From the 1990s to the 2000s, the balance of trade in food staples for Europe and Central Asia, South Asia, and East Asia and the Pacific moved from deficit (i.e., imports exceeding exports) to surplus; however, for Sub-Saharan Africa, this gap greatly expanded. While food trade deficits are expected in regions without a comparative advantage in food production, such as the Middle East and North Africa, they are symptomatic of a missed opportunity in Sub-Saharan Africa, which is endowed with abundant natural resources for efficient production.

### *INVESTMENT FUNDING CHALLENGES*

Investment funding for the agriculture sector, especially primary production, is limited by perceived high risks and low returns. Poor infrastructure on farms and along the supply chains, low access to credit and product markets, and other regulatory hurdles have kept returns from agricultural investments in Sub-Saharan Africa below potential. Over the past decade, the increased inflows of commercial finance, especially foreign direct investment (FDI), have been vastly inadequate. Official development assistance (ODA) has helped, in part, to fill the gap. In 2003–12, ODA for agricultural projects in Sub-Saharan Africa rose 121 percent (from US$1.1 billion to $2.5 billion). Over the same period, the share of aid allocated to the agriculture sector in Sub-Saharan Africa grew from 37.4 percent to 40.3 percent, the highest share increase for the period (Development Initiatives 2015).

The high costs of connecting agricultural land to backbone infrastructure in Sub-Saharan Africa cannot be easily absorbed by most medium-sized farming businesses, let alone small-scale farms. But without these "last-mile" infrastructure investments, the region's farmers cannot increase their productivity. Furthermore, without access to concessional funding, the establishment costs of an outgrower program, especially those involving provision of infrastructure services to small-scale farmer organizations, can be prohibitive, explaining why so few of the nucleus farm and outgrower models have been successfully established.

### *AN IMPROVING OUTLOOK*

The high yield gap between Sub-Saharan Africa and other regions underscores the large potential for Africa to catch up with the productivity frontier (World Bank 2013). The increasing prominence of the agriculture sector among policy makers, the private sector, and the development community has been driven, in part, by the recognition of decades of prior neglect of the sector by governments and donors, as well as the urgent need to mobilize small-scale farmers to increase food production in order to avoid food security challenges in the near term.

Over the past decade, African governments have demonstrated a renewed and growing commitment toward agriculture. The improving policy environment, led by the Comprehensive Africa Agriculture Development Programme (CAADP) (box 1.2), high investor interest, and technological advances that ease implementation of necessary reforms, particularly in land administration, have created excellent conditions for an agricultural transformation.[5]

The outlook for agricultural development in Sub-Saharan Africa is improving.[6] Economic growth and urbanization have fueled an increase in food demand in Sub-Saharan Africa. In addition, continued improvements in infrastructure and the benefits of lower oil prices have resulted in increased domestic food production. Although recent declines in agricultural prices may dampen price incentives for agriculturalists, they may further increase food demand and thus induce farmers to grow food and other agricultural commodities for the market.

## MAJOR APPROACHES TO AGRICULTURAL DEVELOPMENT

There are two major approaches to agricultural development in Sub-Saharan Africa. The first is a cluster approach, which focuses on particular areas with a high level of infrastructure access and development potential. This generally involves support for large farms and commercialized agriculture as growth poles. The second approach is smallholder agriculture, which centers on support for smallholder farmers to increase their productivity and access to markets. These two approaches differ in their implications for electricity supply in rural areas.

### *CLUSTER APPROACH*

Over the last 20 years, one rural development trend in multiple countries across Africa has focused on integrated

### BOX 1.2: AFRICA'S VISION FOR AGRICULTURE: CAADP GOALS

The Comprehensive Africa Agriculture Development Programme (CAADP), initiated in 2003, strives to improve country frameworks to support agricultural development. The CAADP's initial 2015 target, extended through 2025, envisions that the continent should achieve the following goals:

- Attain food security in terms of both availability and affordability and ensure access of the poor to adequate food and nutrition;
- Improve the productivity of agriculture to attain an average annual growth rate of 6 percent, with particular attention to small-scale farmers, especially focusing on women;
- Have dynamic agricultural markets among nations and between regions;
- Integrate farmers into the market economy, including better access to markets, with Africa to become a net exporter of agricultural products;
- Attain more equitable wealth distribution;
- Become a strategic player in agricultural science and technology development; and
- Practice environmentally sound production methods, featuring a culture of sustainable management of the natural resource base (including biological resources for food and agriculture) to avoid their degradation.

*Source:* CAADP 2012.

infrastructure and social development for specific areas. This cluster or corridor development approach has significant implications not only for the development of agriculture, but also for how electrification and other types of institutions develop plans to serve such areas (annex A).

Clusters are geographic concentrations of interconnected companies, including intermediate goods suppliers, service and infrastructure providers, and associated institutions in a particular product space or sector. Clusters benefit from geographical agglomeration economies that may result from the proximity between intermediate and final goods suppliers, labor market pooling, and knowledge spillovers (Marshall 1890; Krugman 1991). Despite falling transportation and communication costs, clusters continue to be relevant today due to the underlying benefits of increased firm productivity, innovation, and formation of new businesses (Porter 1990). Transportation growth corridors, a closely related concept, places the significant economies of scale of infrastructure development at the center of the benefits from spatial agglomeration.

In the case of agriculture, clusters can affect development in several ways. Improved access to infrastructure can lead to increased productivity of farms and companies within a concentrated economic area. As opposed to remote rural areas, these clusters of economic activity benefit from joint access to necessary infrastructure services, linkages to upstream and downstream activities, and connectivity to markets. Better connectivity to markets and access to infrastructure, including electricity, are likely to induce agricultural intensification. Both large-scale and smallholder agriculture will benefit from increased productivity induced by spillovers, greater connectivity, and reduced transaction costs. The ability to serve wider markets for their goods and services will create greater incentives to innovate.

The cluster approach brings together agricultural research stations, nucleus large farms and ranches, commercially focused farmer associations, irrigated block farming operations, processing and storage facilities, transport and logistics hubs, and improved "last-mile" infrastructure to farms and local communities. When occurring in the same geographical area, these investments result in strong synergies for agricultural growth, helping create the conditions for a competitive and low-cost industry.

The essential elements of a cluster approach include the following:

- Having a long-term strategy for agricultural development, recognizing that transformation occurs over an extended period (e.g., 10–20 years);
- Understanding and leveraging vertical and horizontal linkages between farms and other businesses to maximize value addition;
- Commissioning robust analysis of the constraints on commercial agriculture and recommending how these can be addressed;
- Establishing an independent public-private partnership organization to help coordinate and target

agricultural development programs and public investments; and

- Leveraging government and development partner resources to catalyze socially and environmentally optimal private investment.

Electricity is one of the fundamental requirements for cluster or corridor development. Investments in electricity infrastructure must adequately account for long-term demand growth due to increased demand from large farmers, small farmers, farm service businesses, and other tertiary development in such growth areas. Accounting for medium- to long-term demand growth will allow benefits to accrue from economies of scale and thus can lower costs to end consumers.

### *SMALLHOLDER AGRICULTURE*

Most agriculture in Sub-Saharan Africa today involves smallholder farms, usually characterized by landholdings of less than 2 ha, with a subsistence orientation. While the large farm, agribusiness model has an important role to play in promoting agricultural growth in Africa, smallholder agriculture is key to revitalizing the rural economy and tackling poverty.

The question is what role should smallholder or family farms play, in contrast with large farms, in striving for productivity transformation in Sub-Saharan Africa. In agricultural economies, which describes most of Sub-Saharan Africa, smallholder agriculture comprises the majority of employment and production. With rising demand for staple food crops and high-value commodities resulting from rapid urbanization in the region, an increase in smallholder productivity can arise from easing constraints on access to credit, infrastructure, and markets. Targeting the development of smallholder agriculture is also an effective way to reduce rural poverty. Thus, smallholders in Sub-Saharan Africa have a critical role to play as a source of agriculture competitiveness. The World Bank (2009) finds that "contrary to expectations, few obvious scale economies were found in the production systems analyzed for the CCAA study. Compared with those of large commercial farms, family farms and emerging commercial farms were typically found to have lower shipment values at the farm level and/or final distribution point (shipment values reflect production and delivery costs). Large commercial farms can play an important strategic role by contributing to the achievement of the critical mass of product needed to attract local and international buyers, but the value chain analysis shows that investments in smallholder agriculture can be an important source of competitiveness in their own right. An additional benefit of smallholder led agricultural growth is the much higher level of second-round demand effects that occur when income gains are realized by smallholder households, as opposed to large commercial farms."

Hazel et al. (2007) make the case for development of the smallholder sector, pinpointing the importance of infrastructure development to support it. "The case for smallholder development as one of the main ways to reduce poverty remains compelling. The policy agenda, however, has changed. The challenge is to improve the workings of markets for outputs, inputs, and financial services to overcome market failures." The point is that numerous factors can support smallholder agriculture, including the coordinated efforts of farms, the private sector, nongovernmental organizations (NGOs), and government. Support can take the form of agricultural research, agricultural extension, and infrastructure development (e.g., roads and provision of electricity).

Given the "competing barriers" to agricultural development, the provision of electricity infrastructure, by itself, is unlikely to make an appreciable difference. Electricity investments must be coordinated with interventions targeting agricultural development (e.g., improving agricultural inputs and technology adoption; agricultural extension services; research on smallholder farming practices; and other infrastructure, including roads, markets, and water supply). The combination of these inputs will increase the growth of agricultural production and have a multiplier impact on the rural economy.

In short, it is not the role of electricity institutions to promote agriculture; rather, their role is to support agriculture in conjunction with other programs. This may seem a daunting task from a policy perspective, given that, in most governments, electricity, agriculture, rural development, and water institutions reside in isolated "silos." However, in countries with successful rural electrification programs, electricity companies have often found ways to deal with such silos, mainly through outreach and coordination (Barnes 2007). For example, in Tunisia, the main electricity company (STEG) had regular meetings with rural development agencies and coordinated expansion plans to provide electricity in communities that were receiving other development inputs.

Coordinated planning of rural electrification would require a change in the way the electricity companies operate, taking into account expected growth in energy-intensive agricultural activities and development

programs in the pipeline. To do this, electricity companies need to develop an effective information sharing mechanism with relevant agriculture sector stakeholders. This could involve reaching out to relevant agricultural agencies; promoting productive uses of electricity; and understanding future growth and development trends, especially with regard to smallholder agriculture. Electricity access for agriculture and rural businesses could effectively be promoted as part of an overall strategy to support small farmers through a variety of activities (e.g., development of farm cooperatives to purchase and market local farm goods; machine rental; and agricultural extension, including advice on irrigation practices, seeds, and fertilizers).

## AGRICULTURAL GROWTH TO RAISE RURAL WELFARE: REASONS FOR OPTIMISM

There are four main reasons to believe that agriculture in Sub-Saharan Africa is poised for growth that can contribute significantly to raising rural welfare. First, relative to much of the rest of the world, the region's land and water—the major natural inputs necessary for growing crops and raising livestock—are underutilized, creating a huge potential for agricultural growth (figure 1.2). Of the world's total land area suitable for sustainable production expansion—that is, non-protected, non-forested land with low population density—Sub-Saharan Africa has the largest share by far, accounting for about 45 percent.[7] In the case of Latin America, which accounts for only 28 percent of land suited for production, 73 percent of that amount is located within six hours' travel time to the nearest market, compared to just 47 percent in Sub-Saharan Africa—a result of the subcontinent's generally poor state of infrastructure (Sebastian 2014). Sub-Saharan Africa also has significant untapped water resources. Only 2–3 percent of the region's renewable water resources are being utilized, compared to 5 percent worldwide (World Bank 2013). Its irrigation intensity, one of the lowest in the world, represents only 5 percent of total cultivated area, compared to 37 percent for South Asia and 14 percent in Latin America (World Bank 2008). Despite an absolute abundance of water resources, lack of irrigation development and storage capacity has limited the availability of water in certain basins, resulting in water stress. Also, the uncertainties related to climate change raise concerns about future water availability (box 1.3).

Second, despite Africa's overall decline in the share of agricultural exports, a recent disaggregated view tells a more nuanced story. Since the early 1990s, Africa has held its own for some cash crops (e.g., cocoa, rubber, fruits and vegetables, and tobacco) and has even gained market share for others (e.g., cashew, tea, and sesame seed), showing some evidence of its productive potential.

Third, Sub-Saharan Africa is poised for demographic transition and wealth creation, reflecting the growing aspirations of its people. According to the United Nations, between 2013 and 2050, the region's population will more than double, from about 900 million to 2.1 billion (United Nations 2013). While one-third of its population is already living in urban areas, this proportion should increase to 50 percent by 2035. Globally, urban food markets are set to increase fourfold, exceeding US$400 billion by 2030 (World Bank 2013). For Africa's 11 biggest economies, the middle class, defined as those earning at least US$450 per month, tripled between 2000 and 2014 (from fewer than 5 million people to 15 million). Over the next 15 years, these numbers may rise by a further 25 million (Standard Bank Research 2014).

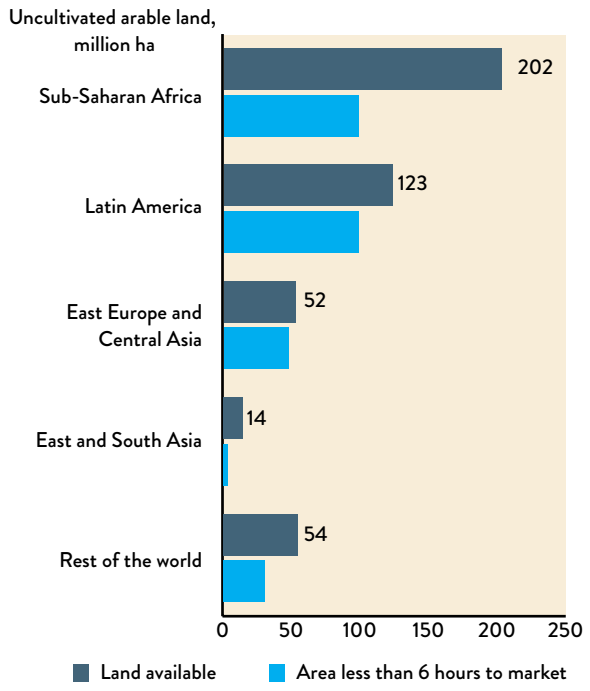
Sub-Saharan Africa's rapid population growth, accompanied by robust economic growth, is creating a huge regional urban market for agricultural goods. A recent World Bank study on agribusiness predicts that the market for agricultural goods and commodities could reach US$1 trillion by 2030 (figure 1.3). It states that "the majority of the increase in food consumption will occur in cities. Based on the United Nations' projections of urbanization and assuming that the per capita value of food consumption is 25 percent higher in urban areas than rural areas, the urban market is set to expand fourfold in 20 years" (World Bank 2013). This expansion in regional demand will create an enormous opportunity for African agriculture and agribusiness.

Fourth, agriculture is critical for managing the urban transition that Africa will undergo. To date, this process has been driven to a large extent by populations being pushed out of rural areas, rather than cities attracting a workforce by acting as growth poles. It would be a more positive process were it driven by improving economic opportunities in the cities that would gradually pull in rural residents, rather than declining conditions and periodic disasters in rural areas that push residents out. The latter situation often leads to conflict and waves of migration that cities find difficult to absorb, typically leading to expanded slums. The objective of a transition strategy—of which electrification is a key element—is thus to enhance living conditions and economic opportunities in rural areas.

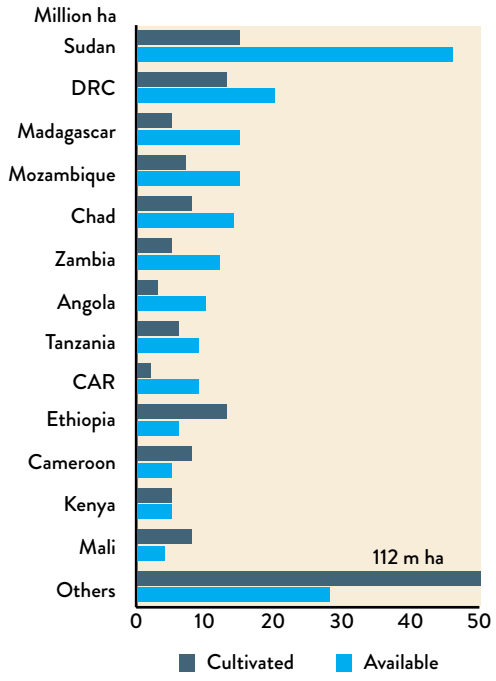
In this context, agriculture and agribusiness can play a critical role in jump-starting the economic transformation through development of agro-based industries in

**FIGURE 1.2:** LAND AND WATER RESOURCES POTENTIAL IN SUB-SAHARAN AFRICA

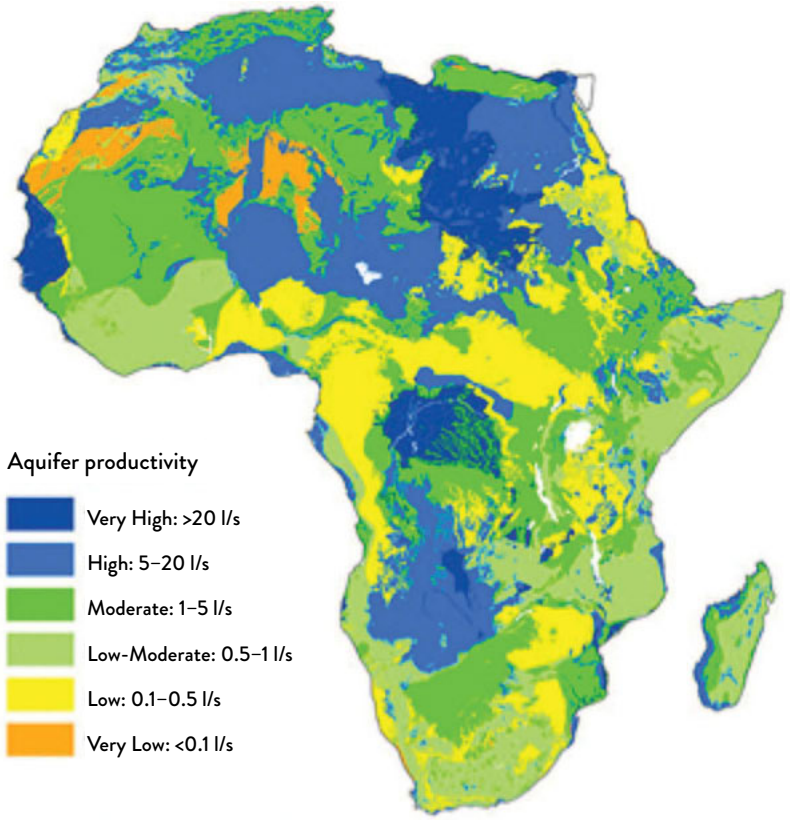
a. Land potential, by world region




b. African countries with largest available land resources




c. Aquifer productivity in Africa



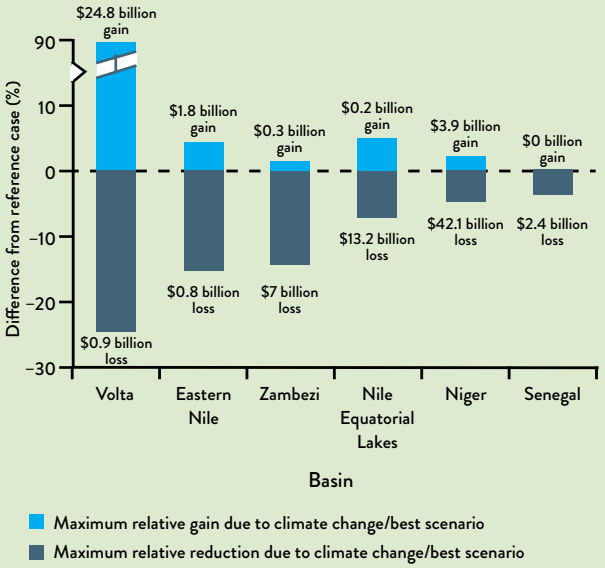

*Sources:* World Bank and Schaffnit-Chatterjee 2014 (figure 1.2 a, b); British Geological Survey (figure 1.2c) (http:// www.bgs.ac.uk/research/groundwater/international/africanGroundwater/maps.html).

## BOX 1.3: MAKING AFRICA'S POWER AND WATER INFRASTRUCTURE CLIMATE RESILIENT

Uncertainty over water availability for productive uses is a critical issue facing Sub-Saharan Africa's infrastructure investments, especially long-lived infrastructure (e.g., irrigation schemes, dams, and power stations). Variations in annual rainfall and monthly rainfall distribution, along with temperature changes due to drier or wetter climates, could put power and water infrastructure at risk, affecting operation and cost over their life span. Beyond impacting the technical performance of infrastructure, uncertainty about drier or wetter futures could significantly modify its financial viability, incurring losses or gains. In a drier scenario, for example, shortfalls in irrigated production could raise demand for food imports, and thus increase food prices (figure B1.3.1).

Cervigni et al. (2015) highlight significant disparities across Africa's seven main river basins: Congo, Niger, Nile, Orange, Senegal, Volta, and Zambezi. The study estimates that, in dry scenarios, loss in irrigation revenue could range between 5 and 20 percent for most basins. For wet estimates, revenue gains could reach 90 percent for the Volta basin, but would be vastly less (1–4 percent) for the other areas. Under the driest scenarios, unmet irrigation demand could drop by more than 25 percent in the Zambezi basin. The magnitude of impact will depend on the willingness and ability of decision makers to integrate climate projections and their uncertainty into the planning and design of power and water infrastructure.

**FIGURE B1.3.1:** CHANGES IN IRRIGATION REVENUES FROM CLIMATE CHANGE, 2015–50 (PRESENT VALUE)

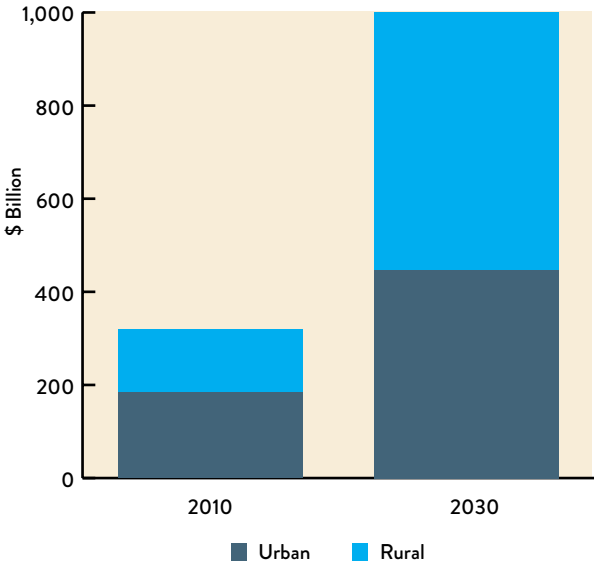



*Note:* The bars reflect, for each basin, the range of economic outcomes across all climate futures; that is, the highest increase (light blue bars) and highest decrease (dark blue bars) of irrigation revenues (discounted at 3 percent), relative to the no-climate-change reference case. The outlier bar corresponding to the Volta basin has been trimmed to avoid distorting the scale of the chart and skewing the values for the other basins. Estimates reflect the range, but not the distribution, of economic outcomes across all climate futures. Each basin's results reflect the best and worst scenarios for that basin alone, rather than the best and worst scenarios across all basins. The Congo and Orange basins are excluded because the effects on irrigation are minimal.

Africa's need to tap its irrigation potential represents a window of opportunity to make power and water infrastructure climate resilient. Although such a paradigm shift will take time, practical steps to integrate climate resilience can be undertaken now. For example, Cervigni et al. (2015) recommend defining and promoting technical standards for integrating climate change into project planning and design and launching training programs targeting relevant stakeholders.

*Source:* Cervigni et al. 2015.

**FIGURE 1.3:** PROJECTED VALUE OF FOOD MARKETS IN SUB-SAHARAN AFRICA




*Source:* World Bank 2013.

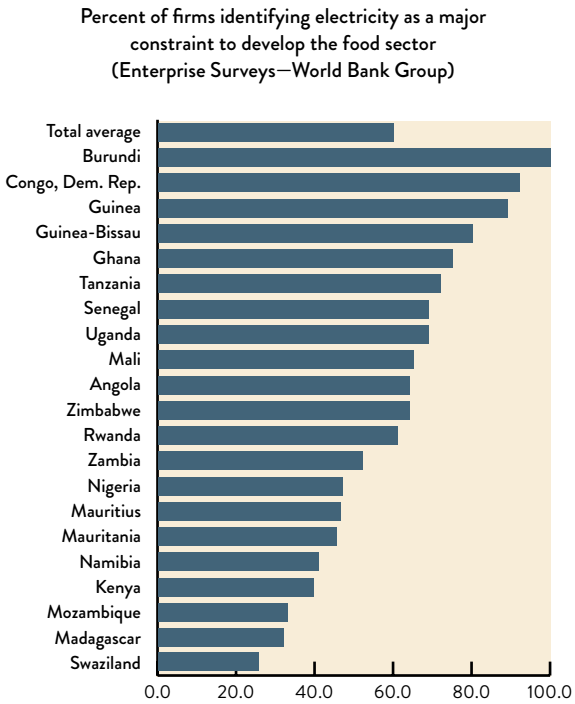
a vibrant agricultural sector. Investments in agricultural productivity can spur the development of downstream agribusiness; in turn, agribusiness investments stimulate agricultural growth through the provision of new markets and development of a vibrant input supply sector. Micro-, small-, and medium-sized enterprises (MSMEs) comprise the bulk of Sub-Saharan Africa's agriculture-related value chains. In West Africa, for example, three-fourths of agriculture-related firms are micro or small enterprises (Staatz 2011).

Taking advantage of this opportunity requires that both farmers and agribusinesses ramp up production, while becoming more competitive; otherwise, the ballooning demand will be filled by imports. This requires developing agriculture value chains and agribusiness to enhance processing, logistics, market infrastructure, and retail networks, all of which require electricity.

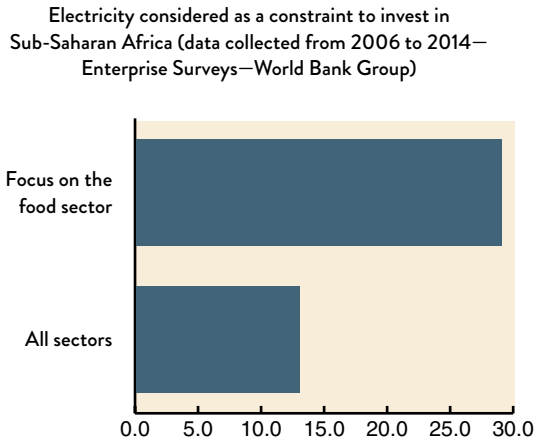
However, electricity remains a critical constraint to the development of the agro-industrial sector. According to data from WBG enterprise surveys, the majority of firms in many countries of Sub-Saharan Africa identify lack of electricity access as a major obstacle (figure 1.4a).

**FIGURE 1.4:** ELECTRICITY AS A CONSTRAINT TO FOOD-SECTOR DEVELOPMENT IN SUB-SAHARAN AFRICA

a. By country




b. Comparison with other sectors




*Source:* WBG 2015 (http://www.enterprisesurveys.org/).

In fact, the fraction of firms in the food sector that consider electricity a constraint to investment is significantly higher than the average fraction in all other sectors (approximately 29 percent, compared to less than 15 percent) (figure 1.4b).

Successful commercial agriculture is typically characterized by the following elements:

- Ample **suitable land**, with **benign climate** conditions and **reliable water availability**.
- **Private-sector participation** in sector development, with higher skills levels and access to international capital and markets, **with strong government support** (e.g., through a favorable policy and regulatory environment and publicly funded research and development and infrastructure).
- Affordable and reliable **access to supporting infrastructure**, in the form of reliable electricity supply, transport links to markets, and irrigation in drier climates (often powered by grid-based electricity).
- **Clusters** of large-, medium-, and small-scale commercial farming, processing, and services firms concentrated in discrete geographical areas. Taken together, the result is a reduction in costs of production through economies of scale, making prices more competitive for regional and global markets, and ultimately increasing the profitability of agricultural activities.

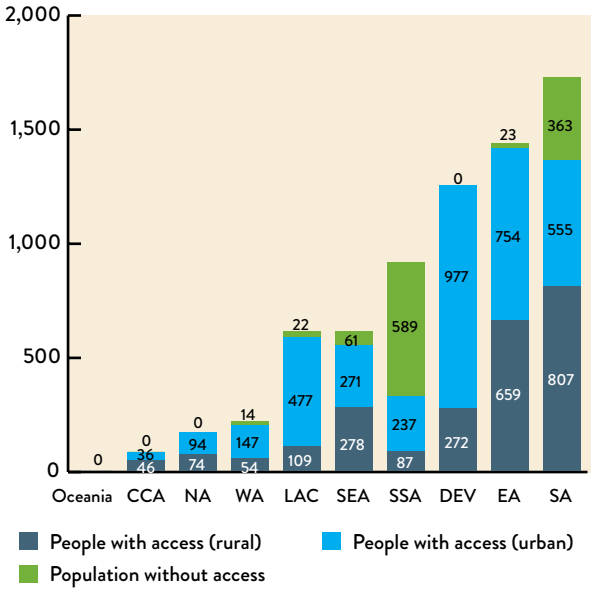
## RURAL ELECTRIFICATION HAS LAGGED BEHIND

A majority of Africans—nearly 600 million people—live without electricity; instead, they rely on kerosene or dry-cell batteries as coping mechanisms. The latest estimates peg Sub-Saharan Africa's electrification rate at 35 percent overall, with 69 percent in urban areas and just 15 percent in rural areas (figure 1.5a). Viewed from space, the picture of Africa's nightlights, showing large sections of perpetual darkness, is a stark contrast to the rest of the developing world, and the evolving disparity is enormous (figure 1.5b).

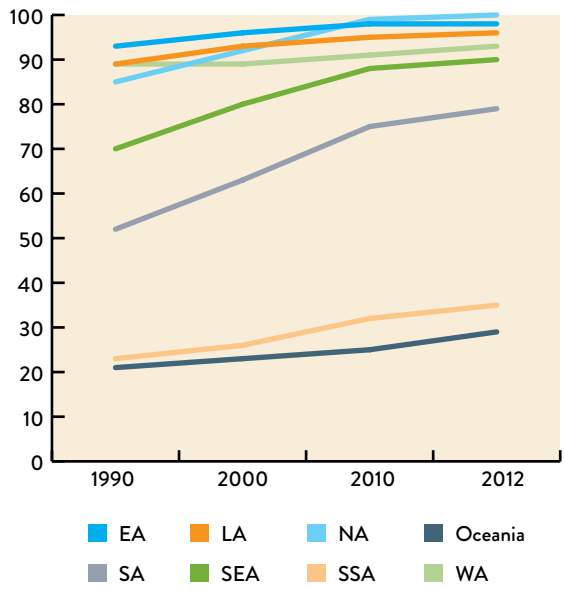
Historically, the region's population growth has outpaced the rate of expanding electricity access, and the gap in rural areas is enormous. Amid a population increase of 202 million, only 59 million people have received electricity. If business as usual continues, by 2030, Sub-Saharan Africa will be the world's only region with an increase in the number of people without electricity

**FIGURE 1.5:** ELECTRIFICATION RATE, BY DEVELOPING REGION

a. Millions of people with and without access, 2012




b. Evolution of access (%), 1990–2012




*Source:* IEA and World Bank 2015.

*Note:* CCA = Caucasus and Central Asia, EA = East Asia, LA = Latin America, NA = North Africa, SA = South Asia, SEA = Southeast Asia, SSA = Sub-Saharan Africa, and WA = West Africa.

access. Furthermore, the urban/rural disparity in electricity access is set to widen as most expansion is likely to occur in densely populated urban areas (IEA and World Bank 2015).

The biggest challenge to rural electrification in the Sub-Saharan Africa region is the lack of commercial viability of expanding connections. Low population density, coupled with the limited purchasing power of most rural consumers, implies that, in many cases, investment in rural grid extension is cost-prohibitive. This problem is compounded by the poor financial health of the region's distribution utilities, owing to a combination of factors (e.g., low consumer base, historical mismanagement, inadequate tariffs, high generation costs, and high rates of technical and nontechnical losses). The high cost of supply, coupled with low tariffs, puts an inordinate strain on sector finances.

This situation, in turn, traps the sector in a self-reinforcing cycle of low investments in expansion and improvement, resulting in an expensive, poor quality electricity supply, circling back to low investments. Thus, many of the region's countries are stuck in a cycle of low generation capacity, excess demand, and inadequate mobilization of private-sector investment. Breaking this negative cycle requires a multipronged approach customized to the financial, economic, and political realities of particular countries. Least-cost grid expansion, wherever viable, should be creatively complemented by a decentralized off-grid strategy based on distributed generation in the form of mini-grids, micro-grids, or stand-alone systems.

## AGRICULTURE AS AN ANCHOR LOAD FOR RURAL ELECTRIFICATION

In recent years, African governments, donors, and the private sector have been reviewing the success stories of such countries as Brazil and Thailand in an attempt to replicate or adapt agribusiness and rural electrification development models that take individual country characteristics into consideration. In the case of India, the most notable example, rural electrification was strongly linked to the promotion of high-yield crop varieties and the spread of irrigated agriculture, facilitated by electric water pumps with subsidized or free electricity. Here it was clear that the financial viability and reliability of rural electrification were linked to promoting productive uses.

The financial viability of agricultural anchor loads rests on the ability to use electricity to generate an increase in agricultural value added and incomes. Generally, the most dramatic changes in agricultural development due to rural electrification have resulted from increased irrigation. With greater access to electricity, it is more cost-effective for farmers to irrigate their fields since electric pumps require low maintenance and are more efficient than diesel alternatives. Irrigation also allows farmers to produce multiple crops in a single year and improve the productivity of existing farms. These advantages lead to higher crop yields and incomes.[8]

This relationship has most often been documented in India, which historically has emphasized the use of irrigation pumps and new agricultural technologies to improve agricultural productivity (Barnes, Peskin, and Fitzgerald 2003). While efforts to improve rural development through electrification have been relatively successful in some countries, the question is whether this experience is applicable to Africa, with its low levels of existing irrigation.

The productive impact of rural electrification depends heavily on several enabling factors: government policy, infrastructure, and complementary development programs. Electrification is an important enabler for the development of rural businesses (e.g., small commercial shops, grain mills, sawmills, and brickworks); however, it cannot produce an explosion of economic activity in the absence of roads and access to finance and markets. If these complementary conditions are inadequate, the growth of rural economies, especially agriculture, will likely remain lethargic and may, in turn, adversely impact the viability of the rural electrification program.[9]

One potential solution to address the region's rural electrification challenge is having an *anchor load*, defined as large consumers that offer power utilities a consistent and substantial source of revenue, which offsets a portion of the fixed costs of electricity supply to rural households. Anchor loads help ease the constraint posed by the low demand profile of rural customers. Guaranteed demand from anchor-load customers ensures the power producer or utility a certain level of revenue, and may help to defray the fixed costs of rural electrification through demand aggregation (along with household and commercial demand in neighboring communities of the anchor load). In short, an anchor load helps overcome the problem of low demand, which constrains the viability of rural electrification.

In some developing countries, the Anchor Business Community (ABC) model is being piloted, using cellphone towers and mining companies as anchor loads.[10] In this context, the supply options range from self-supply

by the agribusiness to intermediate arrangements with an independent power producer (IPP) to grid extension. A recent study that analyzed the integration options between power and mining established a typology of power sourcing options for mines (Banerjee, Romo, and McMahon et al. 2015).

Agriculture can potentially fit into this category of anchor load to sustain small-scale supply arrangements with commercial establishments (including irrigation) and households in rural areas. In this way, electricity demand along the agriculture value chains, as well as commercial/household electricity demand, can create opportunities for the IPPs and mini-grid operators. In addition to demand aggregation, supplying both households and agro-processing may create load balance; the demand of households and agro-processing peak at different times of the day, which can help to disperse capital and maintenance costs over a larger set of consumers.

The development of anchor loads can benefit both centralized and decentralized approaches to rural electrification. In the case of grid extension, promoting the development of relatively large anchor customers in off-grid areas could tip the balance in terms of the economic viability of extending the grid to connect to the anchor load and bringing the grid closer to communities without electricity access. In current-day industrialized economies, such anchor customers as mills and factories were an integral part of the electrification experience. In Sub-Saharan Africa too, national grid expansion plans tend to prioritize district commercial centers and areas with factories or other large commercial customers. Beyond demand from the anchor customer, grid extension can be made viable through the potential to sell electricity back to the grid (in cases where there is an in-house generation facility).

Grid extension may not be viable if anchor customers are not large enough or are located in relatively remote areas. In such cases, smaller isolated grid systems or mini-grids can be used to save on costs associated with transmission infrastructure. Mini-grids can be developed by aggregating demand from the anchor load and surrounding communities, with electricity generation and distribution undertaken through a context-specific combination of a small, in-house power producer and anchor business or public utility.

For both on- and off-grid access solutions, the presence of an anchor-load customer greatly improves the financial viability. In principle, activities along agriculture value chains require electricity and thus might serve this role. The electricity consumption of activities along the various agriculture value chains, aggregated with commercial/household electricity demand, can potentially make it feasible to extend the grid or create opportunities for small IPPs and mini-grid operators. In addition to demand aggregation, supplying both household and agro-processing demand may create a balanced daily load profile, helping to disperse capital and fixed operating costs over a larger set of consumers.

In addition to providing anchor loads, agricultural production can provide fuel for off-grid solutions in rural areas (annex B). Agricultural by-products can serve as cheap sources of locally available fuel for biomass electricity generation; they can be derived from various types of processing (e.g., cotton, groundnut, soybean, wheat, and other cereals), but the most common ones are rice husks and sugarcane waste (i.e., field waste and bagasse).

Such opportunities are now being commercially harnessed in various countries and regions of the world. For example, India has created a business model to serve rural households using husk power, whereby agricultural residue (e.g., rice husks, mustard stems, corn cobs, and certain grasses) is cost-effectively converted into electricity. In this study, the scope of agriculture's role is limited to that of an anchor load in rural areas of the Sub-Saharan Africa region.

## STUDY PURPOSE AND METHODOLOGY

Rural electrification is at a crossroads in Sub-Saharan Africa; for many countries, the challenge is overwhelming, but opportunities are also emerging. It is up to governments, the private sector, and international communities in the region to decide how these opportunities will be harnessed for the benefit of Africans living in the dark. Recently, the WBG's Energy and Extractives Global Practice in the Africa Region commissioned a series of studies to explore potential solutions to the challenge of bringing power to Africa. This study, which follows on the recent initiatives of Banerjee, Romo, and McMahon et al. (2015), Hussain et al. (forthcoming), and Hosier et al. (forthcoming), is designed as a joint effort between the Energy and Extractives, Agriculture, and Trade and Competitiveness Global Practices. It also complements the ongoing analytical work of the Latin America and Caribbean region on energizing agriculture.

This study's overall aim is twofold: (i) to identify potential synergies between agriculture value chains and rural electrification expansion and (ii) to examine the challenges in harnessing this potential. Its specific

objectives are to (i) conduct an evidence-based analysis of the extent of the potential of power-agriculture integration for specific case studies on agriculture value chains; (ii) assess alternative supply arrangements (business models) for providing electricity to the combined power demand of agriculture and local commercial and residential demand; (iii) analyze barriers and institutional mechanisms that will create the enabling conditions for private-sector participation in this space; and (iv) identify operationally relevant opportunities for piloting this concept.

This work builds on two background studies prepared by the consulting consortium of Economic Consulting Associates (ECA) and Prorustica in 2014–15, which involved field visits and stakeholder discussions in the countries covered. The first study analyzed the landscape for rural electrification centered on agricultural activities, while the second examined a set of eight case studies on powered agribusiness activities from across Sub-Saharan Africa (Ethiopia, Kenya, Mali, Tanzania, and Zambia). The primary focus of the landscape study was on power consumption of agricultural activities within value chains, identifying where sufficient demand from the activity makes it possible to provide an economic or socioeconomic rationale for an electrification project that may then be extended to support surrounding communities. The case studies comprised both national grid-connected activities and those powered by distributed generation systems. They included power schemes that had already been developed, as well as those in progress or proposed. The cases covered a range of commodities (e.g., fruits, floriculture, maize, sugar, tea, vegetables, and wheat).

Since agriculture is a dispersed activity with varied scales of production, results of this analysis need to be considered with the following caveats. First, although the study provides an estimate of power demand from agriculture in 2030, it was unable to capture the location of this demand, the extent to which it can be met by simply increasing the generation capacity of national grids (i.e., the grids already extend to production and processing areas), and whether alternative power sources (e.g., isolated electricity mini-grids) are the most viable supply options. Second, the study was unable to capture the necessary financial viability of power supply with reference to the price that the agricultural activities could afford to pay for power.

The rest of this report is organized as follows. Chapter 2 presents the context of power needs from agriculture, while Chapter 3 reports on the detailed analysis of power needs by selected value chains. Chapter 4 discusses power supply arrangements for a suite of case studies in three countries, encompassing technical, economic, and financial analysis. Chapter 5 reviews the potential for harnessing power-agriculture synergies and provides alternative integration scenarios using two simulated case studies. Finally, Chapter 6 summarizes the study's key findings and recommends actions required to promote power-agriculture integration.

## ENDNOTES

1. Households that connect to the electricity grid benefit immediately from better household lighting. With brighter light in the home, children spend more hours studying, adults have more flexible hours for completing chores and reading books, and home-based businesses remain open longer in the evenings, producing more items for sale. Once rural families connect to the grid, television sets, fans, and an array of other household appliances gradually become more affordable (Barnes 2014).

2. The SE4ALL initiative was launched by the United Nations (UN) in 2011. It is co-chaired by the UN Secretary General and World Bank Group (WBG) President; SE4ALL helped place energy access explicitly on the global development agenda, thus filling the gap left by the Millennium Development Goals (MDGs), which did not include any energy access goals.

3. Authors' calculation from the World Development Indicators (WDI) database.

4. Korwama (2011) estimates that 30 percent of Sub-Saharan Africa's agricultural produce is processed, compared to nearly 98 percent in some developed countries.

5. Focusing on the enabling environment, WBG (2016) measures regulations that impact firms in the agribusiness sector. It collects and reports data on 18 indicators for 40 countries across the world; the indicators capture aspects related to production of inputs and market enablers to help policy makers better understand barriers to growth and transaction costs imposed by the regulatory environment.

6. Africa's economy has been expanding at a relatively high rate. Following a very strong decade from the beginning of this century, growth in 2015 was more modest, at 3.7 percent (World Bank 2015). Growth rates over the next several years are projected at well above 4 percent.

7. About two-thirds of this area is spread over eight countries: Angola, Democratic Republic of the Congo (DRC), Madagascar, Mozambique, South Sudan, Sudan, Tanzania, and Zambia (World Bank 2013; Deininger and Byerlee 2011).

8. The impact of electricity will be lower in areas that use gravity-fed irrigation since the value added by electricity is likely to be relatively minor. The main impact will be realized by farmers using agricultural pump sets or other forms of mechanized irrigation.

9. A recent WBG study states that electricity access is critical to promoting a more commercialized agriculture sector in the developing world; it emphasizes the importance of rural electrification as an enabling condition for agribusiness development, and discusses indicators on electricity access, reliability, and affordability (WBG 2015).

10. In the ABC model, anchor customers are the main off-takers for the generated power. Business refers to small local businesses and shops; community refers to households, farming needs (including irrigation), and local institutions.

# Power Needs of Agriculture

## CHAPTER 2

Agricultural transformation in Sub-Saharan Africa implies a shift away from household subsistence farming toward a more market-oriented farming sector that is effectively able to supply demand across the world. Achieving this transformation involves increased use of modern farming inputs, greater value addition through post-harvest processing, and access to markets through transportation and storage.

Electricity is a key input required to create greater value added in the agriculture sector through enabling irrigation, processing, and storage. Growth in agricultural incomes is directly dependent on farmers' ability to increase their yields through irrigation, processing of produce to retain a greater proportion of the value added along the full supply chain, and proper storage of produce to prevent spoilage. A growing agriculture sector will thus produce greater demand for electricity along its value chain, from both on- and off-farm activities. Agricultural transformation, through increasing rural electricity demand, can thus go hand-in-hand with an expansion in rural electricity access.

A structural shift in agricultural markets is set to induce demand for electricity from agriculture. With growing domestic and export markets for agricultural products, the need for increased agricultural productivity will necessitate greater on- and off-farm mechanization of agricultural and agribusiness practices. In addition, economic growth is set to create markets for new products and higher value commodities for urban markets and as intermediate inputs for various industries, especially in the food sector.

Electricity demand from agriculture stems from the various processes along the agriculture value chain—from on-farm irrigation and off-farm grain milling to larger secondary processing (e.g., pulping and packaging) that caters to higher value urban and export markets. An increase in an irrigated area to reach its estimated potential and improving existing irrigation practices will require electricity for water pumping. The mechanization of basic milling or grinding that is largely done manually will require electricity to run machines. Storage of high-value perishables awaiting transport to demand centers will require electricity for chilling; and such processing activities as pulping, drying, heating, and packaging will also demand electricity.

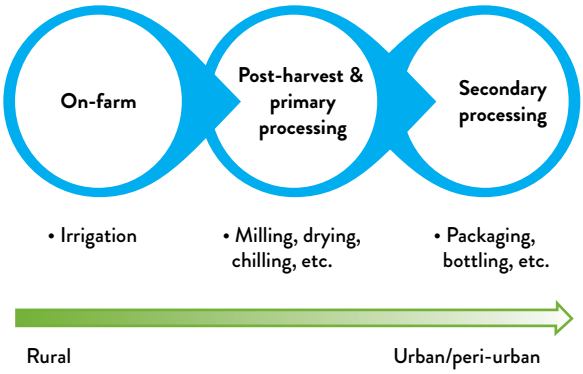
This chapter explores the synergy between agricultural growth and rural electrification and provides initial estimates of power demand from agriculture in 2030. The value generated by agricultural activities that demand electricity can help tip the scales of commercial viability of rural electrification interventions.

### POWER NEEDS ACROSS THE AGRICULTURE VALUE CHAIN

Electricity input is vital for the adoption of modern productivity enhancing technologies and thereby the integration of small-scale farming into high-value and export-oriented value chains. The implications for electricity demand from such a shift in the agriculture sector of Sub-Saharan Africa will be determined by the extent to which modern techniques are adopted at each stage along the value chain and the scale of each activity. In addition to electricity requirements, the potential of various crops to gain from irrigation and processing activities can vary widely.

Depending on crop characteristics and target markets, value chains differ in post-harvest processing and preservation requirements. This creates differing on- and off-farm demand for electricity for each value chain. In order to examine the nature of electricity use along

**FIGURE 2.1:** POWER NEEDS ACROSS AGRICULTURE VALUE CHAINS




agriculture value chains, the sources of growth in future electricity demand can be divided into three sources, as follows (figure 2.1 and annex C):

- The potential for expanded irrigation, which is the primary **on-farm** source of electricity demand.
- The potential growth in **post-harvest and primary processing** activities from both new and existing production; activities include cleaning/drying, milling, cassava processing (chipping), chilling and cold storage, meat processing, and oil extraction.
- The potential growth in **secondary processing** activities that cater mainly to urban markets and provide intermediate inputs to other production processes; activities include thermal treating, canning, bottling, and packaging.

These several activities are presented in decreasing order of rural presence. Virtually all irrigation occurs in rural areas, and post-harvest and primary processing usually occur shortly after the rural harvest, depending on scale. Secondary processing is more likely to take place near trading hubs and demand centers in urban or peri-urban areas, although, under appropriate conditions, some smaller-scale operations can be viable in rural areas. The prevalence of irrigation potential in rural areas and the benefits across value chains imply that irrigation is the largest potential source of power demand from agriculture in Sub-Saharan Africa.

### *IRRIGATION POTENTIAL*

The irrigation intensity in Sub-Saharan Africa is the lowest in the world; only 6 percent of the region's cultivated land is irrigated, compared to 44 percent in Asia (FAO 2005). Irrigation intensity and technique vary across the region. Powered irrigation systems are prevalent in Southern and East Africa, and are emerging in West Africa. To a large extent, West Africa and the Sudano-Sahelian region utilize small-scale irrigation systems, which tend to be gravity fed.

Like other powered activities in agriculture, the electricity requirements of powered irrigation equipment depend on system scale, form of irrigation, and specific geographic conditions—the latter factor making it difficult to develop accurate estimates of electricity use for irrigation. The two primary power demands for irrigation are (i) sourcing bulk water from some water body, such as a dam or river and (ii) distributing it over the cultivated area.

Irrigation systems commonly used in Sub-Saharan Africa range in scale from manual systems to surface flooding and localized systems to center pivots. Manual systems, including simple buckets to support small-scale farmers, require no power. Surface flooding and localized systems (e.g., stationary drip schemes and pressurized systems, such as sprinklers[1]) require power to source the bulk water that cannot be accessed by gravity only. Center pivots may require power for bulk water supply, as well as for pressurizing water for the system and possibly for system mechanics (e.g., motors to rotate the pivot span).

In all four cases, power demand is related to system scale, but will vary per unit of area covered. In each case, pumping bulk water comprises the major demand and will depend on the vertical and horizontal distances of the scheme from the water source (table 2.1).

For irrigation systems that use gravity to redistribute water, power may only be required for bulk water pumping into storage (if needed). The most efficient pumping systems do this to meet infield demand, running nearly continually. But some systems may design their capacity with larger pumps so as to require pumping for fewer hours within a day. This design is inefficient from the viewpoint of electricity supply, as it would require a greater peak generation load.

Benefits from irrigation come from increased yields and reduced weather-related risks. Enhanced irrigation practices may thus result in large benefits from increased crop yields, leading to higher farm revenues. Giordiano et al. (2012) find that Sub-Saharan Africa has considerable area under small-scale irrigation or improved agricultural water management. The study estimates that investments in dry-season irrigation for rice could potentially increase yields by 70–300 percent. The same study estimates that investment in relatively low-cost motorized pumps, benefiting 185 million across the Sub-Saharan Africa region, could generate net revenues of up to US$22 billion a year.

**TABLE 2.1:** POWER DEMAND FOR IRRIGATION, BY SYSTEM TYPE

| System Type | Cultivation Methods Supported | Crops Supported | Power Components | Estimated Power Demand/Unit (kW/ha)[a] | Typical Area Coverage[b] |
|---|---|---|---|---|---|
| Surface flooding (furrow and paddy systems) | Small- and large-scale commercial. | Rice, sugarcane, tomatoes, citrus. | Possibly bulk water, infield pumping. | 0.5–0.9 | 600 $m^2$–20,000 ha |
| Micro irrigation (drip and trickle) schemes | Small-scale and intensive commercial. | Floriculture, horticulture, seedling propagation, citrus, vegetables, potatoes. | Possibly bulk water, infield pumping. | 0.5–0.9 | 600 $m^2$–20 ha |
| Micro jet irrigation | Some small-scale, mostly large-scale commercial. | Floriculture, horticulture, citrus, macadamia, some tree crops. | Possibly bulk water, infield pumping. | 0.5–0.9 | 5–50 ha |
| Portable impact sprinkler systems (drag-line and hand-move) | Small- and large-scale commercial (broad-scale). | Floriculture, horticulture, grain crops, tobacco, bananas, sugarcane, potatoes. | Possibly bulk water, infield pumping. | 0.5–0.9 | 600 $m^2$–20,000 ha |
| Center pivot | Small- and large-scale commercial (broad-scale). | Wheat, barley, soya, maize, groundnuts, sorghum, paprika, tobacco, sugarcane, rice. | Possibly bulk water, infield pumping. | 0.7–2.2 | 9–150 ha (65 ha per pivot is typical on farms of 50–5,500 ha) |

*Source:* ECA and Prorustica (2015).
*Note:* The categories provided in this table are general as no two schemes are identical.
a. Assumes an average distance of 300 m from the water source to the irrigation scheme.
b. Indicates the system scale commonly seen in Sub-Saharan Africa.

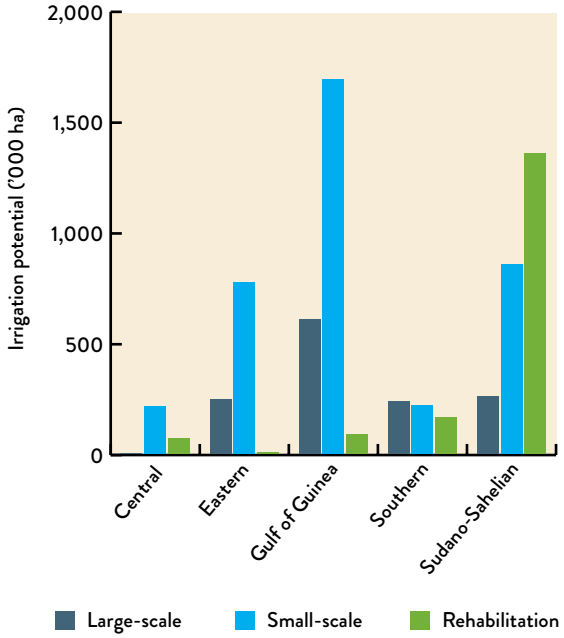
Irrigation offers distinct seasonal advantages for crop production as it can help overcome rainfall variability and even temperature extremes by maintaining adequate levels of soil moisture year round. In the summer, the primary advantages are greater reliability of water supply (i.e., reducing the impact if rainfall is less than expected) and the ability to plant crops early without waiting for rains. In the winter, when rains are not expected, irrigation is indispensable for cropping, allowing for the production of wheat and other winter crops and more crop cycles per year for rice. Therefore, annual use of irrigation allows year-round cropping.

The extent of irrigation and the associated electricity is likely to be characterized by some amount of seasonality. The magnitude of the seasonal variation in irrigation depends on crop choice, weather variations, and irrigation and farming practices. Despite this, multi-cropping, along with the nearly constant need of water supply for efficient cropping (especially under drip irrigation), does reduce seasonal variation to a certain extent.

Africa's grossly underutilized agricultural potential should be tapped by significantly growing the area under cultivation to cover most economically viable areas. You et al. (2009) developed estimates of potential increase in irrigable area in the region using detailed topographical data and economic parameters (figure 2.2). The study found that both large- and small-scale irrigation schemes can be economically developed in Africa, with economic internal rates of return (IRRs) exceeding 12 percent.[2] Investments in irrigation over this cut-off could potentially increase irrigated areas by 7.7 million ha, with 5.8 million ha coming from small-scale schemes.

Countries with the greatest potential for large-scale investment are Ethiopia, Mali, Mozambique, Nigeria, Sudan, Tanzania, Zambia, and Zimbabwe (You et al. 2009).

**FIGURE 2.2:** POTENTIAL NEW OR REHABILITATED IRRIGABLE LAND IN SUB-SAHARAN AFRICA




*Source:* You et al. 2009.

All of these countries have more than 100,000 ha of potential, based on existing or projected development of mainly multipurpose water-storage reservoirs. Except for Southern Africa, small-scale irrigation projects in Sub-Saharan Africa are generally estimated to have higher IRR than large-scale irrigation. This implies that economically viable, small-scale irrigation projects could increase in area under irrigation to a greater extent than large-scale projects (table 2.2).[3]

By far, the greatest potential is found in Nigeria, which accounts for more than 2.5 million ha or nearly half of suitable hectares. Such countries as Cameroon, Chad, Ethiopia, Mali, Niger, South Africa, Sudan, Tanzania, Togo, and Uganda each has at least 100,000 ha of potential.

To begin to tap this potential, the CAADP Program for Investment in Agricultural Water targets region-wide expansion of the irrigated area by 3 million ha, approximately doubling the current area by 2030 (World Bank 2013). In some areas, this expansion could be carried out even more quickly: the World Bank's proposed Sahel Irrigation Initiative has a goal of "doubling the irrigated areas in Sahel in five years through improved public policies and increased private-sector involvement." Much of this irrigation would be gravity fed, but some of it, especially small-scale irrigation, would require pumping for transport and/or extraction. And there is an additional synergy: the development of hydroelectric power sources can often be combined with irrigation projects.

**TABLE 2.2:** POTENTIAL INVESTMENT NEEDS FOR LARGE-SCALE, DAM-BASED AND COMPLEMENTARY SMALL-SCALE IRRIGATION SCHEMES IN SUB-SAHARAN AFRICA

| Region | Large-scale Irrigation | | | Small-scale Irrigation | | |
|---|---|---|---|---|---|---|
| | Increase in Irrigated Area (million ha) | Investment Cost (million US$)[a] | Average IRR (%) | Increase in Irrigated Area (million ha) | Investment Cost (million US$)[a] | Average IRR (%) |
| Sudano-Sahelian | 0.26 | 508 | 14 | 1.26 | 4,391 | 33 |
| East | 0.25 | 482 | 18 | 1.08 | 3,873 | 28 |
| Gulf of Guinea | 0.61 | 1,188 | 18 | 2.61 | 8,233 | 22 |
| Central | 0.00 | 4 | 12 | 0.30 | 881 | 29 |
| Southern | 0.23 | 458 | 16 | 0.19 | 413 | 13 |
| Indian Ocean Islands | 0.00 | 0.00 | n.a. | 0.00 | 0.00 | n.a. |
| **Total** | **1.35** | **2,640** | **17** | **5.44** | **17,790** | **26** |

*Source:* You 2008.

*Notes:* The average value for IRR was weighted by the increase in irrigated area. Benin, Chad, and Madagascar have no profitable, large-scale irrigation; n.a. = not available.

a. These estimates are one-time investment costs rather than annualized figures.

### *PRIMARY AND SECONDARY PROCESSING*

Electricity is a vital input in value-added processing activities, such as post-harvest cleaning and drying to remove moisture and prevent spoilage (e.g., for cereals and legumes), milling (e.g., of maize, rice, and cassava), and crushing. Specific processing activities for high-value agricultural products also rely on electricity inputs (e.g., wet-processed coffee using machinery for pulping). Furthermore, electricity can improve storage of produce through cold chains, thereby reducing income loss from spoilage and increasing the ability to specialize in high-value perishable products (e.g., dairy, meats, fruits, and vegetables). It is estimated that about 30 percent of agricultural produce is wasted due to spoilage. Cold storage and drying can reduce this figure substantially. Electric fans for air precooling, ice-making machines and hydro-coolers can improve cooling efficiency in cold storage rooms.

Though difficult to estimate accurately due to the dispersed potential, primary and secondary processing represent a significant growth area in Sub-Saharan Africa. The expected demand growth for grain milling is likely to increase significantly (e.g., maize in Nigeria, wheat in Zambia, and rice in Tanzania). Similarly, increased demand for processing of cassava—a widely produced and consumed staple in many countries (e.g., Angola, Democratic Republic of the Congo, Mozambique, Nigeria, and Uganda)—is expected due to its perishable nature and use as an industrial input in the manufacturing of glue.

Additional primary and post-harvest processing (if developed to full potential), together with the activities discussed above, could significantly change the rural electricity markets. Table 2.3 summarizes the various activities that can serve as anchor loads for rural electrification, along with the value chains they are part of and examples of countries where they are present and likely to grow.

The creation of opportunities for viable rural electrification on the back of local agricultural development will depend on various site-specific factors, including the scale and profitability of agricultural operations, crop, terrain, type of processing activity, and other local conditions. Rural electrification opportunities will be best served by agro-processing activities that generate electricity demand close to rural population centers, generate enough income to cover electricity supply costs, are sufficiently large in relation to household demand,[4] and have relatively low seasonal variation.

## AGGREGATE ELECTRICITY DEMAND FROM IRRIGATION AND PROCESSING

By 2030, we estimate that electricity demand from agriculture could double from today's level, reaching about 9 GW. This is a simplified estimate as the varied nature of product value chains and associated irrigation, processing, and storage activities makes it impossible to develop a comprehensive, region-wide estimate. The demand emerges from considering the potential increase in irrigation and post-harvest activities. Assumptions about increased development of irrigation and processing potential, unit electricity use, and accompanying growth in crop yields underlie this estimation. Growth in agricultural production catering to domestic and export demand and accompanying movement up the agriculture value chain are expected to increase electricity demand from irrigation and post-harvest processing.

By 2030, about 3.1 GW in additional electricity demand is expected from the development of irrigation potential across Sub-Saharan Africa (figure 2.3). Given the region's significant underutilized water resources, along with the ubiquitous benefits from irrigation across most value chains, it is expected that irrigation will account for a significant portion of electricity demand from the agriculture sector.[5] The estimated demand from irrigation is based on fully exploiting potential areas for new or rehabilitated irrigable areas, totalling nearly 6.8 million ha.[6] This area is dominated by small-scale scheme development in the Gulf of Guinea (with more than 1.5 million ha in Nigeria alone) and rehabilitation of existing schemes in the Sudano-Sahelian region (with over 1 million ha in Sudan) (table 2.4).[7]

Figure 2.3 shows that about an additional 1.1 GW is expected from the development of the region's agro-processing potential. Power demand from the development of agricultural processing activity is based on increased growth in both primary crop production and the proportion of crops that are processed. Currently, the percentage of crop production processed through electrified value chains is quite low (conservatively estimated at 10 percent). By 2030, this percentage is expected to grow to 15 percent as a result of the increased participation of small-scale farmers in formal value chains.

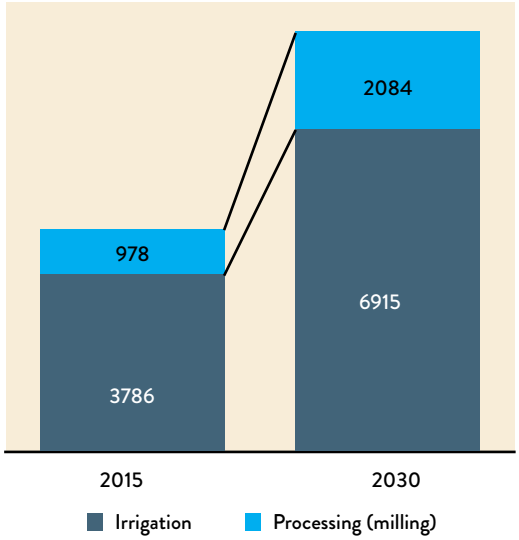
Given the varied nature of processing activities by type, scale, location, and technology, the estimate is based on the electricity requirement of a typical processing

**TABLE 2.3:** KEY POWER-INTENSIVE AGRIBUSINESS ACTIVITIES

| Activity | Value Chains Supported | SSA Countries/ Regions Where Activity Occurs | Scale of Power Demand/ Supply | Growth Potential of Value Chain and Activity |
|---|---|---|---|---|
| New **large-scale irrigation** | Maize, rice, wheat, oilseed, sugarcane, tea, floriculture | Most countries | Single areas can demand > 15 MW of capacity. | Many areas that can be supported likely to require farms of > 250 ha; crop choice depends on market prices. |
| Substitute **power for diesel** in small-scale milling | Maize, rice, cassava, oilseed | Most countries | In unconnected rural towns, demand unlikely to exceed 500 kW for the whole town. | Many towns in agricultural areas will have this demand; risky as anchor load for electrification. |
| New **large-scale milling** | Maize, rice, wheat, oilseed, sugarcane, oil palm, tea, cotton | Most countries | Demand can be > 1 MW from a single mill. | Widespread opportunity. Reliant on base supply from commercial estates; crop choice depends on market prices. |
| **Milking and cold storage** | Dairy | Few countries | > 800 kW peak demand. | Small markets in SSA; climatic conditions not ideal for dairy farming. |
| **Cold storage** | Floriculture, export vegetables | Ethiopia, Kenya, and Uganda (floriculture and export vegetables); Rwanda and Tanzania (export vegetables) | 10 MWh/ha per year. | Continued demand for floriculture in Europe, leading to agribusiness growth in select countries; challenges with horticulture through demand for high quality, competitive retail markets driving down margins and tariff restrictions in European markets. |
| **Biomass**-fueled generation | Rice, oil palm | Many countries (rice); West Africa and East and Southern Africa | Can provide > 10 MW of power (ha/ton). | Beyond Africa, export market for rice is challenging and unreliable for palm oil. Water intensity restricts locations; depends on reliable supply of biomass from commercial estates. |
| **Bagasse**-fueled generation | Sugarcane | Eastern and Southern Africa (South Africa) | Can provide > 10 MW of power (70 kWh/MT of sugarcane, or 243 kWh/MT of bagasse). | Large market for crop, but price-dependent. Water intensity restricts locations; depends on reliable supply of bagasse from commercial estates. |

*Source:* ECA and Prorustica (2015).

**FIGURE 2.3:** ESTIMATED ELECTRICITY DEMAND (MW) FROM AGRICULTURE FOR SUB-SAHARAN AFRICA IN 2030




*Source:* ECA and Prorustica (2015).

activity (milling) and thus does not capture the electricity demand from the potential development of other processing activities or storage.

In 2012, the Food and Agriculture Organization of the United Nations (FAO) estimated crop production at about 852 million metric tons (MT). Assuming a growth rate of 2.4 percent annually (Alexandratos and Bruinsma 2012), crop production would reach 1.3 billion MT by 2030 (table 2.5). The power demand from crop production is estimated by assuming that processed crops will consume, on average, the amount of power needed for an average wheat mill in Zambia—some will have greater consumption and others less. This "average mill" is assumed to handle 8 MT per hour, operating year round at 16 hours per day and 6 days a week. This would result in approximately 40,000 MT per year and have a power capacity demand of 400 kW.

The total estimated electricity demand from agriculture is indicative of the scale of the opportunity for rural electrification to benefit from agricultural growth potential. The overall magnitude of electricity demand provides

**TABLE 2.4:** METHOD FOR CALCULATING POWER DEMAND FROM IRRIGATION

| Category | Prominent Countries with Irrigable Area (thousand ha) | Estimated Proportions/ Power Use | Estimated Power Use (kW/ha) | Estimated Power Use (MW) |
|---|---|---|---|---|
| Large-scale | Ethiopia (191)<br>Nigeria (609)<br>Sudan (238)<br>Zimbabwe (142)<br>Total = 1,352 | Much of East and Southern Africa requires bulk-water pumping, West Africa less so; 50% requires bulk-water pumping and 50% just infield equipment. | 1.2 kW/ha for area requiring bulk water, 0.7 kW/ha otherwise | 1,285 |
| Small-scale | Cameroon (170)<br>Chad (231), Mali (219)<br>Nigeria (1,538)<br>Tanzania (196)<br>Uganda (445)<br>Total = 3,754 | Most schemes are very basic in riparian areas; 40% requires power, and 60% is entirely gravity fed with no power. | 0.7 kW/ha for area using power, 0 otherwise | 1,051 |
| Rehabilitation | Somalia (135)<br>Sudan (1,064)<br>Total = 1,688 | Most rehabilitation consists of gravity fed, colonial-era schemes; 10% is large-scale with bulk water, 30% large-scale without, 20% small-scale with power, 40% small-scale with no power. | 0.7 kW/ha for area using power, 0 otherwise | 793 |

*Sources:* You et al. (2009); ECA and Prorustica (2015).

**TABLE 2.5:** POWER DEMAND FOR CROP PROCESSING

| Year | Primary Crop Production (million MT) | Crops Processed (%) | Processed Production (MT) | Number of 400-kW Mills Required | Total Power Demand (GW) |
|---|---|---|---|---|---|
| 2012 | 852 | 10 | 85.2 | 2,129 | 0.851 |
| 2030 | 1,306 | 15 | 196.0 | 4,893 | 1.960 |

*Sources:* FAO; Alexandratos and Bruinsma (2012); ECA and Prorustica (2015).

a sense of the investment in generation capacity that will be required to meet agricultural needs and the addition to rural electricity demand that is expected, owing to the agriculture sector. The latter informs the likely viability of accounting for agricultural growth in rural electrification strategy and planning.

## ENDNOTES

1. Some sprinklers are pressurized, while others are solely gravity operated.

2. Conditional on having initial investment costs at best-practice levels and if market access, complementary inputs, extension of credit, and a supportive policy and institutional environment are in place.

3. The higher IRR for small-scale irrigation is due to the existence of large amounts high-potential rainfed cultivation located far from large-scale developments that could be profitably converted into small-scale irrigation (You et al. 2009).

4. Although even a relatively small agricultural load can potentially help to push aggregate demand in a given area over the threshold of economic and financial viability.

5. In the context of climate change, the future availability of water will depend critically on improvements in water management practices and planning (box 1.3). World Bank (2016a) predicts that, under business as usual, water management in Southern and East Africa will not experience negative effects on GDP, while other parts of Sub-Saharan Africa could experience about a 6 percent fall in GDP in 2050.

6. You et al. (2009) classifies areas based on their anticipated IRR on irrigation investment. The numbers reported here are based on an anticipated 12 percent return, which is a typical benchmark for such projects.

7. You et al. (2009) was published before the independence of South Sudan and thus classifies the whole of Sudan together.

# Power Needs in Selected Value Chains

## CHAPTER 3

Agricultural production in Sub-Saharan Africa is fairly diversified, and no single cereal crop predominates across the region. In terms of production quantity, maize is the most important, followed by sorghum, millet, and rice; the importance of each crop varies by individual countries. In West and Central Africa today, cereals comprise less than 20 percent of agricultural value added (compared to 35 percent for Asia prior to the Green Revolution), with the remainder coming from other staples (especially roots and tubers), horticulture, export crops, and livestock (Schaffnit-Chatterjee 2014).

Owing, in part, to diversity in agricultural production, agriculture value chains also vary widely across the region and even within countries. Value chains vary by length, technologies utilized, value added, and markets served.[1] Many value chains operate in both informal and formal markets, with the former catering to low-income, domestic consumers and the latter catering to higher income urban and export markets (World Bank 2013).

The value chains for the region's bulk commodities (e.g., maize and rice) are primarily informal, in contrast to more market-oriented, semi-processed and consumption ready products. As a commodity moves along the value chain to the ultimate market and consumer, hygiene and quality standards become more stringent. Such commodities as sugar, tea, and oil palm are processed virtually at the point of primary production, while other commodities (e.g., fruits, vegetables, and livestock products) must be processed within a relatively short period before they deteriorate. Still others have parallel value chains; that is, for the same commodity, some value chains focus on lower end consumers in domestic markets, while others are more formal, with strong processing and stringent quality control.

The need for post-harvest electricity input varies, depending on the nature of the crop, the type of value chain (or targeted market) and local conditions. A case in point is Kenya's dairy sector: 86 percent of the country's milk supply is driven by small-scale farmers and small- and medium-sized enterprises (SMEs), with milk being sold to small-scale vendors. Parallel to this, larger dairy farms with either integrated dairy herds and/or formal links to dairy farmer cooperatives provide pasteurized milk and processed dairy products via cool chains for sale to higher income urban consumers through supermarkets (World Bank 2013).

This chapter examines potential electricity use along 13 selected value chains. Electricity demand from on-farm activities and rural processing presents an opportunity for the development of anchor loads to spur rural electrification. The source of electricity may vary on a case-by-case basis, and opportunities for biomass based generation for particular value chains (e.g., oil palm and sugar) are highlighted. In addition, bottom-up estimates of potential future electricity demand from the selected value chains are presented.

### SELECTION OF VALUE CHAINS

The value chains selected for this study help illustrate the nature of electricity demand from the rural agriculture and agribusiness sectors, along with the power-demand profile. These value chains represent both high growth potential and the ability to create electricity demand for irrigation and/or processing in rural areas (table 3.1). The potential for agricultural electricity demand extends well beyond the value chains discussed here and is often driven by site- and country-specific factors that create

**TABLE 3.1:** ANALYSIS OF COMMODITY VALUE CHAINS, BY SCALE AND REGION/COUNTRY

| Commodity | Scale (if applicable)[a] | Region/Country |
|---|---|---|
| Maize | Small and large | East and Southern Africa |
| Rice | Small and large | Tanzania (primarily) |
| Cassava | Small | West, Central, East, and Southern Africa |
| Wheat | Large | Southern Africa |
| Oilseed | Small (primarily) | East and Southern Africa |
| Horticulture (pineapple) | Small and large | West, Central, and Southern Africa |
| Sugarcane | Small and large | East and Southern Africa |
| Oil palm | Small and large | West and Central Africa |
| Dairy | Small and large | Kenya |
| Poultry | Large | East and Southern Africa |
| Tea | Large | East and Southern Africa |
| Floriculture (roses) | Large | East Africa |
| Cotton | Small | West, East, and Southern Africa |

*Source:* FAOSTAT (http://faostat3.fao.org).
a. Farming systems are defined in terms of labor type and not merely scale. Large-scale commercial farming is defined by family labor that is predominantly managerial, with full-time labor hired for specific tasks and production catering to market supply.

opportunities along other crop and processing activities. The case studies presented in chapter 4 analyze examples of such opportunities.

The commodity value chains shown in table 3.1 were selected according to the following criteria. Starting with the top 20 commodities by production value for 2012 (from FAOSTAT), the list was modified to assure the inclusion of (i) key export commodities (e.g., tea, cotton, and horticulture); (ii) value chains based on assessed electricity use; (iii) commodities with large production volume and importance for local food markets with potential for future growth in processing requirements (e.g., cassava and maize); (iv) commodities that figure in the top ones by value for many countries in the region (e.g., tea and soybean), which may not appear on a region-wide list; (v) commodities with large irrigation schemes (e.g., irrigated wheat); and (vi) value chains with the potential to supply fuel for electricity generation (e.g., oil palm and sugarcane).

Table 3.2 shows the estimated production volume for the selected commodities in 2030, along with their estimated average annual growth rates between 2013 and 2030. Future projections are calculated using the historical growth rate (between 2009 and 2013) for each commodity (FAOSTAT) and applying a concavity parameter to project a declining growth rate over time. The assumed growth rates are qualitatively more conservative than those assumed by Alexandratos and Bruinsma (2012), who predict mostly convex growth rates, owing to large existing potential on the extensive (area expansion) and intensive (yield growth) margins.

According to future production estimates, cassava and maize—primary staple food crops in the region—will remain dominant over the period until 2030. Sugarcane, a well-established industry with conducive growth conditions, is also expected to remain dominant across the region for the foreseeable future. In addition, recent high growth rates of cotton, pineapple, and rice suggest that these commodities will likely gain greater regional importance in the coming decades.

**Cassava.** In terms of production quantity, cassava is Sub-Saharan Africa's most important crop, accounting for more than half of global production. Nigeria is the leading global producer, followed by the Democratic Republic of the Congo (DRC), Angola, Ghana, and Malawi.[2] Cassava is experiencing growing demand as a staple food crop and an intermediate input into various other commercial value chains (e.g., starch and livestock feed). The crop is still mainly grown under small-scale farming conditions with limited use of irrigation. Owing to its drought tolerance and ability to grow in relatively poor soils, production is fairly widespread in rural areas across the region. Further development to make the crop's value chain more market oriented can have large effects on the livelihoods of small farmers. Growth in cassava production depends critically on improved processing and drying of roots to reduce bulk and prevent deterioration.

**TABLE 3.2:** COMPARISON OF HISTORICAL AND PROJECTED COMMODITY GROWTH RATES AND ESTIMATED PRODUCTION

| Commodity | Growth Rate, 2009–13 (%) | Assumed Average Annual Growth, 2013–30 (%) | Estimated Production in 2013 (million MT) | Projected Production in 2030 (million MT) |
|---|---|---|---|---|
| Cassava | 6.4 | 2.8 | 157.7 | 252.7 |
| Maize | 5.8 | 2.5 | 65 | 101.2 |
| Sugarcane | 1.7 | 0.8 | 73.9 | 84.6 |
| Rice (paddy) | 5.9 | 2.6 | 22.6 | 35.5 |
| Wheat | 5.1 | 2.3 | 7.1 | 10.6 |
| Pineapple | 9.5 | 4.2 | 4.4 | 9 |
| Dairy | 1.6 | 0.7 | 3.2 | 3.6 |
| Poultry | 1.5 | 0.6 | 2.7 | 3 |
| Cotton (lint) | 8.1 | 3.5 | 1.3 | 2.5 |
| Oil palm | −0.7 | −0.3[a] | 2.4 | 2.2 |
| Tea | 5.4 | 2.4 | 0.7 | 1 |
| Oilseed (soybean) | 2.6 | 1.2 | 0.5 | 0.6 |

*Sources:* FAOSTAT and World Bank estimates.
a. The oil palm industry is now considered less attractive; some developments are proving unsustainable and are being converted to other uses.

**Maize.** Due to its tolerance of diverse climates, maize is one of the world's most widely grown crops. In 2013, total global production was estimated at more than 1 billion metric tons (MT). In Sub-Saharan Africa, maize is one of the most prevalent cereals, with more than 65 million MT produced in 2013 (table 3.2). However, the region's average yield of 1.4 MT per ha is low compared to the global average of 5 MT per ha, and 11.6 MT per ha in the United States (Iowa) (2009 figures, FAO). A few countries are dominant in maize production, but their market share is less pronounced. Maize's utilization is wide ranging; it serves as a leading food staple and important feed crop, as well as an input in the processing of food, chemicals, and fuels (ethanol).[3] In East and Southern Africa, maize is principally a food staple, accounting for 30–50 percent of low-income household expenditure.[4] As such, growth in production is expected to increase, propelled by growing regional demand.

**Sugarcane.** According to the FAO, sugarcane is the world's largest crop in terms of production quantity, with 1.83 billion MT produced in 2012. Brazil is its largest producer, followed by India. Sub-Saharan Africa accounts for roughly 4–5 percent of global production, with about 74 million MT produced in 2013. The region's largest producers are South Africa, followed by Sudan and Kenya; South Africa and Mozambique lead in terms of area under cultivation (table 3.3). Eighty percent of the world's sugar is produced from sugarcane, while the other 20 percent is from sugar beet (FAO 2009). The most common production model is contracting commercial and small-scale outgrowers to supply the sugar refineries.

**Rice (paddy).** Sub-Saharan Africa has witnessed rapid growth in rice production, driven mainly by urbanization. The compound annual growth rate (CAGR) of domestic production has averaged about 6 percent, with more than 22 million MT reached in 2013. According to the Africa Rice Center's analysis, the region's rice yields have increased in real terms by an average of 108 kg per ha annually, comparable to the Green Revolution's growth rates in Asia (Seck et al. 2013). Despite such rapid growth, rice imports have also increased significantly; in 2012, 12 million MT were imported. The region has considerable potential for production growth through increasing the area under cultivation and increasing yields.

**Wheat.** Among all cereals, wheat is the most highly traded. As of 2013, it was the world's third most widely produced cereal (behind maize and rice), at a total of 713 million MT.[5] In Sub-Saharan Africa, Ethiopia and South Africa are the main wheat producers. Generally, production has not kept pace with the region's growing demand for wheat;

**TABLE 3.3:** COUNTRIES IN SUB-SAHARAN AFRICA WITH SIMILAR COMMODITY PRODUCTION AND PROCESSING SYSTEMS

| Commodity | Countries |
|---|---|
| Maize | Kenya, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe; also Burkina Faso, Ghana, Mali, and Nigeria (but not at such large commercial volumes) |
| Rice | Madagascar and Tanzania |
| Small-scale cassava | Angola, DRC, Mozambique, Nigeria, Tanzania, and Zambia |
| Irrigated wheat | Zambia and Zimbabwe |
| Rainfed wheat | Ethiopia and Kenya |
| Commercial soya | Zambia and Zimbabwe |
| Sugarcane | Ethiopia, Kenya, Malawi, Mozambique, South Africa, Swaziland, Tanzania, and Zimbabwe |
| Oil palm | Cameroon, Côte d'Ivoire, and Ghana |
| Dairy | Kenya, Ethiopia, Rwanda, South Sudan, and Uganda |
| Poultry | Kenya, Malawi, Zambia, and Zimbabwe |
| Tea | Kenya, Malawi, Rwanda, and Uganda |
| Floriculture (roses) | Ethiopia, Kenya, Tanzania, Uganda, Zambia, and Zimbabwe |
| Cotton | Benin, Burkina Faso, Côte d'Ivoire, Mali, Mozambique, Tanzania, Uganda, Zambia, and Zimbabwe |

*Source:* ECA and Prorustica (2015).

thus, wheat imports have been on the rise. Among the region's handful of countries that are fully self-sufficient in wheat production, Zambia is noteworthy; that country's annual production, mainly commercial in scale, totals 300,000 MT (table 3.3).[6] Many parts of East, Southern, and Central Africa are suitable for wheat production.

**Pineapple.** In Africa, horticulture, in the form of tropical fruit production, caters mainly to own consumption and domestic markets; in some countries, it also caters to Europe and other export markets (e.g., canned fruits and pulp). After banana, pineapple is Sub-Saharan Africa's most important tropical fruit. Nigeria is the region's largest pineapple producer. Kenya, the second largest, ranks among the world's top five exporters of pineapple; canned pineapple, exported mainly to Europe, is its largest manufactured export.

**Dairy.** The robust growth in dairy production reported in many parts of Sub-Saharan Africa today is being driven by economic growth and urbanization. Traditionally, milk has been produced for own consumption or local consumption by farmers; however, growing urban demand is increasing the need for cold supply chains to maintain product quality. According to the FAO, the region's dairy production totaled 3.2 million MT in 2013. Along with this demand growth is the demand created for processing milk-derivative products (e.g., cheese, butter, and evaporated milk). Transport of raw milk, which is prone to spoilage, is generally uneconomical; thus, it is kept to a minimum, suggesting that dairy storage and processing centers are located in the vicinity of dairy farms.

**Poultry.** Population growth, changing diets resulting from urbanization, and income growth are the major drivers of Sub-Saharan Africa's ongoing demand for poultry. During 2000–11, poultry (meat) production across the African continent grew by 5 percent per year, reaching 4.62 million MT in 2011. Major producers are in Northern Africa: Egypt, Algeria, Morocco, Libya, and Tunisia. In Sub-Saharan Africa, 2013 production totaled 2.75 million MT, with South Africa and Nigeria as lead producers. These two countries are also the region's major egg producers; and hatcheries are usually large-scale commercial operations. Modern poultry complexes are usually integrated with chicken farms to reduce the costs associated with the transport of live animals. Contract farmers receive chicks from the hatchery, ideally housing them in climate-controlled chicken houses. Broiler processing operations are typically located on-site at poultry farms.

**Cotton (lint).** Cotton is one of Africa's main cash crops among small-scale farmers. In 2013, Sub-Saharan Africa produced 1.3 MT of cotton (lint) (table 3.2). The region's major producers are Burkina Faso, Mali, Côte d'Ivoire, Benin, and Zimbabwe. In West Africa, Burkina Faso and Mali each produce about 400,000 MT per year. In East and Southern Africa, Zimbabwe is the lead producer, with an annual output of 200,000–300,000 MT in seed cotton (table 3.3).

**Oil palm.** The source of palm oil, one of the world's leading edible vegetable oils, oil palm constitutes 60 percent of the global trade in vegetable oils (World Bank 2011a). Oil palm fruit yields two distinct types of oils: (i) palm oil, which is edible, used mainly in the form of vegetable oil and (ii) palm kernel oil, which is extracted from the seed kernel, used as an input to process other foods (e.g., biscuits and margarine), manufacture household products (e.g., soap, shampoo, and cosmetics), and produce biodiesel fuel. Southeast Asia (mainly Malaysia and Indonesia) produces 85 percent of the world's palm oil. In Sub-Saharan Africa, West Africa is the main producer. Nigeria is the largest producer; however, Côte d'Ivoire, DRC, Ghana, Guinea, and Uganda are also establishing major operations. While commercial-scale farmers account for most production, small-scale farmers also find oil palm an attractive crop since it is relatively high yielding and requires limited labor inputs.

**Tea.** Tea is one of Sub-Saharan Africa's most important export commodities, especially for East Africa. Kenya is the world's largest exporter of black tea. In 2011, it produced 378,000 MT, about two-thirds of Sub-Saharan Africa's output. Uganda and Malawi are the region's next two largest producers, while Tanzania and Rwanda are experiencing steady growth in production (table 3.3).[7] Tea-growing usually occurs on large plantations, with processing located either on-site or nearby.

**Oilseed (soybean).** Although Sub-Saharan Africa's soybean production is fairly small by global standards, contributing only 1 percent of global production, the region's production is growing faster than the world average (ACET 2013). South Africa has the highest growth in percentage terms, while Nigeria has the largest absolute growth.[8] Soybean is grown mainly on small farms, while commercial soybean farming is prevalent in South Africa, Zambia, and Zimbabwe. Soybean is sold for both human consumption and as an animal feedstock.

**Floriculture (roses).** The introduction of rose cultivation in Sub-Saharan Africa began in Kenya about three decades ago. To this day, Kenya remains the region's main producer and exporter of roses; that country also has the highest area under rose cultivation, followed by Ethiopia and Uganda. Rose production in Ethiopia has been growing rapidly, and the country is fast establishing itself as a major exporter, to some extent capturing market share from Kenya. Most production is for export markets, especially Europe, which generates more than US$1 billion in export revenues for the region (International Trade Center 2014). On a per hectare basis, rose production is one of the most high-value agricultural activities, generating revenues of $100,000–200,000 per ha.[9]

## ELECTRICITY DEMAND AND FARMING SCALE

Electricity demand along the value chain is likely to vary by scale or type of farming operations (e.g., commercial versus small-scale) due to differences in farming processes (e.g., irrigation) and the extent and nature of post-harvest processing (box 3.1). While farming in Sub-Saharan Africa is predominantly in the form of smallholder agriculture, a significant portion of the future potential rests on increasing yields on such farms by employing more modern inputs and connecting them to higher value markets and value chains (i.e., employing large-scale operations).

It is useful to compare electricity needs across these types of agricultural arrangements. The implication for overall magnitude depends on the evolving proportions of commercial and small-scale farming techniques in the

### BOX 3.1: FARM TYPE DEFINITIONS

Defining farming systems in terms of labor can be useful, given that the definitions do not depend on production scale or crop type. Accordingly, three types of farm systems are distinguished here:

**Family farms.** These small-scale farms are characterized by the predominant use of family labor, lack of permanent workers, and presence of seasonal labor hired during peak production times.

**Small investor farms.** The owners/family members are involved primarily in management and supervisory roles, while the bulk of labor input is provided by hired farm workers; this group is less well-defined in Africa, but most, if not all, of their crops are produced for market.

**Large-scale commercial farms.** Family labor for these farms is exclusively or predominantly managerial. A permanent hired staff of full-time workers, specialized to a certain degree (e.g., drivers), produces primarily for market.

*Source:* Poulton et al. (2008).

region. For example, greater proportional growth in the adoption of commercial-scale farming, which depends more heavily on power input, will induce higher overall electricity demand by the agriculture sector.

Examining typical electricity use for irrigation and processing shows that, for most of the value chains analyzed, irrigation constitutes a large proportion of the potential electricity demand. As small-scale farming largely relies on rainfed or gravity irrigation, electricity demand from commercial-scale irrigated agriculture is an order of magnitude greater than from smallholder agriculture. Figure 3.1 compares typical rates of power usage for large-scale irrigated and small-scale rainfed (or gravity fed) irrigation for selected value chains. For the most widely grown crops in Sub-Saharan Africa, including maize, rice, and cassava, irrigation accounts for the highest potential electricity load.[10]

As shown, potential peak power loads for small-scale informal production are quite small relative to loads from commercially irrigated production on a per unit basis (figure 3.1b), although this is partly offset by the predominance of smallholder agriculture across the region, representing over 80 percent of the cultivated area (Livingston, Schonberger, and Delaney 2011).

Though irrigation accounts for a major part of the potential on a per unit basis, post-harvest processing can play a significant role in supporting rural electrification, especially in the case of some commodity value chains. Adding electricity demand for processing to that for irrigation, commercially oriented value chains such as sugarcane, tea, floriculture, and dairy have the overall highest potential electricity demand (figure 3.1a). Tea is easily the most power-intensive commodity, with demand emanating primarily from processing (figure 3.1c).[11] Activities with potentially large loads from processing (sugarcane, tea, and floriculture) are developed and operated mainly by large single entities or organized groups of small-scale farmers (see case study 6, chapter 4).[12] In such cases, the power load and potential power supply are usually part of the planning process; examining options and incentives for rural electrification can be integrated into the planning stage itself.

However, in Sub-Saharan Africa most agricultural production occurs in small-scale, informal value chains. The potential power demand from small-scale agriculture is much less than from commercial agriculture. Lower yields mean that a larger area is required to produce sufficient production volume for processing facilities. Figures 3.1b and 3.1d exclude small-scale sugarcane, oil palm, and tea since these typically occur only with small-scale farmers operating as outgrowers for commercial estates; thus, the scale of power demand cannot be viewed independent of larger commercial estates.[13] The figures include dairy with zero values to highlight that informal dairy value chains do not utilize power in Sub-Saharan Africa.

Given the economies of scale in generation capacity, commercial agricultural activities are likely to be more financially viable anchor loads to support affordable rural electricity supply to rural Sub-Saharan Africa. However, due to recent technological improvements, accompanied by the creation of enabling regulatory conditions, electricity provision in the form of mini-, micro-, and even pico-grids has dampened the scale economies in electricity generation and distribution investments. Increasingly, advances in renewable energy technologies, such as solar photovoltaics (PV), are allowing viable electricity infrastructure investments catering to smallholder agriculture and rural households. Even for more conventional technologies, ubiquitous small-scale, informal agriculture can enhance the viability of rural electrification on the margin. As discussed earlier, given the diversity of conditions across agricultural areas, site-specific opportunities still exist if cost-effective technologies (e.g., biomass, solar, or small hydro), which may not exhibit strong economies of scale in installed capacity, can be utilized.

## ELECTRICITY DEMAND IN THE SELECTED VALUE CHAINS

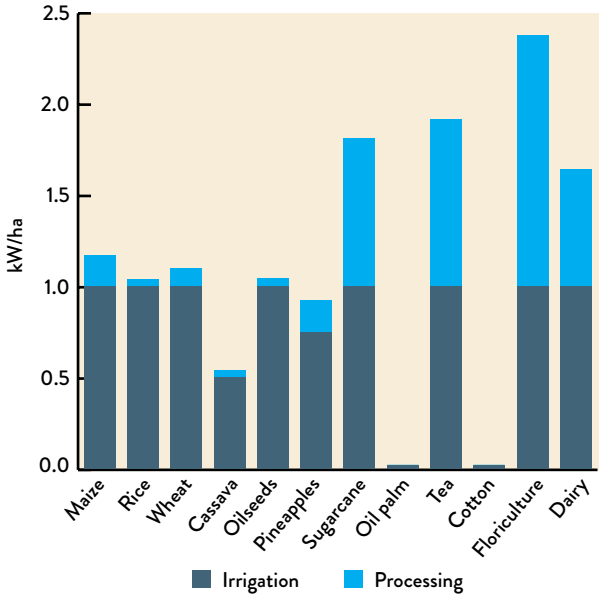
The development of power profiles for each commodity, region, and farm type utilized a range of information sources. Value chains were analyzed in terms of their nature and magnitude of power use for irrigation and processing, growth potential, and ability to serve as an anchor load.

To enable comparison, the power profiles presented below are for (arbitrary) standardized farm sizes of 300 ha, based on the unit electricity demand presented in table 3.4. The 300 ha benchmark was chosen to represent the cultivated area that might constitute a typical project site.[14]

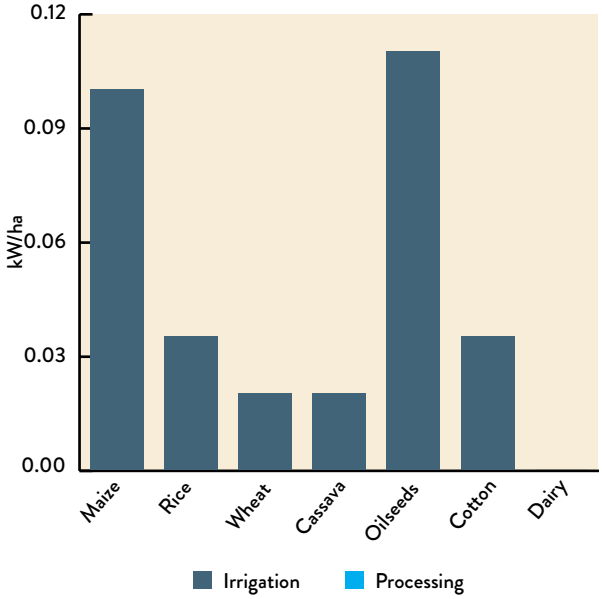
**Maize.** For the maize value chain, the input of rural electricity is primarily for irrigation (largely restricted to large-scale farming) and milling (figure 3.2a). The gain in value from electricity use comes from the higher yields resulting from irrigation and the saving of labor and higher productivity resulting from electricity powered (versus manual) milling. The estimated electricity demand from these two activities is about 1.17 kW per ha for large-scale

**FIGURE 3.1:** POTENTIAL PEAK CAPACITY AND ENERGY DEMAND FOR LARGE- AND SMALL-SCALE SYSTEMS

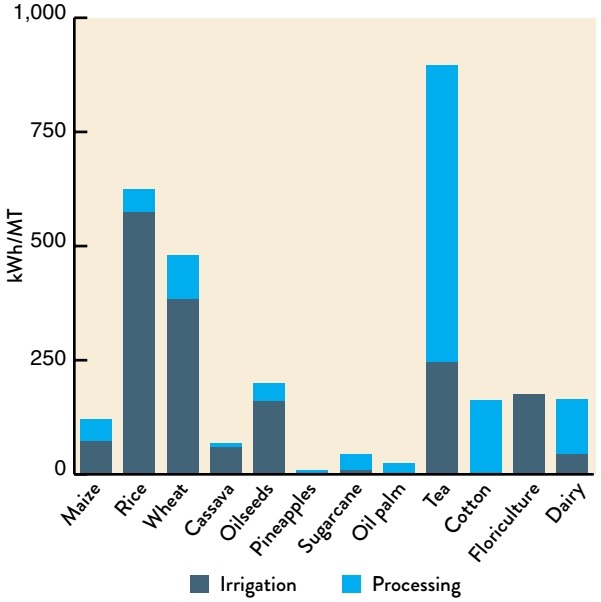
a. Peak capacity: Large-scale irrigated production



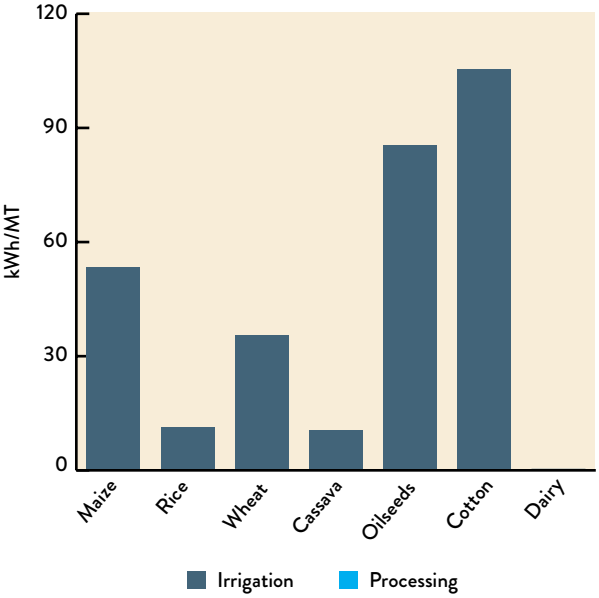

b. Peak capacity: Small-scale rainfed production




c. Energy demand: Large-scale irrigated production

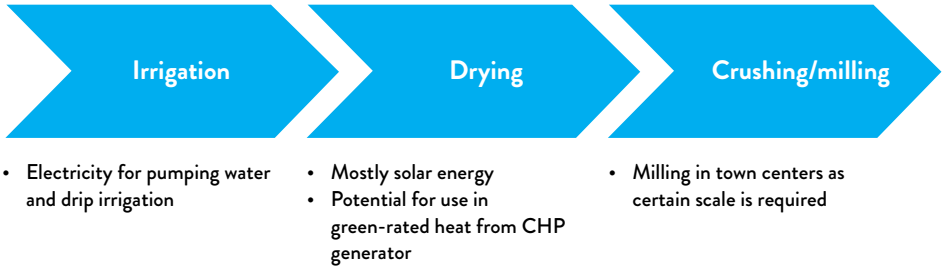



d. Energy demand: Small-scale rainfed production




*Note:* Unit electricity demands are constructed from various sources and field observations by ECA and Prorustica. Figure 3.1a does not plot poultry as it is a significant outlier and not feasible to depict on the same scale. Figure 3.1c omits floriculture due to the incomparability of yield data. Figures 3.1b and 3.1d are restricted to those commodities with significant production on smallholder farms (thus omitting such cash crops as tea, sugarcane, floriculture, and horticulture).

**FIGURE 3.2a:** ELECTRICITY INPUT IN THE MAIZE VALUE CHAIN




production and about 0.77 kW per ha for small-scale irrigated production, suggesting that 300 ha of cultivated maize will require about 250–350 kW of installed power generation capacity.

**Rice.** For rice, irrigation and milling are the primary sources of rural electricity demand (figure 3.2b). Because rice can be grown under a variety of irrigated or rainfed water regimes, electricity demand for irrigation varies by type of cultivation. The value gain from electricity use is from the higher yields resulting from irrigation (an increase of up to 4 MT per ha) and the value added from milling. The estimated electricity demand from irrigation and milling is 1.04 kW per ha for large-scale, irrigated production and 0.03 kW per ha for small-scale (paddy) production with no irrigation. Thus, for a cultivated area of 300 ha, the power demand is in a range of 9–315 kW, depending on farming type. Additionally, rice husk biomass provides a readily available and cost-effective fuel source to generate electricity to supply mills and potentially the neighboring community.[15]

**Cassava.** For cassava, the electricity demand ranges from 0.02 kW per ha to 0.56 kW per ha, depending on whether the land is under irrigation (figure 3.2c). For a 300 ha cultivated area, the power demand would be about 160 kW.

**FIGURE 3.2b:** ELECTRICITY INPUT IN THE RICE VALUE CHAIN

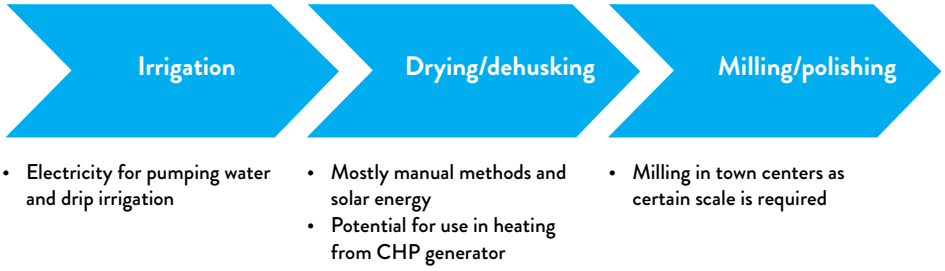
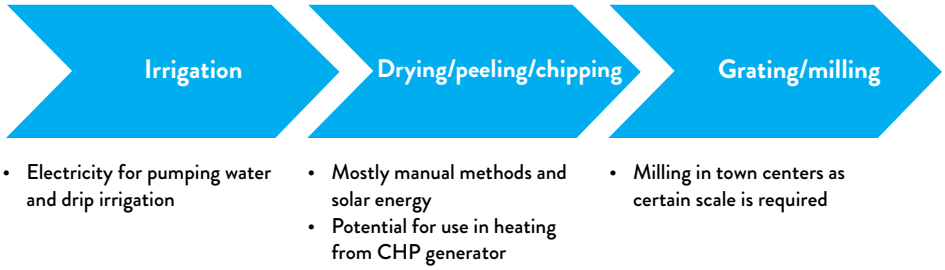



**FIGURE 3.2c:** ELECTRICITY INPUT IN THE CASSAVA VALUE CHAIN




**Processing chain: High-quality cassava flour**

**Wheat.** For winter wheat production, powered activities include irrigation; on-farm drying, cleaning, and conveying in and out of silos; and milling (figure 3.2d). The value added from electricity use is through the higher yields from irrigation (an increase of about 4 MT per ha) and electric milling and processing. The total power demand from irrigation and post-harvest processing is estimated at 1.1 kW per ha for large-scale production and 0.52 kW per ha for small-scale production. For a 300 ha cultivated area, power demand would be in a range of 150–230 kW, depending on the farming type.

**Oilseed (soybean).** For soybean, the value added from electricity use occurs through the higher yields made possible by irrigation and increase in value from processing (figure 3.2e). The total electricity demand resulting from irrigation and milling is estimated at 1.04 kW per ha for large-scale production and 0.64 kW per ha for small-scale production. These figures suggest power demand in a range of 200–300 kW for a 300 ha cultivated area.

**Horticulture (pineapple).** Along the pineapple value chain, juicing and canning activities comprise the main demand for electricity. Irrigation for other horticultural crops (e.g., beans, peas, and potatoes) is fairly limited and usually small in scale. Owing to perishability, electricity is needed for cooling and to power a cold chain from farm to market, although this is usually provided in the form of mobile refrigeration units (reefers). The value added from electricity use in the pineapple value chain includes higher yields resulting from irrigation, increased product value resulting from juicing and canning, and reduced wastage due to cold storage (figure 3.2f).[16] The electricity demand from irrigation is estimated at 0.75 kW per ha for commercial production, implying that 225 kW of power would be needed for 300 ha cultivated area. In addition, the by-products of post-harvest processing can potentially provide biomass for electricity and heat generation, which can significantly reduce power costs.[17]

**Sugarcane.** Sugarcane yields are highly responsive to irrigation; thus, water pumping for irrigation is an important source of electricity demand in the sugarcane value chain. In addition, sugar mills constitute considerable processing demand for electricity (figure 3.2g). The value

**FIGURE 3.2d:** ELECTRICITY INPUT IN THE WHEAT VALUE CHAIN

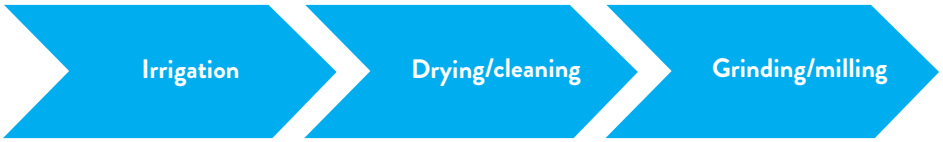



**FIGURE 3.2e:** ELECTRICITY INPUT IN THE SOYBEAN VALUE CHAIN

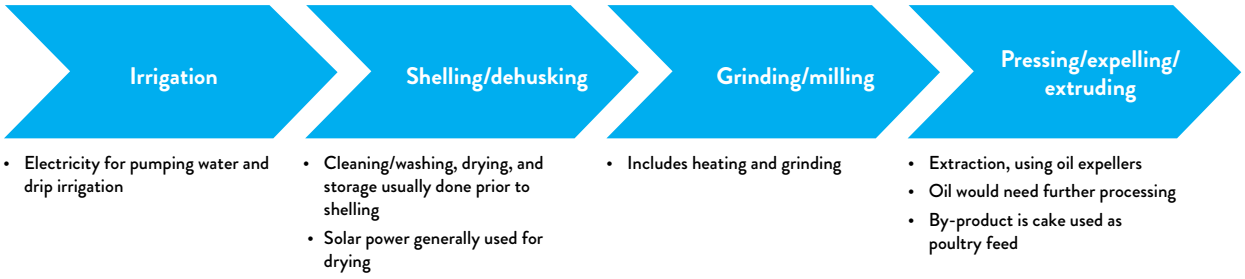



**FIGURE 3.2f:** ELECTRICITY INPUT IN THE PINEAPPLE VALUE CHAIN

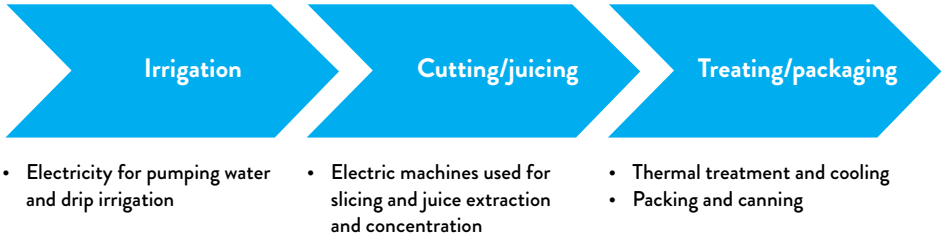


**FIGURE 3.2g:** ELECTRICITY INPUT IN THE SUGARCANE VALUE CHAIN


- Electricity for pumping water and drip irrigation

- Milling: washing, chopping, shredding, and crushing to extract cane juice
- Subsequent clarification, concentration, and crystallization to produce mill-white
- Biomass by-product used for electricity and heat generation

- Further refining of raw sugar produced from milling
- Usually located near urban markets

gains from electricity use are derived from the higher yields from electricity powered irrigation and the price differential between raw cane and partially processed sugar. The increased yields from irrigation could reach 50 MT per ha and even up to 150–200 MT per ha if the latest drip irrigation methods are utilized. On top of the value added, maintaining processing activities close to the farm helps to reduce transport costs. The combined power demand of irrigation and refining is estimated at 1.81 kW per ha for large-scale production and 1 kW per ha for small-scale production. These figures imply that a 300 ha cultivated area will demand 300–550 kW of power, depending on the scale of production and related farming practices.

The biomass residue (bagasse) from sugarcane processing has a high potential to generate electricity. Refineries often produce their own electricity and sell the excess to the grid. Bagasse generated electricity could become important for the rural populations of sugarcane producing nations. For example, in Ethiopia, the Wonchi, Metehera, and Finchaa sugar factories produce approximately 300,000 tons of sugar each year, powering an installed electricity capacity of 62 MW. The electricity is used to power factories, with the surplus power exported to the national grid. For both the South Africa sugar industry and Uganda's Kinyara sugar manufacturer, the power output is approximately 30 kWh per MT of crushed sugarcane.

**Oil palm.** The processing of oil palm usually occurs on or nearby the farm due to its bulky nature and ability to produce biomass used to generate the heat and electricity required for oil extraction and processing. Oil palm irrigation is largely rainfed. The main sources of electricity demand are oil processing and extraction from the fresh fruit bunches (FFBs) (figure 3.2h). Though uncommon, drip irrigation can raise yields by 6 MT of FFB per ha. The value gained from using electricity is through processing and reduced transport costs. For milling, the estimated electricity demand is 0.02 kW per ha, suggesting a 6 kW power requirement for a 300 ha cultivated area. Substantial amounts of solid palm oil waste are available from the palm oil mills, which are energy self-sufficient; that is, they produce their own energy to operate and use the surplus generated to supply estates, sell to the grid, and possibly sell to villages and towns in the area (box 3.2).[18]

**FIGURE 3.2h:** ELECTRICITY INPUT IN THE OIL PALM VALUE CHAIN


- Electricity for pumping water and drip irrigation
- Electricity-powered irrigation uncommon in Sub-Saharan Africa

- Sterilization, stripping, digesting, and pressing used to extract oil extracted from the FFBs

- Refining of extracted crude oil
- Not necessarily nearby oil palm plantations

### BOX 3.2: PALM OIL AND POWER INTEGRATION IN UGANDA

One example of an integrated palm oil/power setup is Uganda's Bugala Power Station, a 1.5 MW biodiesel-fired thermal power plant located on Bugala Island on Lake Victoria. The power station is integrated with the palm oil processing plant owned by Bidco Oil Refineries Ltd., which also owns a 6,500 ha palm oil plantation on Bugala Island. The oil-processing factory generates heat through biomass incineration, used to supply superheated steam to help extract oil and also turn turbines and create electricity in the process. The electricity is used inside the factory, with any excess sold to neighboring towns.

**Dairy.** Dairy production systems can potentially create significant electricity demand in rural areas where there are commercial milk producers or cooperatives. The main source of rural electricity demand from dairy production is cold storage, and machines for electricity powered milking are also becoming more prevalent (figure 3.2i). Another potential source is machinery for processing milk-based products (e.g., butter, cheese, and evaporated milk). The value gain from electricity use results from reduced spoilage due to cold storage,[19] the ability to access urban markets, and the value added from processing milk products. For large-scale operations, the estimated power demand is about 0.61 kW per ha. Animal manure from dairy farms may also be used to generate electricity.

**Poultry.** Hatcheries are usually relatively large-scale commercial operations that require electricity input for a host of processes, including egg incubation and cleaning. For poultry (meat) production, processing plants use electricity to power conveyor belts, cooling and heating, and cutting (figure 3.2j). The value added from electricity use results from reduced spoilage, increased egg-laying productivity, higher labor productivity, value addition from processing, and ability to supply higher value urban markets. The estimated energy demand for commercial-scale broilers (meat) and layers (eggs) is 75 kW per ha each. A typical 1–2 ha operation would generate a demand of about 150 kW (300 kW if the two operations are co-located).

**Tea.** For the tea value chain, electricity demand is from irrigation and processing activities. Irrigation is mainly rainfed since most tea is grown in areas with abundant rainfall. Even so, there is a considerable potential

**FIGURE 3.2i:** ELECTRICITY INPUT IN THE DAIRY VALUE CHAIN

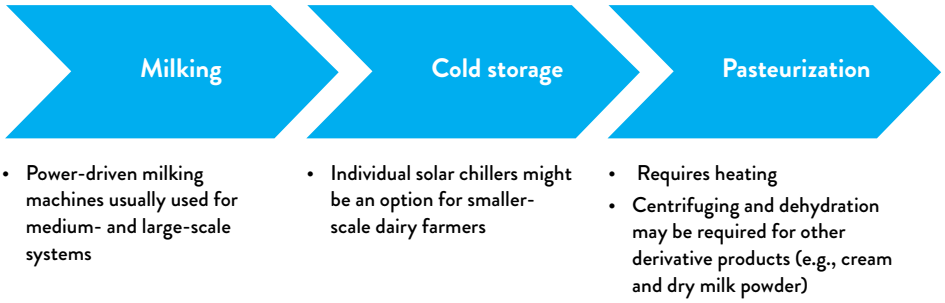



**FIGURE 3.2j:** ELECTRICITY INPUT IN THE POULTRY VALUE CHAIN

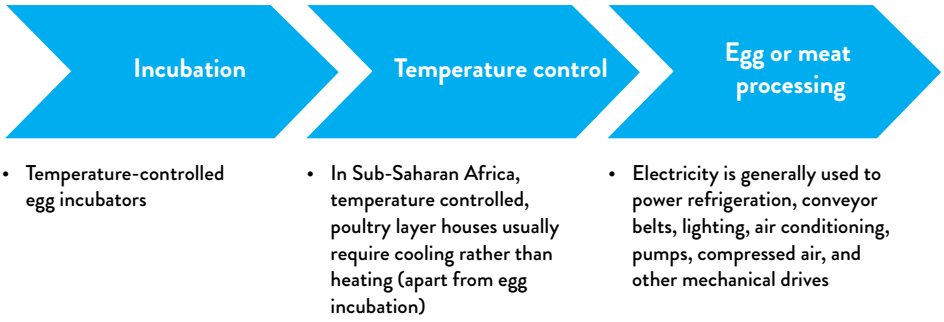


**FIGURE 3.2k:** ELECTRICITY INPUT IN THE TEA VALUE CHAIN

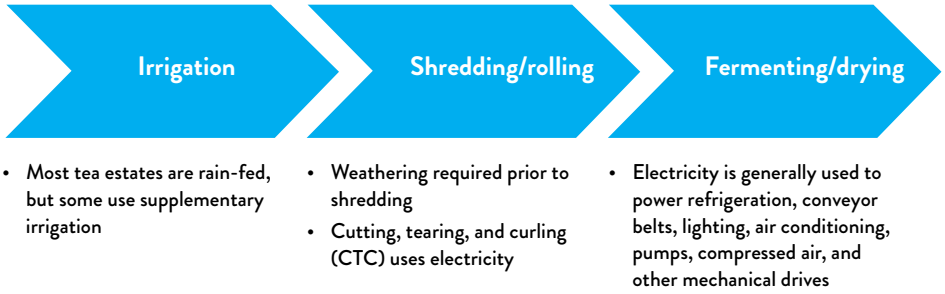
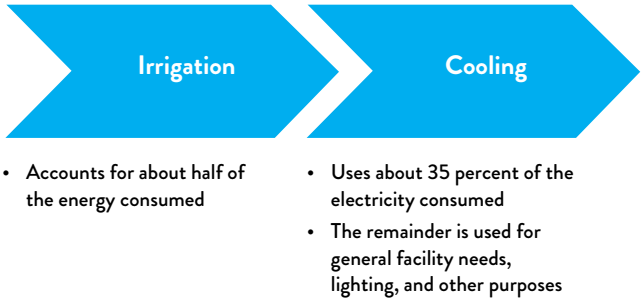



**FIGURE 3.2l:** ELECTRICITY INPUT IN THE FLORICULTURE (ROSES) VALUE CHAIN




value gain from irrigation (i.e., increased yields of up to 8 times from sprinkler irrigation and up to 16 times from drip irrigation) (figure 3.2k). Thus, the value gain from electricity use results from both increased yields in response to irrigation and the value addition from processing (including reduced transport and spoilage costs). In Sub-Saharan Africa, there is considerable potential for tea producers to gain from increasing yields and moving further up the processing value chain. In Kenya, 88 percent of tea production is exported raw in bulk; but in Rwanda and Uganda, processing is rising. Electricity demand from tea cultivation and processing is estimated at 1.91 kW per ha for large-scale plantations and 0.51 kW per ha for small-scale, rainfed facilities. For a 300 ha cultivated area, power demand is in a range of 150–575 kW, depending on the scale of cultivation and associated farming and post-harvest practices.

**Floriculture (roses).** In Sub-Saharan Africa, roses are cultivated mainly in large-scale greenhouses, and most power demand is from irrigation and cold storage (figure 3.2l). Electricity is usually sourced through diesel generation sets. All farms have on-site cold storage, and growing is done in temperature controlled environments. For large-scale production, power demand is estimated at 2.37 kW per ha, with irrigation accounting for nearly half of energy consumption; thus, a 300 ha cultivated area can be expected to have about 700 kW of power demand.

**Cotton (lint).** For cotton (lint) production, electricity powered irrigation is not prevalent. Rather, electric power is used mainly for seed crushing and ginning (figure 3.2m). Due to perishability, cotton ginning must be done soon after harvest. Gins are usually located near reliable power sources in rural and peri-urban towns. Moving ginning closer to farms would save on transport costs and possible

**FIGURE 3.2m:** ELECTRICITY INPUT IN THE COTTON (LINT) VALUE CHAIN

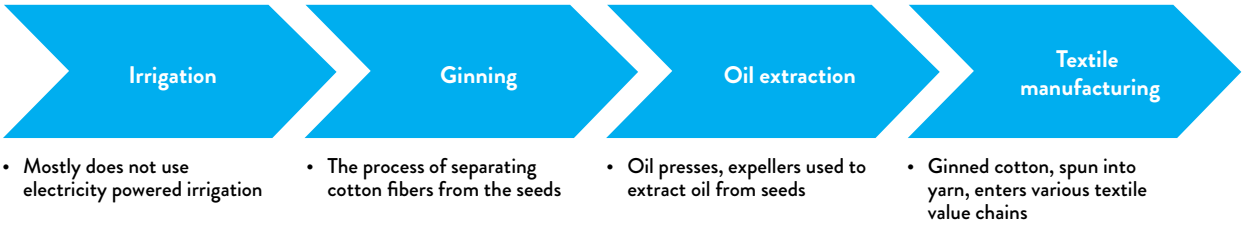


**TABLE 3.4:** POWER DEMAND FOR STANDARD 300 HA CULTIVATED AREA

| Agricultural Commodity | Per Unit Total Electricity Capacity (kW/ha) for Irrigation and Processing | | Electricity Capacity Required for 300 ha Cultivated Area (kW) | |
|---|---|---|---|---|
| | Small-scale | Large-scale | Small-scale | Large-scale |
| Maize | 0.77 | 1.17 | 230 | 350 |
| Rice | 0.03 | 1.04 | 9 | 312 |
| Wheat | 0.52 | 1.10 | 156 | 330 |
| Cassava[a] | 0.56 | | 168 | |
| Oilseed (soybean) | 0.64 | 1.04 | 192 | 312 |
| Horticulture (pineapple)[b] | | 0.75 | | 225 |
| Sugarcane | 1.00 | 1.81 | 300 | 543 |
| Oil palm[b] | | 0.02 | | 6 |
| Tea[c] | 0.51 | 1.91 | 153 | 573 |
| Cotton (lint)[b] | 0.03 | 0.03 | 9 | 9 |
| Floriculture (roses)[b] | | 2.37 | | 711 |
| Poultry[b] | | 75.00 | | 22,500 |
| Dairy[b] | | 0.61 | | 183 |

*Note:* Choice of the 300 ha benchmark reflects the amount of cultivated area that may constitute a typical project site. For example, this would amount to 300 households, each having 1 ha of landholdings. While this benchmark is somewhat arbitrary (i.e., project sites are likely to have a variety of crops under cultivation), it can be used to construct back-of-the-envelope estimates on electricity demand from the value chains presented.
a. Cassava is small-scale only.
b. Horticulture (pineapple), oil palm, cotton (lint), floriculture (roses), poultry, and dairy do not use electricity for small-scale operations or are only large-scale operations.
c. Small-scale tea cultivation uses rainfed irrigation.

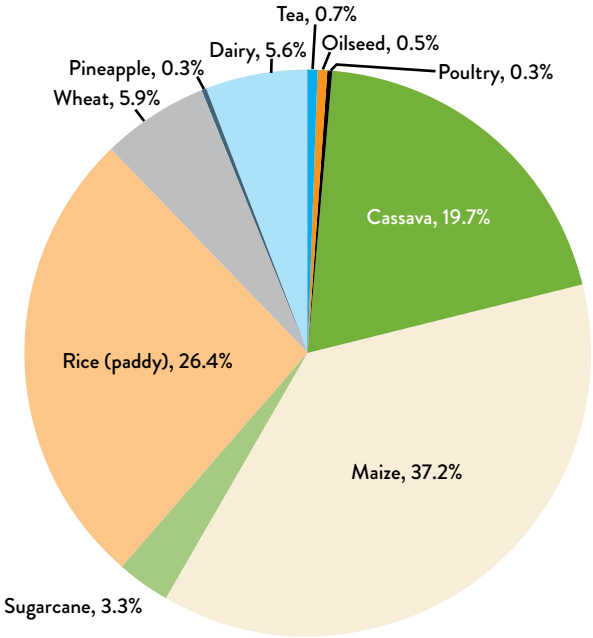
spoilage. Cottonseed crushing is done to produce cottonseed oil (used in some instances as a biofuel for vehicles) and livestock feed. The power demand from cotton cultivation and processing is estimated at 0.03 kW per ha for both large- and small-scale farming production. This implies that a 300 ha cultivated area will have about 9 kW in power demand.

For each of the 13 selected value chains, table 3.4 summarizes the estimated electricity demand for a 300 ha cultivated area and the per-hectare electricity demand estimates from irrigation and processing. The unit estimates show that per-hectare electricity demand is largest for poultry by far, followed by floriculture, tea, and sugarcane. The potential per-hectare demand for poultry (meat) is considerably higher because the process is much more intensive, using less land for a much larger yield. The higher per-hectare demand estimates for large-scale production mainly reflects the use of commercial-scale irrigation and the power input required to process large yields. The range of values for the 300 ha cultivated area is considerable. For small-scale production, potential electricity demand ranges from 9 kW for rice or cotton (lint) to 300 kW for sugarcane. For large-scale production, it ranges from 6 kW for oil palm to 711 kW for floriculture (roses); poultry is an outlier, at 22.5 MW. These estimates are useful for considering whether the economics of these values chains make them viable anchor loads for rural electrification.

Using the forecasted production for the 13 value chains presented in table 3.2, along with the constructed unit electricity demand for each commodity, a bottom-up estimate of the total increase in demand for electricity stemming from the selected value chains can be constructed. The calculations show that electricity demand could increase by 2 GW (from 3.9 GW in 2013 to 6 GW in 2030). This figure represents nearly half of the total potential increase in electricity demand from agriculture calculated for Sub-Saharan Africa in chapter 2 (4.2 GW).

To the extent that the value chains selected represent the best potential of the agriculture and agribusiness

**FIGURE 3.3:** POTENTIAL POWER DEMAND IN 2030 FROM PROCESSING FOR SMALL-SCALE AGRICULTURE, BY SELECTED VALUE CHAINS




*Note:* The underlying calculations assume concave production growth until 2030, based on historical average growth rates (2009–13), and 15 percent of the crop being irrigated and processed—no estimate available for floriculture

sectors in Sub-Saharan Africa, the estimated electricity demand provides a good indication of the possible electricity-agriculture synergies (figure 3.3). The required underlying assumption is the percentage of irrigated and processed production. Clearly, even by 2030, not all production is likely to be cultivated on irrigated land or processed using electricity driven machinery. With little detailed data available on irrigation and processing proportions by value chain, this study makes conservative assumptions for each of the value chains considered: only 15 percent of the land is assumed to be irrigated and 15 percent of crops are assumed to be processed.[20]

## ENDNOTES

1. Of course, all of these factors are correlated. A value chain catering to export markets would likely add more value to the primary product through many production and processing steps and use of greater modern inputs.
2. FAOSTAT 2013 (http://faostat3.fao.org).
3. FAOSTAT 2014 (http://faostat3.fao.org).
4. International Institute of Tropical Agriculture (IITA) (http://www.iia.org/maize).
5. FAOSTAT 2013 (http://faostat3.fao.org).
6. In Zambia, an abundance of water and access to cheap grid electricity have played a significant role in the adoption of large-scale irrigated farming systems.
7. Tea and coffee are Rwanda's most important exports (e.g., tea exports in 2013 totalled US$55 million); see FAOSTAT 2014 (http://faostat3.fao.org).
8. Production growth in Nigeria is driven by poultry-sector demand.
9. Estimates of ECA and Prorustica (2015).
10. For further analysis of commercial irrigated agriculture's potential, see case studies 1 and 3 (chapter 4).
11. The load from processing rainfed tea is just 0.6 kW per ha.
12. Floriculture may not demand a large load in absolute terms as estates are seldom larger than 50 ha (requiring less than 120 kW for production). Exceptions may be additional power requirements for staff housing (see case study 5, chapter 4).

13. Data for horticulture (pineapple) is missing and therefore not included.

14. A complementary analysis is the ongoing work in Latin America and the Caribbean on energizing agriculture; the study estimates energy demand for processing for selected value chains, and proposes energy efficiency options and associated costs (World Bank 2016b).

15. In India, this model has had some success through husk power systems.

16. Data on the electricity requirements of post-harvest activities (juicing, cooling, and canning) were unavailable.

17. An example is Del Monte's biogas plant in Kenya, which is based on pineapple residue.

18. The produced biomass consists of empty fruit bunches (EFBs), palm kernel shells, fibers, and possibly solids from decanters; in most cases, this biomass is used to boil water and generate (super-heated) steam.

19. According to the FAO, economic losses for the dairy sector in Kenya, Tanzania, and Uganda total up to US$56 million per year.

20. The assumption for the irrigated proportion of a crop is in the ballpark of the CAADP target of doubling the land under irrigation by 2030; considering that about 6 percent of cultivated area is currently irrigated (FAO 2005), irrigated production has disproportionately greater yield, and the selected value chains are the best performing crops in the region.

# Lessons from Ongoing Power-Agriculture Integration Projects

## CHAPTER 4

This chapter presents a suite of case studies on power-agriculture integration in several countries of Sub-Saharan Africa. All three countries covered—Tanzania, Zambia, and Kenya—show a high potential for on-farm and agro-processing activities to contribute toward regional and, in some cases, national power-sector development. These cases offer indicative analysis of specific project areas in terms of their potential and viability for furthering rural electrification.[1] The objective is to provide a point of reference for the potential of power-agriculture integration and to highlight some of the important issues to consider in trying to promote such an integration. Each case study project asks (i) whether the investment in expanding rural electrification is economically viable and (ii) under what conditions private-sector participation in electricity supply is feasible.

A standard cost-benefit analysis reveals that most of the projects analyzed are economically viable and are thus worth undertaking by governments.[2] The social and economic benefits generated as a result of rural electrification often outweigh the costs incurred and may justify well-designed subsidies to improve the financial viability of the project. Indeed, if the economic value of the grid extension exceeds the economic costs (due to positive externalities), an otherwise financially unviable project can be undertaken with subsidy financing to cover the shortfall.

In many cases, private-sector participation is desirable for developing and operating electricity supply as it can improve supply efficiency and reduce the financial and capacity burden on public-sector providers. Thus, when analyzing various supply options, it is instructive to consider their commercial viability in order to understand whether private-sector participation is viable and the amount of subsidy that may be required to attract private-sector operators and developers.

Another important consideration is the trade-off between affordability and cost recovery in setting electricity tariffs. While different regulatory environments afford different levels of flexibility in tariff setting for individual schemes, it is instructive to assess the tariff level that can optimally balance the cost recovery objective and affordability, in particular with respect to the anchor customer. The case studies aim to answer two key questions: (i) Up to what price is power affordable for agriculture activities? and (ii) Below what price is power uneconomic to supply?

Each case study is organized into four sections: (i) power demand (agriculture and residential/commercial), (ii) power supply options and commercial arrangements, (iii) financial viability, and (iv) economic viability. Annex D presents the maps corresponding to the case study project areas.

### CASE STUDY 1. TANZANIA: SUMBAWANGA AGRICULTURE CLUSTER

The Sumbawanga agriculture cluster is located in the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), on the country's western border (map D.1). SAGCOT focuses on the coordinated development of small and commercial agriculture, physical and market infrastructure along the transport corridor that runs from Dar es Salaam through to (and immediately across) the Zambian border at Tunduma.[3] Small-scale farmers are integrated into commercial value chains as outgrowers and benefit from the agglomeration economies that lower costs of access to shared infrastructure and inputs (e.g., electricity, roads, markets, labor, and extension services) (table 4.1).

**TABLE 4.1:** SUMBAWANGA AGRICULTURE CLUSTER AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Expansion of electricity supply to support the development of an agriculture cluster and surrounding households through main power grid extension. |
| **COMMODITIES** | Maize, sunflower, finger millet, paddy, and sorghum. |
| **DESCRIPTION** | Powered irrigation and residential demand are the main drivers of increased power demand.<br>Grid extension is a viable option given that the grid extension passes through the Sumbawanga cluster to connect other load centers beyond it. Forecasted size of the load and limited local generation potential make grid extension the most feasible option.<br>Powered irrigation is an important concentrated source of electricity demand. In its absence, greater dispersion of electricity demand over a wider area may reduce viability; thus, a greater cultivated area will be required to have large enough demand from processing. |
| **FINANCIAL VIABILITY** | As a stand-alone project, it is marginally financially unviable. A relatively small increase in electricity demand from agriculture or residential consumers would increase the financial viability of the grid extension. |
| **ECONOMIC VIABILITY** | Economic benefits would be significant (US$134 million) and justify the project. The benefits come mainly from household cost savings, small-scale irrigation, and increased commercial sale of produce. |

Still at a concept stage at the time of this writing, the Sumbawanga agriculture cluster aims to integrate small-scale and commercial farming, along with processing and storage facilities, transport, and logistics hubs, and improved 'last mile' infrastructure to farms and local communities over an area of 27,000 km$^2$. The cluster has strong natural characteristics for agricultural development, including proximity to Lake Tanganyika, good quality soils, and high rainfall. However, owing mainly to its geographical isolation, the area lacks both physical infrastructure (e.g., good roads, rail access, and power) and market infrastructure (e.g., integrated production and processing, traders, finance, and input suppliers).

Access to reliable and affordable electricity is critical to realize the cluster's potential. Currently, the Sumbawanga area benefits from a power capacity of 10.6 MW serving a population of just over 1 million people (table 4.2).[4] Where it is available, farmers and agribusinesses purchase power from TANESCO (including from its mini-grids). There is very little powered irrigation, but a few farmers use petrol and diesel-powered pumps which are inefficient in water use and costly to run. To date, there has been little penetration by solar pumps.

**TABLE 4.2:** SUMBAWANGA GEOGRAPHIC AND DEMOGRAPHIC FEATURES

| Feature | Value |
|---|---|
| Estimated population (2012) | 1,000,000 |
| Population growth rate (%) | 4.0 |
| Electricity connection rate (% of households) | 7.0 |

*Sources:* SAGCOT; ECA and Prorustica (2015).

With demographic and agricultural growth, forecasted demand for electricity is expected to far exceed the currently available capacity. To meet this future demand, the Government of Tanzania, through the Tanzania Electric Supply Company Limited (TANESCO), intends to extend a 220 kV line from Tunduma (on the Zambian border) to Sumbawanga (and beyond through Mpanda to Kigoma on Lake Tanganyika).

### *POWER DEMAND*

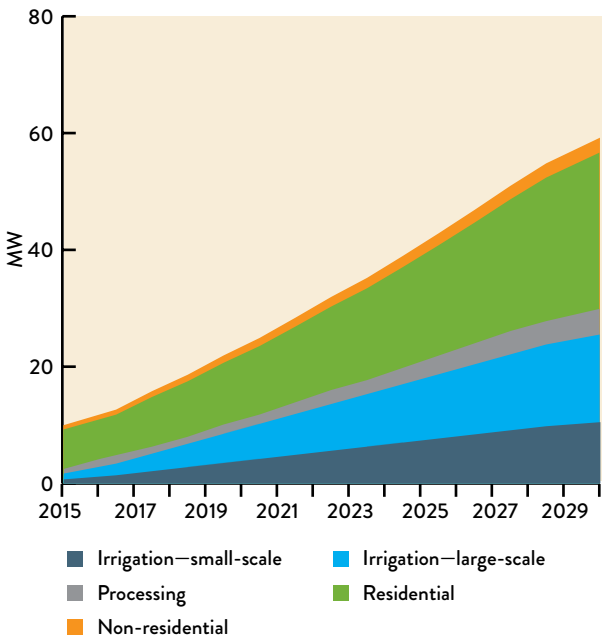
The annual power demand in the Sumbawanga region has the potential to increase to an estimated 60–70 MW by 2030. Irrigation and residential demand are the expected main drivers of load growth, with commercial and processing loads playing a relatively less significant role (figure 4.1).

**Agricultural demand**. The majority of growth in electricity demand from agriculture will come from developing the region's irrigation potential, roughly estimated at 50,000 ha.[5] Assuming 35,000 ha of this amount is dedicated to small-scale agriculture implies a total energy demand of roughly 25.5 MW by 2030 from both bulk water pumping and in-field irrigation. Newly irrigated land, higher quality inputs, crops switching, and knowledge sharing are expected to increase yields from 461,000 MT to 1.09 million MT by 2030 (table 4.3).

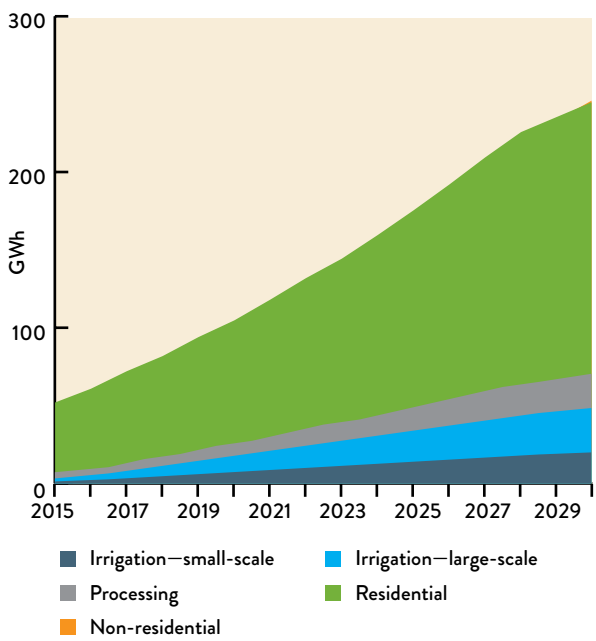
**FIGURE 4.1:** ESTIMATED PEAK LOAD AND ENERGY DEMAND, BY SECTOR

| Source of Demand | Power Capacity Demand (MW) | | Energy Demand (MWh/year) | |
|---|---|---|---|---|
| | 2012 | 2030 | 2012 | 2030 |
| Irrigation | 0.0 | 25.5 | 0 | 48,450 |
| Processing | 0.4 | 4.4 | 2,000 | 22,000 |
| Residential | 3.9 | 26.7 | 26,232 | 174,327 |
| Commercial | 0.2 | 2.6 | 85 | 1,056 |
| **Total** | **4.5** | **59.2** | **28,317** | **245,833** |

a. Peak load




b. Energy demand



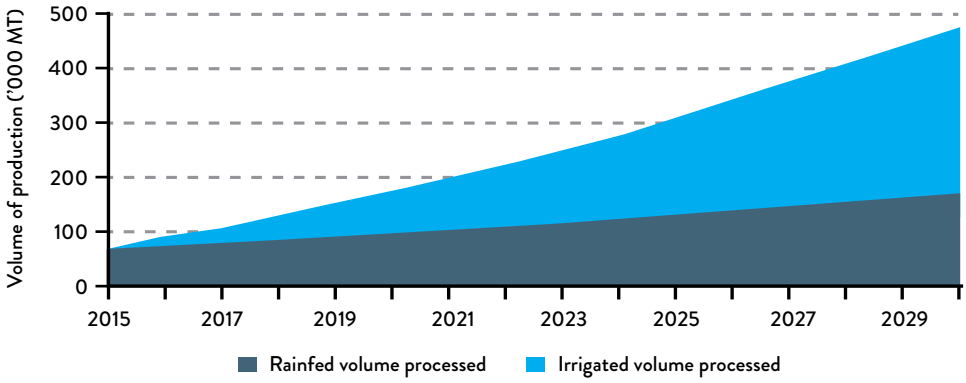

*Source:* ECA and Prorustica (2015).

**TABLE 4.3:** TOTAL POWER DEMAND FROM AGRICULTURE BY 2030

| Agriculture Activity | Power Capacity Demand (MW) | Hours of Operation/Year | Energy Demand (MWh/year) |
|---|---|---|---|
| Irrigation | 25.5[a] | 1,900 | 48,450 |
| Processing | 4.4[b] | 5,000 | 22,000 |
| **Total** | **29.9** | **6,900** | **70,450** |

*Sources:* SAGCOT; JICA; Rukwa District Council; WREM International; ECA and Prorustica (2015).
a. Based on a potential area of 50,000 ha under irrigation and an estimated power demand for irrigation of 0.65kW/ha (0.3kW/ha for small-scale farms and 1kW/ha for commercial farms).
b. Based on a processed production of 472,500 MT and an estimated 11 mills required (400 kW).

**FIGURE 4.2:** ESTIMATED VOLUME OF CROPS THAT MAY UTILIZE ELECTRICITY FOR PROCESSING




*Source:* ECA and Prorustica (2015).

The power demand for post-harvest processing will depend on the crops produced and the volume of production. Electricity demand is expected for post-harvest processing of crops (e.g., milling and oil extrusion) such as maize, paddy rice, beans, millet, sorghum and sunflower.[6] Greater electricity supply and better access to markets for farmers would boost the electrification rate of agro-processing activities. An estimated 40 percent of the current crop yield and an assumed 75 percent of the increased yield due to irrigation expansion will be processed by 2030. Together, this implies an estimated power demand of about 4.4 MW by 2030 (figure 4.2).

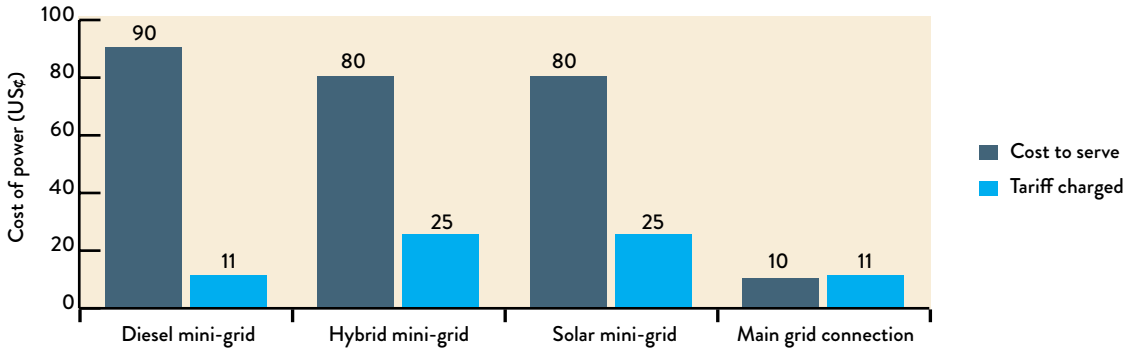
**Residential/commercial demand**. Based on the regional population growth rate of 4 percent, Rukwa's population is expected to reach 2 million by 2030, representing 400,000 households.[7] Considering the households' annual consumption and anticipating that their demand and consumption will likely evolve over time with the adoption of additional electric appliances, residential consumers will be the main driver of energy demand (table 4.4).

**TABLE 4.4:** RESIDENTIAL AND COMMERCIAL DATA TO CALCULATE POWER DEMAND

| Residential | 2012 | 2030 |
|---|---|---|
| Population | 1,000,000 | 2,025,817 |
| Population growth | | 0.04 |
| People per household | 5 | 5 |
| No. of households | 200,000 | 405,163 |
| Household connection rate | 7% | 20% |
| Households connected | 14,000 | 81,033 |
| Per household peak consumption (kW) | 0.28 | 0.33 |
| Per household energy consumption (kWh/month/HH)[a] | 156 | 179 |
| Total peak (MW) | 3.9 | 26.7 |
| **Total energy consumption (MWh)** | **26,232** | **174,327** |
| **Commercial** | | |
| No. of customers | 6 | 75 |
| Consumption peak (kW) | 34 | 34 |
| Consumption energy (kWh) | 14,085 | 14,085 |
| Total peak (MW) | 0.2 | 2.6 |
| **Total energy consumption (MWh)** | **85** | **1,056** |

*Sources:* SAGCOT; ECA and Prorustica (2015).
a. Assumes a daily demand of 5.13 kWh per household.

**FIGURE 4.3:** COMPARATIVE COST OF POWER SUPPLY OPTIONS IN SUMBAWANGA




*Source:* ECA and Prorustica (2015).

Commercial demand from current loads averages 85 kWh per month across six TANESCO customers, with a peak load of 0.21 MW. Should per-customer demand levels remain as observed when electricity was supplied in other areas of comparable size (e.g., Morogoro, Iringa, and Mwanza), the number of customers would increase to 75; thus, annual power consumption would rise to 1,056 MWh by 2030, and power-capacity demand would reach 2.6 MW (table 4.4).

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

The analysis considered various options for additional power capacity to meet projected demand. Localized generation potential from diesel, solar, hybrid, hydro, and bagasse/biomass was considered, along with the option to extend the national grid. Preliminary analysis showed insufficient potential for hydro- and biomass-based generation, so these options were ruled out.

The option to expand mini-grid capacity, based on diesel, solar or a hybrid of the two, was also found unviable for the region. The cost of a diesel-based mini-grid is estimated at US¢90 per kWh, which is much higher than the cost of extending the national grid.[8] Even if hybrid solutions enable the lowering of generation costs (i.e., at US¢80 per kWh), they are still much more costly than grid extension. Finally, solar mini-grids are not adapted to the load profiles of agro-processing and irrigation activities, which would imply expensive investments in storage and backups (figure 4.3).

The least-cost method is thus estimated to be an extension of the national grid. This would allow for more efficient generation capacity sizing for demand on the system at more competitive costs. In deciding how much transmission capacity to invest in, it is more feasible to install adequate capacity to meet future projected demand rather than upgrade capacity in response to increase in demand. The subsection below describes a scenario where sufficient capacity is directly incorporated into a project's initial design.

### *FINANCIAL VIABILITY: EXTENSION OF MAIN GRID FROM MBEYA TO SUMBAWANGA AND RUKWA*

The financial viability of grid extension is estimated from the perspective of TANESCO. To supply activities in Sumbawanga, both grid extension and generation capacity expansion are required. However, generation capacity expansion is on a national least-cost basis; the focus here is on the viability of the transmission and distribution network development (table 4.5).

The costs associated with provision of grid electricity to Sumbawanga consist of the cost of electricity generation and transmission and distribution costs (expansion and operation). The corresponding revenues would be those of electricity sales at the national tariff level (table 4.6).

**TABLE 4.5:** ESTIMATED CAPITAL AND OPERATING COSTS FOR TRANSMISSION AND DISTRIBUTION EXPANSION

| Grid Extension Assumptions | Distance (km) | Cost (thousand US$/km) | Total Cost (million US$) | Operating Expense Assumption (%) | AC Losses (%) |
|---|---|---|---|---|---|
| 11 kV | 200 | 15 | 3.3 | 3 | 4.6 |
| 33 kV | 200 | 35 | 7.7 | 3 | 4.6 |
| 220 kV | 350 | 138 | 53.1 | 3 | 4.6 |
| **Subtotal (million $)** | | | **64.1** | | |
| Present value (million $) | | | 61.2 | 18.3 | 3.8 |
| **Total (million $)** | | | | | **83.4** |

*Sources:* Ministry of Energy and Minerals (MEM), Power System Master Plan; ECA and Prorustica (2015).

**TABLE 4.6:** ESTIMATED POWER CONSUMPTION AND TRANSMISSION AND DISTRIBUTION TARIFF REQUIREMENT

| Variable | Value |
|---|---|
| Cost (million US$) | 83.36 |
| Estimated consumption (MWh) | 1.2 million |
| **Transmission and distribution, tariff requirement (US¢/kWh)** | **6.9** |

*Source:* ECA and Prorustica (2015).

**TABLE 4.7:** FINANCIAL PRESENT VALUE OF GRID EXTENSION

| Variable | Value (million US$) |
|---|---|
| Revenue, based on TANESCO tariff | 167.34 |
| Transmission costs | (83.36) |
| Generation costs | (89.83) |
| **Effective project shortfall** | **(5.85)** |
| **Internal rate of return (%)** | **12** |

*Sources:* ECA and Prorustica (2015); World Bank.
*Note:* Assumes a consumption of 1.2 million MWh over 20 years. The generation cost is based on cost for the upcoming Kiwira coal plant, at US¢ 7.5 per kWh (TANESCO 2012 Power System Master Plan Update, May 2013). The coal plant near Mbeya is expected to be completed by 2020. The average retail tariff is about US¢ 14 per kWh.

At the assumed 10 percent average cost of capital, the project is marginally financially unviable as a stand-alone project (table 4.7). However, TANESCO's ability to attract financing on more favorable terms or greater revenues from electricity demand, would improve the project's financial viability. On the other hand, a larger proportion of consumers paying lower lifeline tariffs, lower electricity demand, and/or higher costs would further reduce the financial viability of the investment in grid extension.

### *ECONOMIC VIABILITY*

Analysis of the project's economic viability adds social net benefits to the financial net benefits accruing to the developer (TANESCO). Thus, the economic analysis includes benefits accruing to newly connected households, benefits from improvement in agricultural yields, market access, and jobs creation (table 4.8).

The economic analysis shows that the economic benefits significantly outweigh the associated costs. In fact, the benefits accruing to the households alone are sufficient to justify the investment in grid extension.

**TABLE 4.8:** ECONOMIC COSTS AND BENEFITS OF SUMBAWANGA GRID EXTENSION

| Economic Cost/Benefit | Beneficiaries (number) | Present Value of Cost/Benefit (million US$) |
|---|---|---|
| Net financial costs | | (5.85) |
| Household cost savings[a] | 52,671 households by 2030 | 42.00 |
| Small-scale irrigation | 35,000 farmers (1 ha each) | 34.50 |
| Margin uplift from market access | All small-scale farmers | 26.80 |
| Import substitution | Tanzania broadly | 8.52 |
| No. of jobs created by electrifying the agriculture field | 3,750 | 24.00 |
| No. of jobs created by electrifying the town | 550 | 4.20 |
| **Economic net present value** | | **134.14** |

*Source:* ECA and Prorustica (2015).
a. These are the additional households that are assumed to be connected from the grid extension project—over and above the baseline (w/o project). Additional household benefits may include better health outcomes from reduced fuel use, better educational outcomes for school going children, women's time savings, and better nutrition.

## CASE STUDY 2. TANZANIA: MWENGA MINI-HYDRO MINI-GRID

The 4 MW Mwenga mini-hydro mini-grid project is located in Tanzania's Southern Highlands, close to the Mufindi Tea and Coffee Company (MTC) (map D.2). The project is operated by the Rift Valley Energy (RVE), a 100 percent subsidiary of the Rift Valley Corporation, which also owns MTC. The project came about as a result of MTC's need to supplement electricity from the main grid to ensure access to a reliable source of uninterrupted power. Cofinanced by the European Union (EU) and the Rural Energy Agency (REA), the project was developed as an independent power producer (IPP) to supply power to the main grid, local tea industry, and surrounding rural communities. The project was the first green-field development under the Small Power Purchase Agreement (SPPA) scheme. The SPPA was signed with TANESCO in 2009, and the plant was commissioned in 2012 (table 4.9). RVE owns and operates the distribution network connecting roughly 20 villages and relies on a mobile phone based pre-paid vending system for electricity billing.

Notwithstanding its long and complex development process, Mwenga is considered Tanzania's most successful private mini-grid development project. For the tea factory, the mini-grid is an opportunity to switch from grid-based power to a more reliable supply produced by renewables. Although the project was initially designed to supply only the MTC, having power lines extending from

**TABLE 4.9:** MWENGA MINI-HYDRO MINI-GRID AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | A 4 MW hydro mini-grid connected to the main grid. Main local anchor load is the Mufindi Tea Estates and Coffee Limited; 2,600 households connected in the surrounding communities. |
| **COMMODITIES** | Coffee, tea. |
| **LESSONS LEARNED** | The tea estate is the main anchor load of the grid connected mini-grid. Given the seasonality in tea processing operations, the peak load demand more than doubles during the summer season. This impacts the choice of power supply arrangement.<br>Excess supply was sold to the grid, which helps mitigate the impact of seasonality. While residential consumers are numerous, their power demand is not high enough, at least initially, to mitigate the impact of a seasonal anchor load. |
| **FINANCIAL VIABILITY** | The project's financial viability depends critically on the ability to sell excess power to the main grid. Despite financial viability, capital subsidies were provided for the project to keep local electricity tariffs low. |
| **ECONOMIC VIABILITY** | Economic benefits are positive (US$9 million) and come from households' energy cost savings, reduced reliance on diesel backup for the tea estate, and job creation from new electrified businesses. |

the hydro plant through nearby villages facilitated the connection of 2,600 households, as well as other community facilities. Beyond enhancing electricity access, the project has replaced the use of diesel and kerosene with sustainable hydropower among neighboring communities.

### *POWER DEMAND*

Demand for power from the Mwenga mini-grid comes from the main grid (TANESCO), commercial and community users, agriculture, and residential customers. As local demand is expected to grow, the sales to the grid are expected to decline. Local demand growth is expected to be led by the informal and semi-formal agriculture and forestry sectors, highlighting the significant economic development potential of the project.

**Agricultural demand**. In terms of power for agriculture, MTC mainly requires electricity for processing. Specifically, electricity is used to power large motors, fans, and vibrating sieves (used to cut to length the leaves, and wither, dry, sort, and grade the tea). The tea factory's peak load averages about 700 kW (with a summer peak of 900 kW and a winter peak of 400 kW), with an annual power consumption of 2,880 MWh.[9]

**Community and commercial demand**. In addition to supplying agro-processing activities, the Mwenga mini-grid project specifically targets facilities such as schools and clinics, as well as small commercial businesses, thereby improving electricity access for productive uses. According to RVE, annual power consumption for community and commercial users is estimated at 2,988 MWh.

**Residential demand**. Residential customers comprise the majority of the customer base; however, most residential customers have very low demand and pay lifeline tariffs. Annual demand from the 2,600 customers is estimated at just 936 MWh (table 4.10).

All excess power from the mini-grid (about 80 percent of generated power) is sold to TANESCO, in accordance with its SPPA and feed-in tariff (FiT) arrangement; these have been instrumental in guaranteeing offtake and have helped justify development of a scheme of its size, thus benefiting from economies of scale. Selling power only to local consumers would not have justified the project in terms of its scale or commercial viability.

### *POWER SUPPLY OPTIONS, COMMERCIAL ARRANGEMENTS, AND FINANCIAL ANALYSIS*

Proximity to the Mwenga River enabled the tea plant to access a renewable source of power, with sufficient volume and head to develop a 4 MW run-of-the-river, mini-hydro plant. The project is owned and operated by MTC's sister company and both are held by the RVC parent company.

The project was developed as a private-public partnership and partly funded through public funds, including elements of grant and concessional loans from the EU and REA.[10] The use of concessional funds was necessary to reduce the tariff burden on local electricity customers. While the electricity regulator allowed RVE to set cost-reflective tariffs, as per Tanzania's SPP framework, fairness and affordability concerns led to the tariff being set in line with the tariff on the main grid. The regulator has allowed recent adjustments in the tariff, which is currently TZS 100 per kWh up to 75 per kWh (equivalent to US¢6.25 per kWh under the pre-devaluation exchange rate). However, since 80 percent of the generated power is sold to TANESCO under the SPPA and FiT, the viability of Mwenga's hydro plant is not relying on the profitability of selling electricity to local communities.

**TABLE 4.10:** ESTIMATED POWER DEMAND FROM MWENGA MINI-HYDRO PLANT

| Customer Group | Connections (current) | Forecast Connections (2030) | Approved Tariff (TZS/kWh) | Total Monthly Usage (all customers) (MWh) |
|---|---|---|---|---|
| Households | 2,600 | 5,600 | 100 | 78 |
| Commercial | 374 | 557 | 205 | 114 |
| Public/community services | 468 | 668 | 205 | 135 |
| Tea estate | 1 | 1 | Uncertain | 240 |
| TANESCO | 1 | 1 | 189 | 1,922 |
| **Total monthly usage (MWh)** | | | | **2,489** |

*Source:* RVE.

**TABLE 4.11:** ECONOMIC COSTS AND BENEFITS OF MWENGA MINI-HYDRO PLANT

| Economic Cost/Benefit | Benefits | Present Value of Cost/Benefit (million US$) |
|---|---|---|
| Net financial costs | | 0.0 |
| Development subsidies received by project | | (7.1) |
| Household cost savings (no. of households)[a] | 5,600 | 6.4 |
| Tea company savings from reduced diesel backup requirement (hours/year)[b] | 288 | 1.4 |
| Jobs created by electrifying villages (no.)[c] | 1,120 | 8.6 |
| **Economic NPV** | | **9.3** |

*Source:* ECA and Prorustica (2015).
a. Households are assumed to save $14 per month from access to electricity; b. diesel backup requirement is assumed to be 10% of the total power consumption; c. it is assumed that 65 percent of the businesses will each create 1.5 jobs. Each job created is valued at the average expected salary: $1500/year.

### *FINANCIAL ANALYSIS*

The financial analysis considers the Mwenga mini-hydro project from the perspective of the revenues and costs incurred by the owner, RVE. However, information on revenue, operating cost, and capital expenditures was confidential and thus not available. Despite this limitation, discussions with the operator allow us to make certain salient points:

- Tanzania's SPP framework allows RVE to charge a tariff that should ensure full cost-recovery, including a return on capital, even if all capital is at commercial rates, and adjusted for any subsidies received.
- In practice, social concerns implied that the tariff was set equal to the main grid. Thus, in order to accommodate this lower tariff, subsidies for capital expenditure were sought to reduce the effective cost recovery, such that it aligned with the tariff.

Given that RVE, a private-sector company, continues to operate the facility, one can assume that the project at least breaks even financially.

### *ECONOMIC ANALYSIS*

Economic net present value (NPV) is estimated at about US$9 million, based on a 10 percent discount rate over the assumed project life till 2030 (table 4.11). Benefits accrue from household energy cost saving, reduced reliance on diesel backup for the tea estate, and job creation from newly electrified businesses.

## **CASE STUDY 3.** ZAMBIA: MKUSHI FARMING BLOCK

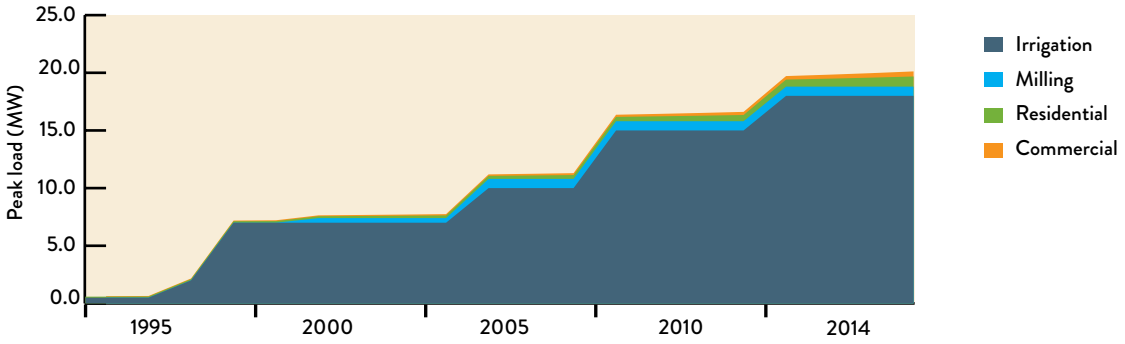
The Mkushi farming block project is located in Zambia's Central Province (300 km northeast of Lusaka) and stretches over 176,000 ha of land (map D.3). The Mkushi farming block is one of Sub-Saharan Africa's largest multi-farmer commercial farming areas outside South Africa. Mkushi produces the largest share of Zambia's wheat (40 percent) and soybean (21 percent), and is its sixth largest maize producer. Other export crops grown in the area include tobacco, soya, vegetables, and coffee (Chu 2013). Mkushi experiences distinct dry winter seasons (May to October) and wet summer seasons (November to April). Irrigation is thus critical for growing winter crops, especially wheat (table 4.12).

Electrification of the Mkushi farming block occurred over time, given the evolving demand and difficulty of raising the necessary capital. Mkushi was first connected to the grid in 1996 through a 33 kV line. This effort was financed by the government and a group of 20 farmers who contributed US$10,000 per km (50 percent of the total cost), which was the policy of the Zambia Electricity Supply Corporation (ZESCO) at the time. However, unreliable power supply due to inadequate feeder capacity meant that farmers had to continue to use backup diesel generators for irrigation. A subsequent grid expansion was undertaken in 2000, followed by a third in 2005 to connect all farmers and many households in the area. Expansion of the national grid into the area has enabled the area under irrigation to expand to about 18,000 ha

**TABLE 4.12:** MKUSHI FARMING BLOCK AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Extending a transmission line into a farming area with significant agricultural potential. |
| **COMMODITIES** | Wheat, soybean, tobacco, soya, vegetables, coffee. |
| **DESCRIPTION** | Irrigation counts for more than 90 percent of total power demand. Given their interest in the project, farmers accepted to contribute to capital costs. The grid extension enables a significant increase in household connection rates (from 2 percent in 1995 to 7 percent in 2014). However, more than 30,000 households remain unconnected to the main grid. |
| **FINANCIAL VIABILITY** | From a purely financial perspective and as a stand-alone project, grid extension to Mkushi was not profitable for the utility. However, in order to expand access to new farmers coming into the area, sharing of capital costs was an appropriate and successful approach to project financing. |
| **ECONOMIC VIABILITY** | Thanks to household energy cost savings, increased yields from irrigation on small-scale farms, and job creation, the project's economic NPV was positive (US$46 million). |

**FIGURE 4.4:** TOTAL PEAK LOAD IN MKUSHI, 1995–2014




*Source:* ECA and Prorustica (2015).

and led to the subsequent development of milling activities.

Out of 150 commercial farms hosted on the farming block in 2014, 80 farms have developed irrigation schemes to enable wheat production in winter and to supplement summer crops. The availability of water and the connection to the national grid, supported by ZESCO and the Zambia National Farmers Union, were central to development of these irrigation schemes and processing facilities.

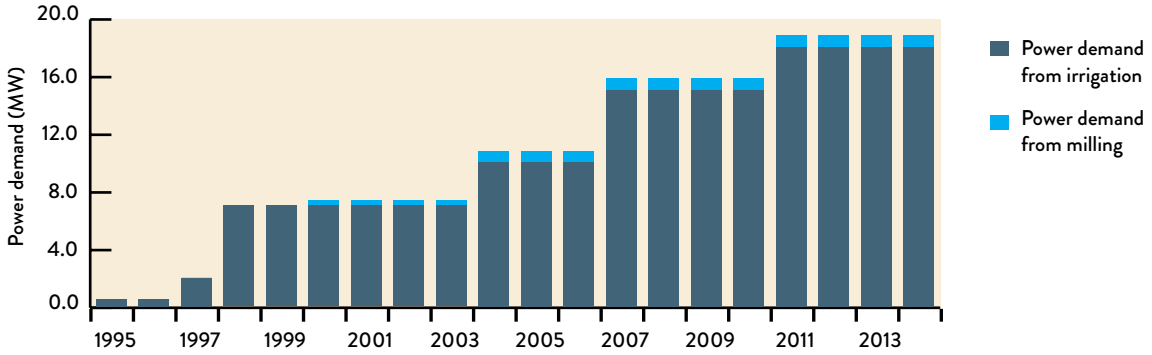
### *POWER DEMAND*

Between 1995 and 2014, overall peak load in Mkushi (from agriculture, residential, and commercial consumption) increased from 0.6 MW to 20.1 MW. Over that period, irrigation accounted for more than 89 percent of total power demand (figure 4.4).

**Agricultural demand**. Among agriculture activities, irrigation has been the main driver of power demand, with milling accounting for only a small share of total agricultural power demand. Power demand for irrigation grew from 0.5 MW to 18 MW between 1995 and 2014, with a yearly consumption of 34,200 MWh in 2014 (figure 4.5).[11] In addition to development of irrigation schemes, two mills were installed in the area following arrival of the grid. Power demand for milling was estimated at 800 kW,[12] for a consumption of 4,000 MWh (table 4.13).

**Residential/commercial demand**. Between 1995 and 2014, household connection rates grew from 2 percent to 7 percent, with the corresponding number of connected households increasing from 362 to 2,516 (table 4.14). Over the same period, power demand from residential and commercial customers increased from 0.13 MW to 1.32 MW, with households representing 67 percent.

**FIGURE 4.5:** POWER DEMAND FROM IRRIGATION AND MILLING IN MKUSHI, 1995–2014




*Source:* ECA and Prorustica (2015).

**TABLE 4.13:** POWER REQUIREMENTS FOR IRRIGATION AND MILLING IN THE MKUSHI FARM BLOCK

| Agricultural Activity | Requirement | 1995 | 2000 | 2005 | 2014 |
|---|---|---|---|---|---|
| Irrigation | Irrigated land area (ha) | 500 | 7,000 | 10,000 | 18,000 |
| | Power demand (MW) | 0.5 | 7 | 10 | 18 |
| | Power consumption (MWh) | 950 | 13,300 | 19,000 | 34,200 |
| Milling | Power demand (MW) | 0 | 0.4 | 0.8 | 0.8 |
| | Power consumption (MWh) | 0 | 2,000 | 4,000 | 4,000 |

*Sources:* Ministry of Agriculture; ECA and Prorustica (2015).

**TABLE 4.14:** ELECTRIFICATION RATES AND POWER LOAD OF HOUSEHOLDS IN MKUSHI

| Consumer Type | 1995 | 2000 | 2005 | 2014 |
|---|---|---|---|---|
| **Residential** | | | | |
| Households (no.) | 18,092 | 21,488 | 25,521 | 34,782 |
| Household connection rate (%) | 2 | 3 | 4 | 7 |
| Households connected (no.) | 362 | 603 | 1,004 | 2,516 |
| Power demand per household (kW) | 0.24 | 0.26 | 0.29 | 0.35 |
| Peak demand (MW) | 0.09 | 0.16 | 0.29 | 0.88 |
| Total consumption (MWh)[a] | 222 | 408 | 751 | 2,247 |
| **Commercial** | | | | |
| Total demand (MW) | 0.04 | 0.08 | 0.15 | 0.44 |
| Total consumption (MWh)[b] | 190 | 349 | 642 | 1,921 |

*Sources:* Ministry of Agriculture; Zambia Census 2010; ECA and Prorustica (2015).
a. Assuming household energy consumption of 75 kWh/month. b. Assuming that commercial consumers operate 14 hour per day 6 days a week.

Total power demand in 2014 was 20.1 MW, with corresponding annual energy demand of 42,368 MWh. Of this amount, 18 MW came from irrigation, 0.8 MW from processing, 0.88 MW from households, and 0.44 MW from commercial customers.

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

Zambia has one of the lowest electricity tariffs in Sub-Saharan Africa owing to fully depreciated hydropower dominating the generation mix. This implies considerable benefits from reliable electricity supply to farmers who previously relied on backup diesel generation. This, along with the relative proximity of the main grid, ruled out a mini-grid option.

As described above, to extend the grid to Mkushi, farmers were initially required to apply to ZESCO, specifying their peak demand load. They were required to cofinance up to 50 percent of the cost of the line extension and pay for the transformers.

### *FINANCIAL ANALYSIS*

Given the cofinancing arrangement, the financial analysis of extending the grid to the Mkushi farming block was analyzed from the perspective of both ZESCO and a representative farmer newly settled in the area. From the utility's standpoint, even after capital costs were partially paid for by customers, the revenue generated from the grid extension remained below the costs incurred. The financial NPV was estimated at US$8.9 million, mainly because of the very low electricity tariffs (table 4.15).

The farmer was required to invest in half of the line extension for 20 km (US$10,000 per km), a transformer ($50,000), and irrigation capital ($2,500 per ha).

**TABLE 4.15:** FINANCIAL ANALYSIS OF MKUSHI FARMING BLOCK FROM THE PERSPECTIVE OF THE UTILITY AND A REPRESENTATIVE FARMER

| Factor | Thousands of US$ | | | |
|---|---|---|---|---|
| | 1995 | 2000 | 2005 | 2014 |
| **UTILITY** | | | | |
| Tariff revenue | 14 | 161 | 244 | 424 |
| Capital costs | 1,300 | 10,000 | 5,045 | 0 |
| Operating costs | 39 | 339 | 342 | 342 |
| Net benefits | −1,325 | −10,178 | −5,142 | 82 |
| **Financial NPV**[a] | **−8,89** | | | |
| **REPRESENTATIVE FARMER (500 ha of irrigated land)**[b] | | | | |
| **Wheat** | | | | |
| Extra profit | 60 | | | |
| **Maize** | | | | |
| Extra production because of irrigation (MT) | 1,250 | | | |
| Extra profit | 199 | | | |
| Total extra revenue from irrigation | 259 | | | |
| Capital costs | 1,500[c] | | | |
| Electricity consumption from irrigation (MWh) | 950 | | | |
| Cost of electricity | 33 | | | |
| Net benefits | −1,275 | 226 | 226 | 226 |
| **Financial NPV** | **523** | | | |
| **IRR (%)** | **17** | | | |

*Note:* The financial NPV is calculated over a 20-year project life starting from the initial investment (1995–2014).
a. The estimated negative NPV is over 20 years. Given the magnitude of the stream of revenues relative to the costs, considering 30-year project life will not make the project financially viable from the utility's perspective.
b. Irrigated production of 500 ha of wheat in winter and 500 ha of maize in summer.
c. For a 20km connection expansion.

However, after deducting the cost of electricity and capital costs from the extra profit generated by irrigation, the financial NPV for a representative farmer was positive ($522,653), showing that the representative farmer benefited from increased yields, owing to supplementary summer irrigation, as well as irrigated winter cropping (table 4.15).

### *ECONOMIC ANALYSIS*

From an economy-wide perspective, between 1995 and 2014, the largest benefits from access to grid electricity accrued from savings on electricity expenditure, displacement of imports due to increased wheat and maize yields and job creation (table 4.16). The economic NPV is estimated at about US$46 million, which justifies the 130-km grid extension (table 4.17).

The project faced various implementation barriers. Since it was not financially profitable for the utility, the shortfall had to be covered by subsidies. Other issues that had to be overcome included lack of access to capital for project financing, lack of coordination between farmers, and insufficient grid capacity to provide reliable power supply. Moreover, ZESCO and farmers competed over water availability and use; the utility wanted water for its hydropower plant, while the farmers wanted it to irrigate their lands.

**TABLE 4.16:** NET SOCIAL BENEFITS OF GRID EXTENSION, MKUSHI

| Factor | 1995 | 2000 | 2005 | 2014 |
|---|---|---|---|---|
| **Savings on Energy Consumption** | | | | |
| Electrification rate (%) | 2 | 3 | 4 | 7 |
| Households electrified (no.) | 362 | 603 | 1,004 | 2,516 |
| Savings from grid electrification per household ($/month) | 10 | | | |
| Total savings on energy consumption (million $) | 0.04 | 0.07 | 0.12 | 0.30 |
| **Import Savings** | | | | |
| **Wheat** | | | | |
| Irrigation area (ha) | 500 | 7,000 | 10,000 | 18,000 |
| Production (MT) | 3,000 | 42,000 | 60,000 | 108,000 |
| Import substitution value of wheat (million $)[a] | 0.21 | 2.94 | 4.20 | 7.56 |
| **Maize** | | | | |
| Production without irrigation (MT) | 2,750 | 38,500 | 55,000 | 99,000 |
| Production with large-scale irrigation (MT) | 4,000 | 56,000 | 80,000 | 144,000 |
| Benefit of locally grown production over imports (million $)[a] | 0.11 | 1.51 | 2.15 | 3.87 |
| **Revenue from Job Creation** | | | | |
| Job creation from area under irrigation | 143 | 2,008 | 2,868 | 5,163 |
| Extra income from irrigation (million $) | 0.22 | 3.01 | 4.30 | 7.74 |
| **Present Value of Social Benefits over the Period 1995–2014 (million $)** | | | | **65.47** |

*Note:* Assumes a 10 percent discount rate over a 20-year project life.
a. Import substitution is valued at the difference between farm gate price in Zambia and import price.

**TABLE 4.17:** ECONOMIC COSTS AND BENEFITS OF GRID EXTENSION, MKUSHI

| Factor | Value (million US$) |
|---|---|
| Financial NPV of utility | −8.90 |
| Present value of capital cost contributions from farmers | –10.83 |
| Present value of social benefits | 65.47 |
| **Economic NPV** | **45.74** |

*Source:* ECA and Prorustica (2015).

## CASE STUDY 4. ZAMBIA: MWOMBOSHI IRRIGATION DEVELOPMENT AND SUPPORT PROJECT

The Mwomboshi Irrigation Development and Support Project (IDSP) is situated along the banks of the Mwomboshi river in Zambia's Central Province (World Bank 2011b) (map D.4). The IDSP aims to support irrigation development in order to increase agricultural yields and incomes in the area. The project also includes support for complementary infrastructure, including roads and electricity. Irrigation will be developed from water storage (via construction of small- and medium-sized dams) and transport to individual farms (table 4.18). An extension of the grid to and within the site will be funded under the project and handed over to the utility to operate (ZESCO).

Direct beneficiaries of the IDSP are the area's 3,700 inhabitants, along with small-scale and commercial farmers. Commercial farms are located along the southern bank of the river, while small-scale farming is mainly on the north side. The connection to electricity is critical to enable irrigation development, which creates greater opportunities to increase incomes.

Covering 100,000 ha, on-farm irrigation development can be categorized into four tiers: (1) small parcels of less than 1 ha each, which utilize flood irrigation systems; (2) individual farms with parcels in a range of 1–5 ha, which utilize spraying irrigation schemes; (3) plots larger than 60 ha each, cultivated by a community or commercial farm that uses modern irrigation systems (e.g., center pivots); and (4) large parcels cultivated by large-scale commercial farmers that are supplied water through a bulk-water storage facility (figure 4.6).

### *POWER DEMAND*

Currently, Mwomboshi's access to grid electricity is low. The northern bank of the river has no electricity supply. Among small-scale farmers who are not connected to electric power, only a small portion uses petrol or diesel pumps for irrigation purposes. Along the southern bank, electricity from the national grid is used to power staff housing, crop irrigation, processing, and other small-load activities (e.g., offices, water pumping, and tea drying).

Planning for sufficient capacity to consider future loads from expanded farming activities includes upgrading the current 11 kV line to a 33 kV line with a 30 km grid extension to the north side of the river, which would provide all farmers with electricity. By 2031, it is estimated that the aggregated peak load from agriculture, households, and commercial activities will reach 6.4 MW, representing an 18.5 percent average annual increase from the 2016 peak load (figure 4.7a). Driven by irrigation, power consumption is forecasted to reach up to 15,000 MWh by 2031 (figure 4.7b).

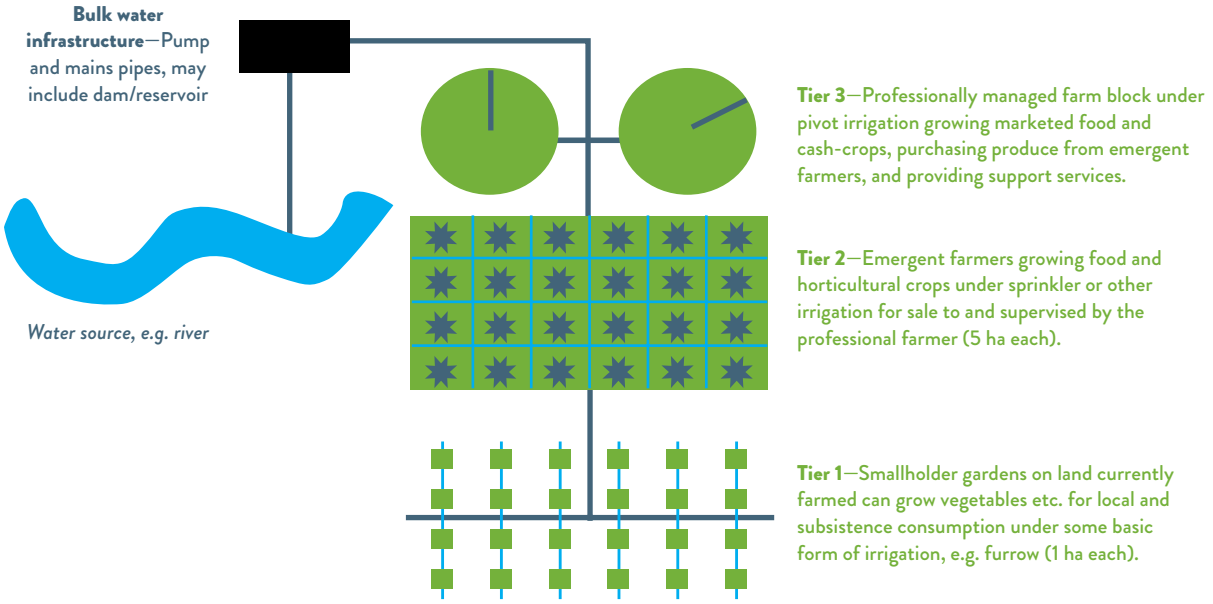
**Agriculture demand (irrigation)**. In addition to the 439 ha currently underirrigated in Mwomboshi, the IDSP plans to add an extra 3,200 ha, distributed between small-scale and commercial-scale farms. This will allow for the release of bulk water supplied from a water storage dam through pump stations for irrigation schemes. The project will become the area's major power load, requiring 2 MW to supply the southern bank of the dam and 3.1 MW for the north side. Once the first pumps are installed, the power consumption of pumping stations is forecasted to rise from 872 MWh in 2016 to about 10,000 MWh by 2031 (table 4.19).

**Agriculture demand (milling)**. Development of the region's wheat milling capacity will evolve along with the increasing yields expected from irrigation. Total energy

**TABLE 4.18:** MWOMBOSHI IRRIGATION DEVELOPMENT AND SUPPORT PROJECT AT A GLANCE

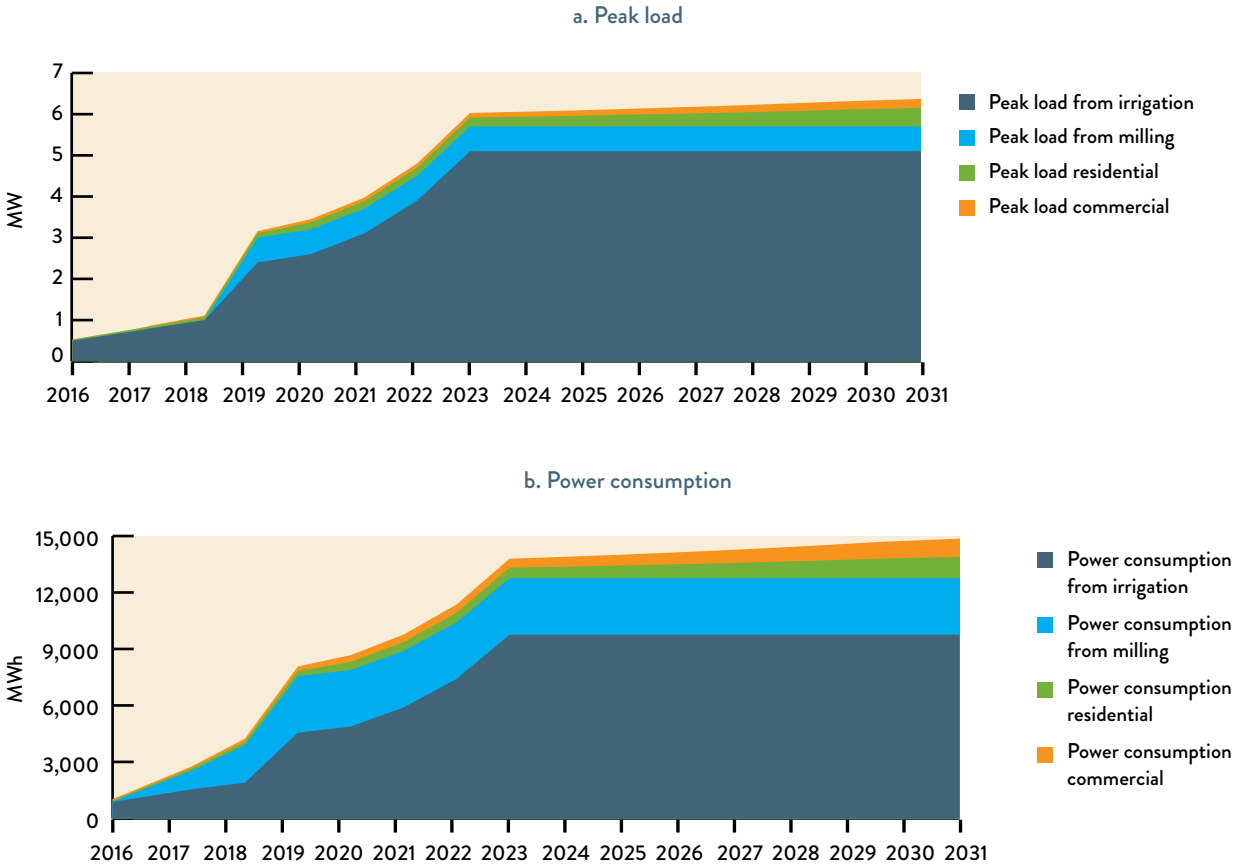
| | |
|---|---|
| **PROJECT OVERVIEW** | Grid upgrade and extension to support irrigation development and household electrification. |
| **COMMODITIES** | Tobacco, wheat, poultry, maize, sunflower, horticulture (tomatoes, onions, bananas). |
| **DESCRIPTION** | Electrification is mainly driven by irrigation of small-scale and commercial farming, leading to crop diversification and increased yields. The project also targets near universal residential access in the area by 2031.<br>Proximity of the existing grid and power needs meant grid extension was the only option considered viable. |
| **FINANCIAL VIABILITY** | Positive financial NPV estimated at US$1.1 million. |
| **ECONOMIC VIABILITY** | Positive economic NPV estimated at US$2.0 million for the power line extension, mainly from greater irrigated tomato and maize production. |

**FIGURE 4.6:** MWOMBOSHI IDSP PLOT SITES DEVELOPED FOR SMALL-SCALE FARMERS




*Source:* World Bank 2011b.

**FIGURE 4.7:** MWOMBOSHI PEAK LOAD AND POWER CONSUMPTION FORECAST




*Source:* ECA and Prorustica (2015).

**TABLE 4.19:** IRRIGATION POWER REQUIREMENTS IN MWOMBOSHI, ZAMBIA

| Irrigation Requirement | 2016 | 2031 |
|---|---|---|
| Power demand (MW) | 0.5 | 5.1 |
| Power consumption (MWh) | 872 | 9,757 |

*Source:* ECA and Prorustica (2015).

**TABLE 4.20:** MILLING POWER REQUIREMENTS IN MWOMBOSHI, ZAMBIA

| Milling Requirement | 2016 | 2031 |
|---|---|---|
| Power demand (MW) | 0 | 0.6 |
| Power consumption (MWh) | 0 | 3,000 |

*Source:* ECA and Prorustica (2015).
*Note:* Assumes a mill operates 5,000 hours per year (16 hours a day, 6 days per week)/mill size: 200 kW.

demand from milling is expected to be significantly lower than that from irrigation (table 4.20). The first mill is expected to be installed when total production from commercial farmers and the marketed portion (80 percent) of small-scale production reaches 20,000 MT. The plan is to add an additional mill for every 20,000 MT of extra production.

**Residential/commercial demand**. The IDSP plans to increase household connections from 15 percent (2014) to 97 percent (2031). Based on a per-household power demand estimate, peak load would increase by 2 percent a year as the household load evolves over time. Total residential peak load should therefore increase from 0.03 MW in 2016 to 0.45 MW by 2031, while electricity consumption over this period should rise from 78 MWh to 1,137 MWh. Nonresidential demand, led by commercial activities, is assumed at half of residential power consumption. Its peak consumption is thus expected to increase from 0.015 MW in 2016 to 0.22 MW by 2031 (figure 4.8).

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

Since the southern part of the area is already connected to the national grid, no other supply option has been considered for improving power availability. To do so, the Ministry of Agriculture and Cooperatives and ZESCO will sign a Memorandum of Understanding (MOU) framing responsibilities for the construction and maintenance of the new power line. ZESCO will own the assets and be responsible for line maintenance after construction and will recover its operating costs through tariff revenues.

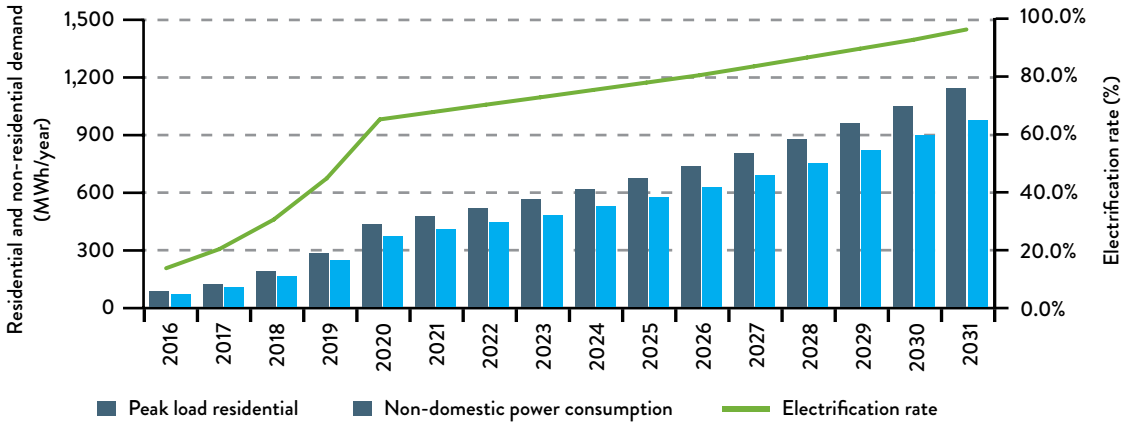
### *FINANCIAL ANALYSIS*

From ZESCO's perspective, the grid upgrade project in Mwomboshi is financially viable, with a positive NPV of US$1.1 million. Given the current average electricity tariff of US¢3.5 per kWh and the estimated level of demand, the utility's revenues are calculated as the additional revenues received by the utility due to the project (table 4.21).

### *ECONOMIC ANALYSIS*

The IDSP is estimated to generate positive net benefits with a NPV of US$2.0 million. The economic benefits are driven largely by the increase in yields of irrigated tomato,

**FIGURE 4.8:** RESIDENTIAL AND COMMERCIAL DEMAND, ELECTRIFICATION RATE 2016–2031




*Source:* ECA and Prorustica (2015).

**TABLE 4.21:** FINANCIAL ANALYSIS, MWOMBOSHI

| Factor | Assumption |
|---|---|
| Electricity tariff (US¢/kWh) | 3.5 |
| Transmission tariff (US¢/kWh) | 1.0 |
| Transmission OpEx (% of CapEx) | 3 |
| Cost of capital (%) | 10 |
| Line expansion (km) | 30 |
| Cost of grid expansion ($/km) | 30,000 |
| Total cost of transformers ($) | 175,000 |
| **Net Present Value (NPV) Calculations 2016–2031** | |
| Present value of revenues (million $) | 2.4 |
| Capital costs (million $) | 1.1 |
| Present value of operating costs (million $) | 0.3 |
| **Financial NPV (million $)** | **1.1** |
| **IRR (%)** | **20** |

*Source:* ECA and Prorustica (2015).

wheat, and maize production (table 4.22). Irrigation will allow farmers to increase production through better yields and crop diversification. The electrification savings to farmers from using diesel pumps and switching to electrified irrigation schemes will be minor since only a small number of farmers are currently using these irrigation solutions. As a result, the total present value of social benefits for the entire project is estimated at US$34 million. However, as these benefits are the result of the whole irrigation project in Mwomboshi (not only the electrification component), the share of the cost of power line extension is used as a benchmark to allocate the share of benefits accruing to the electrification investments in the project area.

## CASE STUDY 5. KENYA: OSERIAN FLOWERS AND GEOTHERMAL POWER

The Oserian Development Company Limited (ODCL) operates a 216 ha flower farm—including roses, carnations, and statice—situated in Kenya's Nakuru County (map D.5). The farm produces and exports 380 million stems annually, and employs 4,600 people (table 4.23).

ODCL is a pioneer business in its use of heat from geothermal wells for internal power generation and consumption; its 50 ha Geothermal Rose Project is the largest of its kind. In addition to geothermal heat, a 3.2 MW generator is dedicated to powering the farm's operations and distribution within its estate. Although the company is connected to the main grid and purchases electricity from the utility, it can generate power at a lower cost. To increase output by 0.4 MW, a planned upgrade of the generation plant aims to provide power to both industrial activities and some 2,000 households.

### *POWER DEMAND*

Currently, ODCL's power demand is 3.2 MW, with 13 MWh in annual consumption. Seventy percent of the company's total energy consumption is for industrial use—mainly heating, ventilation, air conditioning (HVAC), refrigeration, irrigation (pumping, drip irrigation, and spraying), and lighting. Except for heating directly supplied by steam, many other industrial processes (e.g., ventilation, refrigeration, and irrigation) require electricity.

Part of the power generated by ODCL is distributed within the company's estate to the community (e.g., staff housing, schools, and clinics) and sister companies (e.g., tourism lodge). Currently, 2,000 households are connected to electricity through a mix of power from ODCL's own power generation (95 percent) and utility power (5 percent). However, 2,000 other households within the estate remain without an electricity connection. ODCL is planning an increase in power generation by improving generation efficiency (via installation of a partial condenser). The improvement in efficiency is expected to increase generating capacity by 0.4 MW. The expansion project seeks to supply these additional households for basic electricity uses (e.g., lighting and mobile phone charging) and to power such facilities as schools

**TABLE 4.22:** ECONOMIC COSTS AND BENEFITS OF THE IDSP PROJECT, MWOMBOSHI

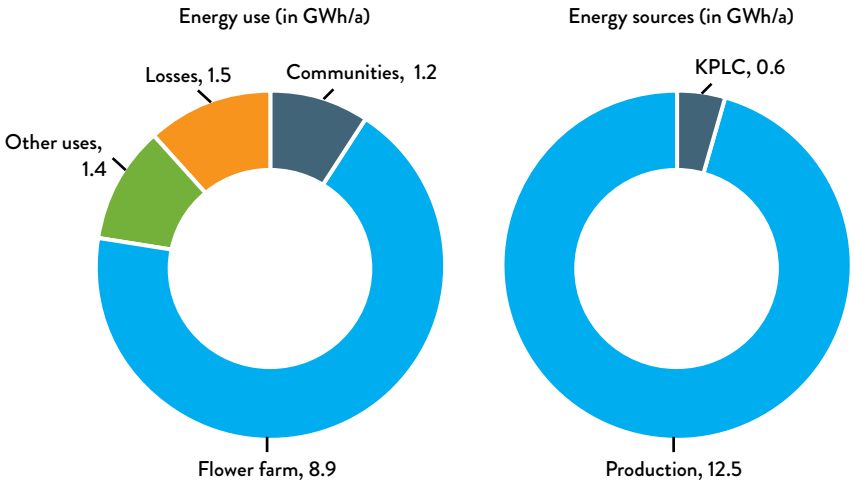
| Benefit | 2016 | 2019 | 2031 |
|---|---|---|---|
| **Revenue from job creation**[a] | | | |
| Jobs resulting from the project | – | 313 | 313 |
| **Present value of increase in employees' income ($ million)** | **3.4** | | |
| **Increase in profit revenue** | | | |
| *Small-scale (MT)* | | | |
| Tomato production with project | 5,000 | 57,833 | 57,833 |
| Maize production with project | 1,000 | 6,403 | 6,403 |
| Wheat production with project | – | 3,602 | 3,602 |
| **Present value of profit of extra production ($ million)** | **20.5** | | |
| *Commercial (MT)* | | | |
| Wheat production with project | 2,634 | 12,240 | 12,240 |
| Maize production with project | 3,512 | 16,320 | 16,320 |
| **Present value of profit of extra production ($ million)** | **3.5** | | |
| **Savings from import substitution** | | | |
| **Present value of wheat and maize import substitution savings ($ million)** | **6.7** | | |
| **Savings from household electrification** | | | |
| Electrification rate (%) | 15 | 46 | 97 |
| Electrified households without project | 93 | 101 | 144 |
| Electrified households with project | 93 | 283 | 598 |
| **Present value of household electrification savings ($ million)** | **0.2** | | |
| **Total present value of economic benefits ($ million)** | **34.0** | | |
| Financial NPV of utility ($ million) | 1.1 | | |
| Share of line upgrade project cost to total IDSP project cost (%)[a] | 2.6 | | |
| Net social benefits ($ million) | 0.9 | | |
| **Economic NPV ($ million)** | **2.0** | | |

*Source:* ECA and Prorustica (2015).
*Note:* Assumes that present values are over the 15-year period (2016–31).
a. Because the project has multiple complementary investments, it is hard to disentangle the benefits accruing to the power line extension without a simplifying assumption; it is thus assumed that the accrual of benefits to electricity versus other investments is in the same proportion as the accrual of costs.

**TABLE 4.23:** OSERIAN FLOWERS AND GEOTHERMAL POWER PROJECT AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Expansion of the estate geothermal generating capacity and its distribution network to power the farm's operations and distribution within the estate (staff housing, community facilities, and sister companies). |
| **COMMODITIES** | Floriculture. |
| **DESCRIPTION** | ODCL's captive power generates 95 percent of its requirements internally. Industrial use (heating, ventilation, irrigation, and lighting) represents 70 percent of the company's total energy consumption. Since no power is exported to the grid or sold beyond the estate, ODCL has a license from the Energy Regulatory Commission for captive power generation and distribution. |
| **FINANCIAL VIABILITY** | With a positive financial NPV, the planned expansion project of 0.4 MW and electrification of 2,000 households is financially viable. |
| **ECONOMIC VIABILITY** | Positive economic benefits estimated at US$2.5 million. The main economic benefit is based on increased household electrification and, as a result, the savings are due to lower energy consumption costs (e.g., less use of kerosene and no more payment for cell-phone charging services and disposable batteries). |

**FIGURE 4.9:** POWER USES AND SOURCES AT ODCL




*Source:* ODCL.

and a clinic. The limited increase in capacity implies that monthly household consumption may be constrained; however, households willing to upgrade may get individual connections through the state-owned utility, Kenya Power and Lighting Company (KPLC) (figure 4.9).

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

ODCL's captive power generates 95 percent of its requirements. Power is generated from a farm-operated plant, and steam is bought from the Kenya Electricity Generating Company (KenGen) under a 15-year purchase agreement. Since no power is exported to the grid or sold beyond the estate, ODCL has a license from the Energy Regulatory Commission for captive power generation and distribution. ODCL supplies power to staff workers within the estate using a mix of geothermal generation and the main grid supply. Households consume low levels of energy and are not metered individually, and KPLC bills ODCL rather than individual households. Over the years, ODCL has developed a skilled, in-house engineering team dedicated to geothermal power generation.

To meet unmet power demand and offset electricity purchased from the utility, an investment of US$1 million is planned for expanding geothermal plant capacity up to 3.6 MW (figure 4.10). An additional $0.2 million will be required to finance the distribution network extension. ODCL is considering charging electricity customers a cost-reflective tariff, but this would require an additional $0.2 million investment in individual meters.

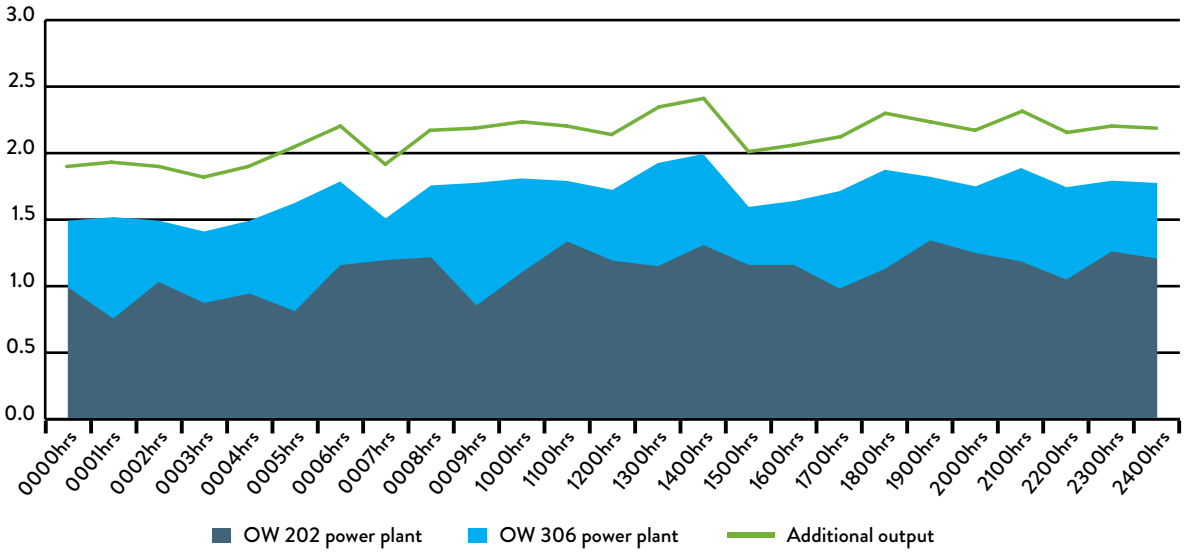
After this generation expansion, it is expected that the plant will generate an additional 2,500 MWh per year. This will include 600 MWh to offset electricity bought from KPLC, another 600 MWh to supply the local population that does not yet have access to power, and the remaining 1,300 MWh to cover ODCL industrial processes (figure 4.11).

### *FINANCIAL VIABILITY*

The planned expansion project of 0.4 MW and electrification of 2,000 households is marginally financially viable, with a positive financial NPV of US$3,742. The costs incurred for generation and distribution expansion and operation are slightly more than offset by the revenue from cost reduction in electricity purchased from KPLC. An investment of US$1.2 million is required for expansion of generation (partial condenser) and the distribution network (conductors, transformer, and switchgear). Also, operating cost is not expected to increase as the expansion will not consume additional resources (e.g., the same volume of purchased steam). In fact, the increased output will lower the per-unit cost from US¢6 per kWh to US¢5 per kWh. The operating cost will therefore amount to $125,000 (table 4.24).

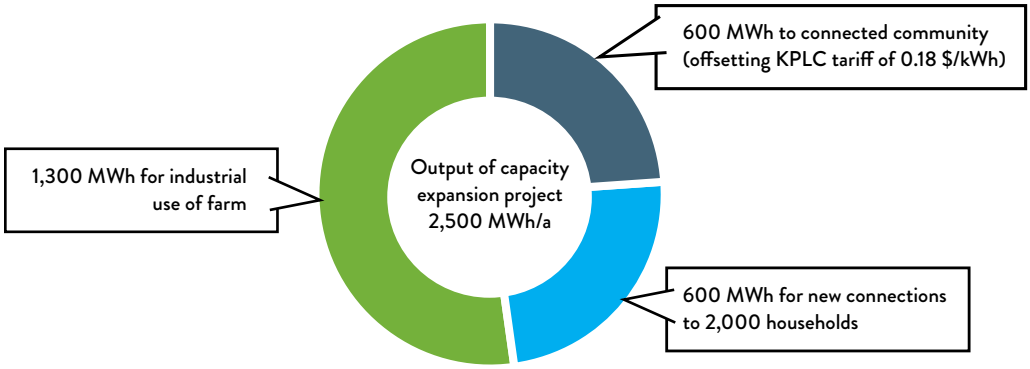
In comparison, the savings from the reduced purchases from KPLC amount to $342,000. Staff households are to be supplied electricity free of charge. Charging households cost-reflective tariffs would incur additional costs due to metering and billing. Considering these costs in the analysis shows that, in order to break even, a cost-recovery tariff of US¢8 per kWh would be required.

**FIGURE 4.10:** OUTPUT OF ODCL'S POWER PLANTS AND EXPECTED INCREASED OUTPUT




*Source:* ODCL.

**FIGURE 4.11:** ELECTRICITY OUTPUT OF CAPACITY EXPANSION PROJECT AND INTENDED USES




*Source:* ECA and Prorustica (2015).

**TABLE 4.24:** FINANCIAL ANALYSIS, ODCL

| Item | US$ Amount |
|---|---|
| Revenues | 342,000 |
| Power generation Opex costs | 125,000[a] |
| Capex costs | 1,200,000[b] |
| Margin | –983,000 |
| Discount rate (%) | 10 |
| **Financial NPV ($ amount)** | **3,742** |

*Source:* ECA and Prorustica (2015).
a. Assumes a cost per kWh of $0.05.
b. Assumes $1 million for distribution and $200,000 for metering.

### *ECONOMIC ANALYSIS*

The expansion project constitutes a relatively small portion of the estate's electricity use; most electricity is used for irrigation and refrigeration. The main economic benefit from the expansion project is thus from increased household electrification and, as a result, the savings due to lower energy consumption costs (e.g., less kerosene use and no more payment for cell-phone charging services and disposable batteries). An electricity connection is estimated to save households US$11 per month, implying

$2.5 million in total net economic benefit (NPV) over the life of the project. No significant impact is expected in terms of job creation or commercial development.

## CASE STUDY 6. KENYA TEA DEVELOPMENT AGENCY HOLDINGS: MINI-HYDRO MINI-GRIDS

This case study analyses the mini-hydro based tea factory electrification project of the Kenya Tea Development Agency (KTDA). The agency is planning the implementation of several small-scale (≤ 15 MW) run-of-the river hydropower projects at various locations in Kenya to serve a number of tea factories under its management (map D.6).

KTDA is the single largest producer and exporter of tea in Kenya. The company was created in 2000, subsequent to privatization of the Kenya Tea Development Authority. KTDA is the holding company of a number of subsidiaries owned by small-scale tea companies. The agency currently manages 63 factories in Kenya's small-scale tea subsector. Currently, its network covers about half a million small-scale farmers, with each tea factory owned by 5,000–10,000 tea farmers (table 4.25).

KTDA Power Company Limited, a subsidiary of KTDA, is charged with consolidation, investment, and management of energy initiatives undertaken by tea factories managed by KTDA. Notably, KTDA Power Company supports the development of hydropower projects in the small-scale tea subsector aimed at reducing factory operating costs, improving power supply reliability, and diversifying tea farmers' revenue sources. The power generated from these schemes will be used primarily in the tea factories, with the surplus sold to KPLC under a power purchase agreement (PPA). KTDA is in the process of setting up several small hydropower projects for its tea factories. One hydropower plant has been operational in the Imenti tea factory since 2010; an additional 17 projects are in the pipeline, ranging from 0.5 MW to 9 MW, eight of which are at an advanced stage of development, with feasibility studies completed.

### *POWER DEMAND*

Considering the near-term pipeline, along with the operational Imenti plant, the total installed capacity is 24.4 MW. About 40 percent of power generated will be used primarily for the tea factories' self-consumption, supplying mainly tea industrial processes. The remaining 58 percent of output will be sold to KPLC under a PPA and feed-in-tariff (FiT) scheme. Farmers will benefit from the electricity supplied to the factories that they partially own, but residential electricity connections will only be provided through KPLC, and not directly though KTDA. Approximately 187,500 small-scale farmers, representing 25 tea factories, will benefit from these power projects to run their farming activities. Currently, 70 percent of neighboring households (i.e., more than 130,000 farmers) lack access to electricity.

**TABLE 4.25:** KENYA TEA DEVELOPMENT AGENCY HOLDINGS: MINI-HYDRO MINI-GRIDS AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Development of hydropower plants powering tea factories and staff housing, and selling surplus power to the grid. |
| **COMMODITIES** | Tea. |
| **DESCRIPTION** | The operational power plant and eight projects have a total installed capacity of 24.4 MW. About 187,500 small-scale farmers, representing 25 tea factories, will benefit from these power projects to run their farming activities.<br>Mini-hydro plants provide a more reliable power supply to tea factories at lower cost and avoid the need for backup generators. |
| **FINANCIAL VIABILITY** | Evaluation of a sample project (North Mathioya) shows that the project is financially viable, with a NPV of US$3.3 million. Revenues accrue from the sale of power to the grid and cost savings by tea factories. |
| **ECONOMIC VIABILITY** | The same sample project is evaluated as economically viable, with a NPV of US$10 million. Direct and indirect impacts on rural electrification include the following: electrification of staff housing, reduced connection costs for surrounding households, development of stand-alone home systems. About 30,000 households will benefit from electricity connections. |

### *POWER SUPPLY OPTIONS*

The KTDA tea factories have two feasible supply options for meeting their power requirements: (i) purchase from the main utility at the retail tariff or (ii) self-generate electricity through the planned hydropower projects. Grid-supplied electricity is often unreliable, with frequent outages and voltage fluctuations. The need for a reliable power supply for tea operations requires investment in backup diesel generation, which adds to the overall cost of electricity. Where feasible, a captive mini-hydro generation plant, with the ability to sell excess power to the main grid, is an attractive option both financially and in terms of increased reliability.

In terms of commercial arrangements, KTDA Power Company leads the project development cycle (e.g., permitting acquisition, securing land, and raising capital) and forms special purpose vehicles (SPVs) in the form of regional power companies for each project (e.g., North Mathioya Power). The factory farmers served by the mini-hydro plant are shareholders, and raise 35 percent of the investment cost as equity from deductions of farmers' tea revenues. Electricity to residential consumers in the area will be provided through KPLC and not directly through the project.

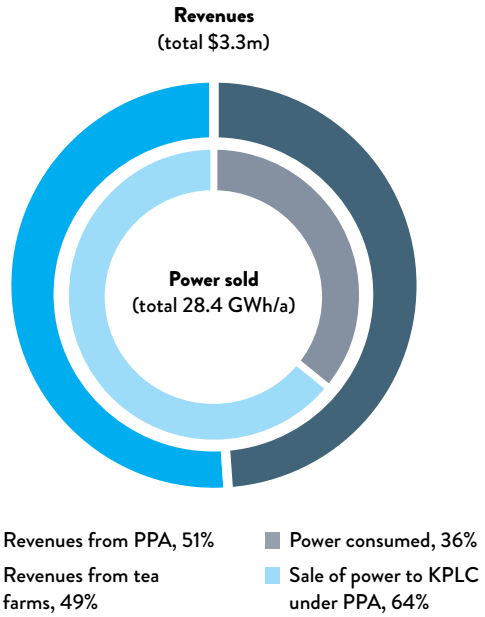
### *FINANCIAL ANALYSIS*

The financial analysis focuses on the North Mathioya (5.6 MW) hydropower project from the perspective of the SPV owners. Project revenues derive from the sale of electricity to the grid at the FiT.[13] The remaining electricity sold to tea factories is valued at the avoided cost of grid plus diesel backup electricity at US¢16 per kWh (figure 4.12).[14]

The costs include the capital and annual operating expenditures of the generation plant incurred by the SPV, at US$22.5 million and $165,800, respectively. Comparing the present value of the stream of revenues and costs, the project is estimated to be financially viable, with a NPV of $3.3 million (at 10 percent cost of capital) and an IRR of 13 percent.

Although the project does not include household or community electrification, except for factory staff housing, a simplified financial analysis shows that such activity would be financially unviable without subsidies. Despite the relatively high margin between household retail rates (US¢20 per kWh) and the PPA rate (US¢9 per kWh), distribution and retail would require an additional capital expenditure of US$15 million and administrative expenses of about $1 million per year, as well as pressure to reduce tariffs along with KPLC's national rates. Given these assumptions, subsidies for both capital expenditure and operating expenses would be required.

**FIGURE 4.12:** KTDA'S NORTH MATHIOYA HYDROPOWER PROJECT: FINANCIAL BENEFITS AND POWER SOLD




*Source:* ECA and Prorustica (2015).

### *ECONOMIC ANALYSIS*

Although KTDA power projects are not involved in the retail sale of electricity to neighboring communities, they have several direct and indirect impacts on rural electrification. First, they provide electricity to staff housing, which represents an average of 60 households per factory. Second, they may facilitate grid access for the surrounding households by reducing connection costs. Third, these areas will be targeted by a pilot project—led by the KTDA subsidiary, Greenland Fedha (microfinance institution), and the KTDA Foundation—which aims to finance solar home systems (SHSs) for farmers and support their grid connections.

The estimate of economic benefits is based on facilitating households' access to electricity connections. Tea factory activities remain unchanged, although they gain access to a more reliable, cheaper source of power supply. Approximately 30,000 households will benefit from electricity connections, which will offset their expenditure on traditional or more expensive forms of energy.

The project will facilitate grid connection by connecting the generation facility. Costs are estimated at US$500 per grid connection, with a monthly electricity bill of $3 per household. Also, the above-mentioned SHS scheme in place for farmers will further increase connections,[15] with an average household savings of $11 per month.[16] Thus, development of the North Mathioya hydropower project will provide households net economic benefits; the project's NPV is $6.7 million, implying $10 million in total economic NPV.[17]

## KEY CONCLUSIONS FROM THE CASE STUDIES

The six case studies discussed in this chapter offer varied contexts for power-agriculture integration. Each is unique in terms of the type of anchor load and country setting; thus, one must be cautious about generalizing from the lessons learned from any particular case. Keeping this in mind, this section discusses key findings from the six case studies in terms of large power loads, supply options, financial and economic viability, and financing of development.

### *LARGE POWER LOADS*

The viability of providing electricity depends critically on the existence of a large and stable demand for electricity (or supply, especially if the grid is supply constrained). In rural areas, it is likely that the largest single source of power demand is either agriculture or an agriculture-related commercial activity. Residential electricity could also be a significant source of demand (e.g., in the case of Tanzania's Sumbawanga agriculture cluster); however, this demand is often relatively dispersed, which reduces its viability.

In rural agricultural areas, irrigation is often the single largest potential source of electricity demand, as exemplified in Tanzania's Sumbawanga agriculture cluster, Zambia's Mkushi farming block and Mwomboshi's IDSP. These projects also show that the loads for agro-processing activities (e.g., milling and extrusion) are comparative smaller, suggesting that the latter activities, taken alone, may not be sufficient to justify rural electrification investments. These several projects also highlight how irrigation and processing are often linked. The Zambia cases show how increased yields from irrigation are an important prerequisite for the development of large-scale processing activities; the agriculture cluster concept in Tanzania also shows this cause-and-effect relationship between irrigation and processing. Increase in the scale of processing activity can lead to a significant increase in power demand.

The seasonality of power demand from the agriculture sector can significantly constrain a project's viability. Large seasonal differences in electricity-dependent agricultural activity will impact the cost recovery of investments in electricity supply. In such cases, it is important to consider ways to mitigate the impact of a variable load. One option, especially for mini-grid or captive generation, is the ability to sell excess power to the grid, as in the cases of mini-hydro development in Tanzania (Mwenga) and Kenya (KTDA).[18] Increased processing activities in the post-harvest season may complement electricity demand from irrigation, and irrigation itself may reduce seasonality in agricultural production and thus electricity demand by allowing multi-cropping (e.g., in the case of Zambia's Mkushi farming block).

Finally, when considering agricultural anchor loads, it is more risky for the investment to depend on a single large customer since any negative shock to the customer would negatively affect operating revenues for the electricity supplier. For this reason, agricultural clusters (e.g., Sumbawanga in Tanzania) can be used to increase the viability of rural electrification. Clusters development, by design, has load diversity and thus involves less risk than reliance on a single anchor load. While not included in the case studies discussed in this chapter, the presence of a private electricity supplier and private off-takers will price any such risk into the supply contract, thus increasing the price of electricity for all customers. In such cases, diversified cluster development can also help reduce the price of electricity. The public sector may also help mitigate this risk through a grid connection and FiT, subsidies to increase the customer base, or various guarantee/insurance instruments.

### *SUPPLY OPTIONS*

Most of the grid extension projects are justified by irrigation development, with agro-processing as a supporting activity. These developments require cultivating suitable commodities (e.g., maize, wheat, rice, and sugar), typically grown on large-scale commercial farms, enabling large production volumes. Small-scale farmers can then be incorporated alongside; however, they also need other forms of support, including access to a reliable water supply, good physical and market infrastructure, and clear land with good quality soils.

The case studies discussed indicate that the national grid usually plays an important role in the viability of rural electrification investments—either in the form of the main supply option for agricultural and rural electricity demand (e.g., the Sumbawanga cluster in Tanzania) or as the main off-taker of the locally generated electricity from a small power producer (e.g., the Mwenga mini-hydro mini-grid in Tanzania). Whether the grid is the most viable supply option depends on various factors, including distance to the grid, size and stability of electricity demand, grid reliability, and local resource potential for generation.

Supplying rural electricity demand though small power producers (SPPs) depends critically on local generation potential (e.g., for mini-hydro, geothermal, and biomass). Viable generation potential can be a cost-effective option in cases where the grid is far away, unreliable, or expensive. In the latter case, especially, SPPs may benefit primarily from selling to the grid and supplying local agricultural activities and residential customers in the process (e.g., Tanzania's Mwenga mini-hydro mini-grid).

Companies specializing in the agriculture or agribusiness sectors may be unwilling to enter into electricity generation and, especially, the distribution business. This would be a departure from their core activities and may not be financially attractive enough to change their business model. In this respect, a variety of arrangements are possible, depending on the context and capacity of the entities involved. For Kenya's Oserian geothermal project and KTDA's mini-hydro project, the companies chose to develop and operate the generation plant and supply their operations, preferring to sell power to the grid and leave retail power supply to the utility. For Tanzania's Mwenga mini-hydro project, by contrast, RVE manages the mini-grid generation and distribution, including retail power sales.[19]

### *FINANCIAL AND ECONOMIC VIABILITY*

The case studies discussed show that a rural electrification project can be financially viable where there is a creditable large off-taker and access to concessional loans/grants for capital investments. All six projects were estimated to generate economic benefits well in excess of associated costs, thus implying that all were economically viable.

Tautologically, financial viability rests on the ability to charge cost-reflective tariffs. In the case of mini-grid development, charging consumers a tariff that is much higher than the grid tariff might be difficult to do, even if the regulation allows it. Given this difficulty, financial viability, in most cases, depends on the ability to sell bulk power and lower costs. The Oserian geothermal and KTDA projects show that estate-type developments (floriculture and tea in these respective cases) can undertake financially viable electricity investments, benefiting from reduced electricity costs and selling excess electricity to the grid. Another example is the case of the IDSP in Zambia, where a grid extension was financially viable from the utility's perspective, owing to proximity to the grid (i.e., lower costs) and complementary investments in a large irrigation scheme that increased electricity demand. In contrast, grid extension to the Mkushi farming block, also in Zambia, was not financially viable for the utility, despite a capital cost-sharing arrangement with beneficiary farmers.

The choice of optimal tariffs—such that costs are recovered and electricity consumption is affordable to farmers, businesses, and other customers—depends on the size of the financial surplus generated from electricity consumption and the constraints on how to allocate it across various suppliers and customers. Additional considerations, such as parity with the main grid tariff, are the main determinants (e.g., Mwenga mini-hydro mini-grid in Tanzania).

If there is flexibility in setting tariffs, then the range of feasible tariffs would be determined by the difference between the customer's willingness to pay (WTP) and the supplier's willingness to accept (WTA).[20] A customer's WTP will be determined by the monetary benefit from consuming a unit of electricity. For households, this may be a reduction in spending on their current energy supply options, which are usually more expensive and less reliable (e.g., kerosene lamps or batteries). For agricultural consumers, it may be driven by a reduction in backup energy supply and/or increased revenues from higher productivity. A supplier's WTA will be determined by development and operating costs, often represented by the levelized cost of electricity (LCOE) (table 4.26). Assuming the WTP is more than the WTA, an optimal tariff may be negotiated based on some surplus allocation rule. Otherwise, if the WTP is lower than the WTA, the government must step in to provide subsidies to bridge the gap as long as the project remains economically viable.

For all six of the cases analyzed in this chapter, the economic viability was high. For projects that are not financially viable, economic viability is an important criterion to determine whether subsidies should be provided and at what level. Even with financial viability, subsidies

**TABLE 4.26:** TYPICAL LCOE VALUES FOR SMALL-SCALE GENERATION AND DISTRIBUTION SYSTEMS

| Generation System | | | | |
|---|---|---|---|---|
| Technology | Size Range (kW) | Power Plant Capital Expenditure (US$/kW) | LCOE (US$/kWh) | Operating Time (hours/year) |
| Diesel genset | 5–300 | 500–1,500 | 0.3–0.6 | Any |
| Hydro | 10–1,000 | 2,000–5,000 | 0.1–0.3 | 3,000–8,000 |
| Biomass gasifier | 50–150 | 2,000–3,000 | 0.1–0.3 | 3,000–6,000 |
| Wind hybrid | 1–100 | 2,000–6,000 | 0.2–0.4 | 2,000–2,500 |
| Solar hybrid | 1–150 | 5,000–10,000 | 0.4–0.6 | 1,000–2,000 |
| **Distribution System** | | | | |
| Distribution Type | | Voltage Level | LCOE (US$/km) | Required Length |
| Low-voltage | | 400 V | 5,000–8,000/km | 30 customers/km |
| Average connection cost: $350/customer; average distribution cost: $200/customer. | | | | |
| Medium-voltage | | 33 kV | 13,000–15,000/km | |
| **Total ($/kWh)** | | | **0.25–1** | |

*Source:* IED Reference Costs for Green Mini-Grids.

may be incorporated into the project to achieve other goals, such as grid parity in terms of tariffs or greater adoption of electric irrigation.

### *FINANCING OF DEVELOPMENT*

All six projects analyzed shared two common issues: (i) making projects financially viable and (ii) providing funding for viable projects. Several ways have been identified to make projects financially viable. To benefit from economies of scale, capacity for local generation can be increased beyond the level of local demand, and surplus power can be sold to the grid. This option is particularly relevant in countries that have introduced FiT programs set above the utility's avoided costs. Selling excess power makes it possible to lower the per-megawatt cost, but relies on the ability to sell excess generated power. For example, the capacity of Tanzania's Mwenga mini-hydro mini-grid is greater than what the tea estate requires; therefore, the surplus is sold to the utility and nearby rural customers.

Another option, as done for the main grid extension projects in Zambia (Mkushi and Mwomboshi), is to require the beneficiaries to partially finance projects and share the development costs with major customers. In this way, farmers partially contribute to the capital costs in exchange for receiving power. A further option is load balancing across beneficiary categories, which enables the spread of fixed costs, especially capital costs, across a larger pool of customers with diverse peak-load profiles. For example, since productive users need electricity during the day and households' peak load is in the evening, the system peak load should be lower than the sum of individual peak loads. However, load balancing requires an analysis of load profiles to optimize supply, and the level of additional benefit depends on the proportion of capital costs in total costs and the load matching between customers. The utilities—owing to their larger-capacity cross-subsidization and ability to spread costs over a wider customer base—are usually in a better position to do so.

As detailed for the Mwenga and KTDA projects, selling power to more reliable customers, such as the utilities, increases a project's viability since anchor customers are assumed to be better payers. This is especially true in countries where clear schemes for renewable energy FiTs have been introduced with dedicated funding. Although relying on the utility still depends on its ability to afford payments, the anchor-customer approach has reduced the risk of the utility's non-payment by giving certainty on tariffs.

Finally, the role of subsidies to cover certain costs should be highlighted. All of the distributed schemes analyzed in this chapter have received subsidy payments to decrease the level of cost recovery through retail tariffs. This approach contributes to ensuring maximum capacity development, increasing the project's NPV, improving

tariff affordability for customers, and attracting private-sector participation. Subsidies are particularly necessary for most privately developed, small-scale projects under 5 MW. By subsidizing household connections, which tend to be financially unviable, developers can be encouraged to expand their customer base to capture additional subsidies, prioritizing smaller customers close to each other rather than larger ones.

## ENDNOTES

1. The analysis presented in these case studies is indicative only and not a comprehensive feasibility study.

2. The only exceptions are projects based on quite expensive sources of power generation for small demand loads.

3. SAGCOT aims to facilitate the development of seven agribusiness clusters along the southern corridor of Tanzania's Southern Highlands.

4. This comprises 3 MW from a 66 kV line into Zambia, 5 MW from a mini-grid in Sumbawanga, and a 2.6 MW mini-grid in Mpanda; both are isolated, diesel based mini-grids operated by TANESCO.

5. ECA and Prorustica estimates, consistent with the SAGCOT investment blueprint, constructed from own analysis and various official sources.

6. Other products such as cassava and livestock are also likely to demand electricity for processing, but for the sake of simplicity, are not included in the calculations here.

7. According to Tanzania's national census, Rukwa had 1 million inhabitants in 2012.

8. The cost calculations consider all capital and operating expenditures; the calculations are based on ECA analyses conducted for small-scale systems in Kenya, Tanzania, and elsewhere in Sub-Saharan Africa.

9. Assumes that the factory operates 16 hours per day, 6 days a week for 10 months out of the year.

10. EU funds were through the African, Caribbean, and Pacific Group of States facility; and REA funding was supported by the World Bank's Tanzania Energy Development and Access Project (TEDAP).

11. Assumes that the area's power demand from irrigation is 1 kW per ha and average irrigating hours per year are about 1,900 (with a 15 percent load factor), representing in part the seasonality in demand for irrigation.

12. Assumes that the average mill has a power demand capacity of 400 kW and operates 5,000 hours per year.

13. US¢9.29 per kWh under a FiT.

14. Assumes a diesel generation cost of US¢60 per kWh (KTDA) and an overall tariff decrease of 5 percent annually.

15. Since this analysis focuses on the impact of an anchor load on household electrification, we restrict it to grid-connected households.

16. Observed for mini-grid development in Kenya.

17. If we assume that 50 percent of the 30,000 households connected are from SHS, then the household net benefits increase to US$14 million and the overall NPV to $17.2 million.

18. Apart from the mitigating impact of seasonal variation, the ability to sell excess power to the grid also helps invest in large generation capacity and reduces costs due to economies of scale in generation.

19. Enabling small-scale, private power generation and distribution requires clear regulations and purchasing processes (e.g., PPAs and FiTs); regulations in Tanzania are relatively transparent in this regard.

20. The difference between WTP and WTA is a measure of the total surplus generated by the electricity sale/consumption.

# Opportunities to Harness Agriculture Load for Rural Electrification

## CHAPTER 5

What is Sub-Saharan Africa's potential for harnessing power-agriculture synergies for rural electrification? This chapter considers this question, using a simulation model and case studies from Ethiopia and Mali—two countries that exhibit a range of innovative options moving forward to 2030. Before turning to the case studies, the chapter presents a hypothetical case illustrating the conditions under which power demand from agriculture could be economically viable.

### SIMULATION OF POWER DEMAND IN A STYLIZED AGRICULTURAL SETTING

A simplified simulation model was developed to analyze the relationship between agricultural activity, power demand, and the geographic area that a power supply would serve (table 5.1). The model assumed a theoretical circular area around the generation source, with electricity consumers distributed uniformly throughout. Further simplifying assumptions were made about what percentage of this area was under cultivation and the proportions split between small-scale and commercial farmers. The electricity demand from each of the two farmer groups were estimated separately, with differing proportions of area under irrigation and yields (on rainfed and irrigated summer and winter crops). The model assumed that there were two crops: summer maize and winter wheat. Across Sub-Saharan Africa, maize is a common summer crop on both mixed-used commercial and small-scale farms. In the winter months, irrigated wheat is commonly grown. Based on the areas under irrigation, assumptions about the power load of bulk water pumping and infield irrigation systems were made.[1]

For each farming type, the production volume was used to calculate the milling load for the area, based on assumptions about the proportions of milled production. With total milling volumes, the total load requirement for milling was estimated, based on the load characteristics of an assumed average mill. Household and business connections for the given area were also estimated, based on assumptions about a consistent population density and members per household, connection rate, household power consumption, and proportion of this load for business consumption.

The stylized analysis from the simulation model helps to determine the general features of power demand from agricultural areas. Based on the average power demand from agricultural sources, the results show that a fairly large area of coverage would be required to aggregate sufficient electricity demand from customers; based on the model assumptions, a 50 km radius area would, on average, aggregate 60 MW of demand.

In the simulation, as in the case studies, irrigation accounts for a substantial proportion of power demand from agriculture (figure 5.1).[2] The irrigation power load is dependent on choice of crops and availability of bulk water. Some systems with a large body of available water nearby the infield irrigation system may require little bulk water pumping; however, in cases where water must be pumped into storage before utilization, additional electricity is required. As such, total observed power loads for irrigation are in a range of 0.5 kW–2.0 kW per ha.

**TABLE 5.1:** ASSUMPTIONS FOR TYPICAL AREA/AGRICULTURAL ACTIVITY/POWER DEMAND MODEL

| Assumption | Basis | Small-scale Value | Commercial Value | Overall Value |
|---|---|---|---|---|
| Proportion of total land area under cultivation (%) | Observations of other large-scale production areas | | | 25 |
| Proportion of farming type within cultivated area (%) | Observations of other large-scale production areas | 70 | 30 | |
| Proportion of irrigated land (%) | Observations of other large-scale production areas | 20 | 50 | |
| Summer crop yield (rainfed) (MT/ha) | Maize yields observed | 1.5 | 6 | |
| Summer crop yield (irrigated) (MT/ha) | Maize yields observed | 4 | 8 | |
| Winter crop yield (irrigated) (MT/ha) | Wheat yields observed (not grown without irrigation) | 2 | 5 | |
| Proportion of crop milled (%) | Observations of other production areas | 25 | 80 | |
| Irrigation load requirement (kW/ha) | Average, based on schemes observed | 0.3 | 1.0 | |
| Milled load (kW) | Average mill, consultant calculations | | | 200 |
| Hours of operation (hrs/day) | Average mill | | | 16 |
| Days of operation (hrs/year) | Average mill | | | 313 |
| Population density (per km$^2$) | Comparison with other countries | | | 50 |
| People per household (no.) | Comparison with other countries | | | 5 |
| Household connection rate (%) | Comparison with other countries | | | 50 |
| Peak household consumption (kW) | Various household power-consumption studies | | | 0.3 |
| Business load as proportion of household load (%) | Various rural business power-consumption studies | | | 50 |

*Source:* ECA and Prorustica (2015).

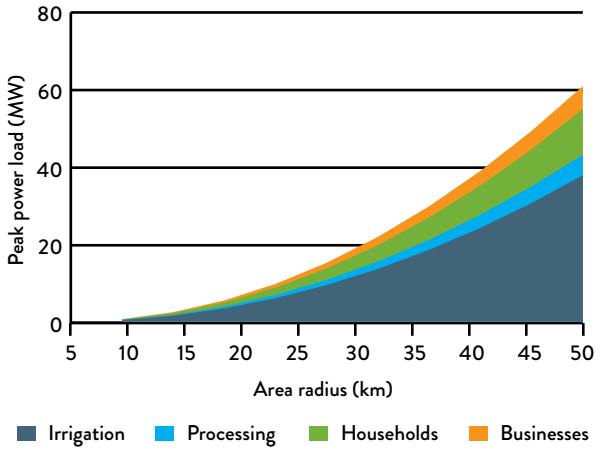
The relatively low load for processing suggests that the machinery used for typical post-harvest processing operations (e.g., mills) does not require large amounts of electricity, in part, because of the small size; also, it may be in operation for fewer hours in a year. Thus, most crop-processing loads are fairly small for the volume processed, with the exception of such activities as sugar processing, which provides much or all of its own power.

The total power load for a given area is highly sensitive to the assumed area under commercial irrigation, reiterating the importance of irrigation to power loads (figure 5.2). By contrast, the impact of the proportion of crop processed is relatively low, especially as this load is already minimal.

## SIMULATION STUDY 1. ETHIOPIA: POWER GENERATION FROM SUGAR ESTATES

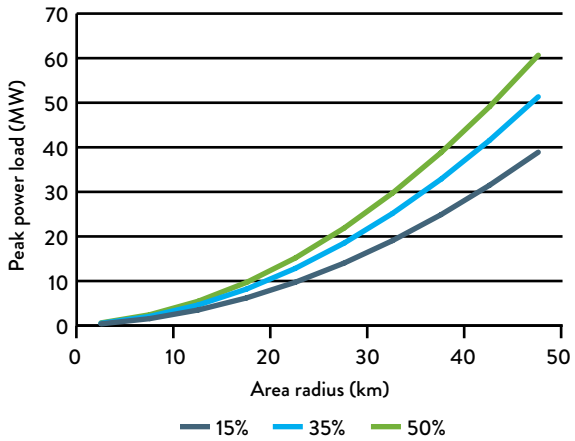
Sugarcane is an important crop in Ethiopia (map D.7). Indeed, the Ethiopian Sugar Corporation (ESC) aims to increase national annual production nearly eightfold

**FIGURE 5.1:** POWER DEMAND AND BREAKDOWN FOR A GIVEN AREA RADIUS




*Source:* ECA and Prorustica (2015).

**FIGURE 5.2:** SENSITIVITY OF POWER LOAD TO CHANGES IN PERCENT OF COMMERCIAL IRRIGATION




*Source:* ECA and Prorustica (2015).

**TABLE 5.2:** ETHIOPIA: POWER GENERATION FROM SUGAR ESTATES

| | |
|---|---|
| **PROJECT OVERVIEW** | Self-generation of power from bagasse and sale of power surplus to the main grid. |
| **COMMODITIES** | Sugar. |
| **DESCRIPTION** | Sugar processing and irrigation are the largest sources of electricity demand.<br>Irrigation makes it possible to extend the sugarcane production season and therefore smooth the annual profile of both production and processing. Processing and refining are the most power consuming activities in the sugar estate.<br>Typically, a sugar processing plant can produce enough electricity from bagasse to meet its own electricity demand, and sell excess power to the grid.<br>The viability of connecting such processing plants to the grid depends on the amount of excess power produced, the cost of producing it relative to other sources, and additional customers that can be connected. |
| **FINANCIAL VIABILITY** | From the utility's perspective, extending the grid to the sugar estate is not financially viable—the net present value (NPV) is negative because the utility does not benefit from sales to the estate, which self-supplies; from the sugar estate's standpoint, the project is highly profitable (US$139 million). |
| **ECONOMIC VIABILITY** | The economic NPV for the whole period is positive ($367 million), thus justifying development of the project. |

within five years. To do so, the government has launched the Sugar Development Programme, with the objective of upgrading existing estates and commissioning new ones (table 5.2).

This simulation analyzes a representative example of power-agriculture integration on sugar estates in Ethiopia. Sugar estates have the potential to generate power from bagasse, a natural by-product of sugar refining. Hypothetically, the potential electricity generation is enough to cover the electricity needs of the refinery and associated facilities and sell the surplus to the main grid or other supply schemes.

### *POWER DEMAND*

**Agriculture (Irrigation).** Traditional sugarcane production is heavily water dependent. Irrigation ensures year-round production of the crop and therefore a smoothing of the annual profile of processing activity. This means that sugar facilities operate throughout the year with a consistent electricity demand.

Irrigation is also a major source of power demand in the sugarcane production process. In Ethiopia, irrigated land is expected to increase from 1,500 ha to 9,000 ha over 20 years. The associated power demand from

irrigation over the same period is expected to rise from 0.8 MW to 4.7 MW,[3] with power consumption increasing from 2,340 MWh to 14,040 MWh (table 5.3).[4]

**Agriculture (Processing and refining).** Processing and refining are the most power-consuming activities in the sugar estate, depending highly on production volume. Considering forecasts in terms of yield rates and production increases, the power requirements for processing irrigated sugarcane will amount to 6,300 MWh in year 1 of the hypothetical model, rising to 37,800 MWh five years later. For processing rainfed production, power consumption will increase from 3,150 MWh to 18,900 MWh over the same 20-year period (figure 5.3).

Beyond processing, refining activities also consume power for centrifuging raw sugar and crystallization. Over the 20-year period, electricity consumption from refining is estimated to rise from 300 MWh to 1,800 MWh, while power load will increase from 0.09 MW to 0.54 MW.[5]

**Staff housing.** In addition to agricultural needs, sugar estates also require power for staff housing and other supporting activities. Given that the average household electricity consumption in rural Ethiopia is about 0.10 kW (increasing to 0.15 kW by year 20),[6] total electricity demand from staff housing is estimated at 0.02 MW in year 1, increasing to 0.21 MW by year 20.

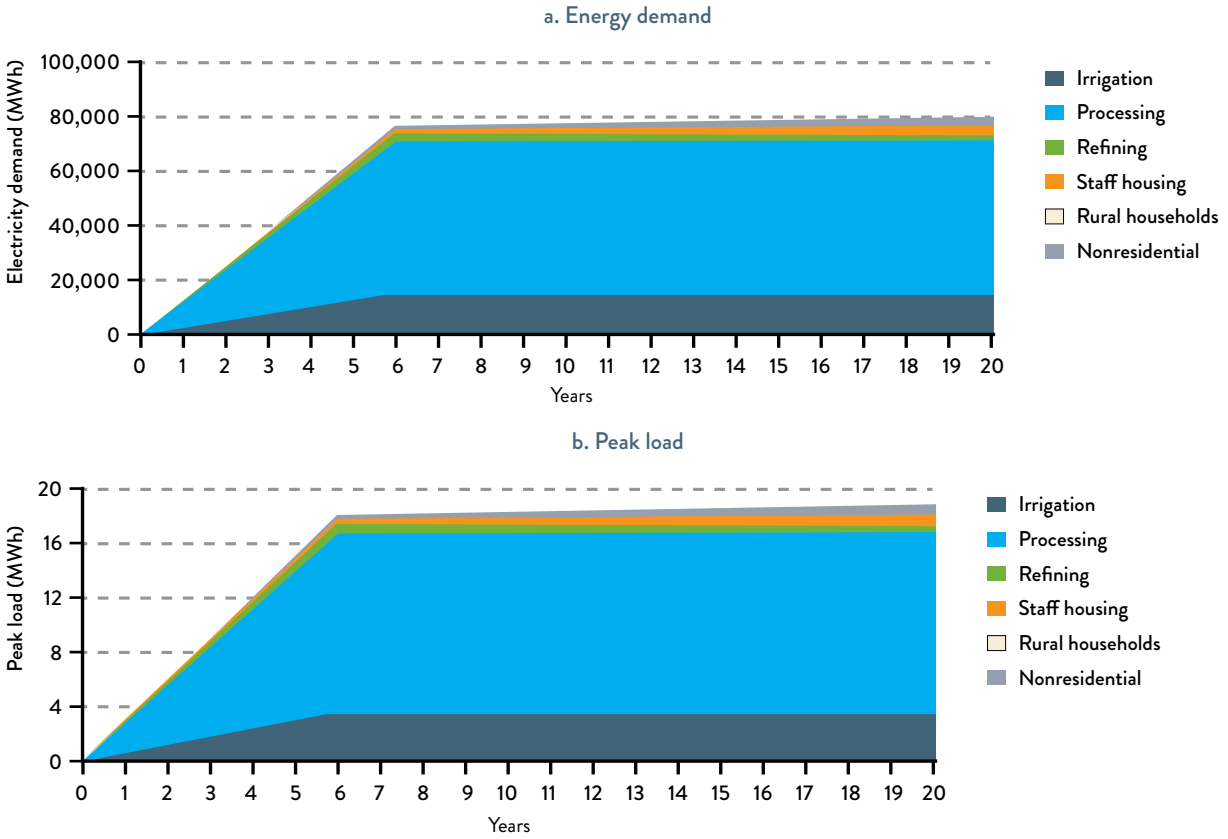
**Residential/Commercial demand.** In this model, the area is not yet connected to the grid, but a 30-km

**TABLE 5.3:** TOTAL POWER DEMAND FROM AGRICULTURE AND RESIDENTIAL/ COMMERCIAL LOADS

| Demand Source | Power Capacity Demand (MW) | | Energy Demand (MWh/year) | |
|---|---|---|---|---|
| | Year 1 | Year 20 | Year 1 | Year 20 |
| Irrigation | 0.8 | 4.7 | 2,340 | 14,040 |
| Processing | 2.9 | 17.5 | 9,450 | 56,700 |
| Refining | 0.1 | 0.5 | 300 | 1,800 |
| Residential (including staff housing) | 0.1 | 1.5 | 384 | 3,783 |
| Commercial | 0.1 | 0.6 | 278 | 2,780 |

*Source:* ECA and Prorustica (2015).

**FIGURE 5.3:** ESTIMATED ENERGY DEMAND AND PEAK LOAD, BY SECTOR




*Source:* ECA and Prorustica (2015).

grid extension is finalized once the sugar factory is built. Thanks to the proximity of houses and the factory, the electrification rate rises sharply to 85 percent by year 4. As the population grows from 28,500 to 50,386 by year 20,[7] with household growth following the same trend,[8] the total electricity load from rural households will reach 1.3 MW by year 20. For commercial activities surrounding the sugar estates, consumption is expected to increase from 278 MWh in year 1 to 2,780 MWh by year 20 (table 5.3).[9]

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

Bagasse is commonly used to generate electricity in sugar factories. It is mainly used as a boiler fuel to generate steam to meet the sugar factory's heating and power needs. The level of net electricity generation assumes (i) a bagasse generation potential of 29 MT for every 100 MT of sugarcane produced and (ii) a 70 kWh generation capacity for every MT of sugarcane. Since irrigated and rainfed processing of sugarcane do not occur simultaneously, the power capacity of generation equals the maximum capacity of the two, that is 47 MW by year 20 (table 5.4).

**TABLE 5.4:** SUGAR FACTORY POWER GENERATION IN YEARS 1 AND 20

| Sugarcane Processing Type | Electricity Generation Capacity (MW) | | Electricity Demand (MWh/year) | |
|---|---|---|---|---|
| | Year 1 | Year 20 | Year 1 | Year 20 |
| Irrigated | 3.8 | 22.5 | 12,600 | 75,600 |
| Rainfed | 5.8 | 35.0 | 6,300 | 37,800 |
| **Total** | **5.8** | **35.0** | **18,900** | **113,400** |

*Source:* ECA and Prorustica (2015).

Beyond meeting its own power needs, the sugar factory can generate surplus power.[10] This supports the development of estate activities, especially irrigation, before enough on-site bagasse has been produced. It also covers shortfalls in power generation during planned annual maintenance when the mills are not operating (May–September) (table 5.5).

The capital cost of extending the grid line 30 km to the sugar estate and surrounding villages is US$2.4 million (table 5.6).

**TABLE 5.5:** NET POWER GENERATION FROM SUGAR FACTORY BY YEAR 20

| Agricultural Activity | Power Capacity Demand (MW) | Hours of Operation/Year | Energy Demand (MWh/year) |
|---|---|---|---|
| Irrigation (A) | 4.7 | 3,000 | 14,040 |
| Processing (B) | 17.5 | 3,360 | 56,700 |
| Refining (C) | 0.5 | 3,360 | 1,800 |
| **Total demand** | **22.7** | | **72,500** |
| Power generated during processing (D) | 35 | | 113,400 |
| **Net power surplus D − (A + B + C)** | **12.3** | | **40,900** |

*Source:* ECA and Prorustica (2015).

**TABLE 5.6:** CAPITAL COST ASSUMPTIONS FOR GRID CONNECTION

| Cost Component | No./Distance (km) | Unit Cost | Cost (million US$) |
|---|---|---|---|
| 230 kV shunt/line/transformer (thousand $/unit) | 15 | 25 | 0.4 |
| Associated switchgear (thousand $/unit) | 1 | 120 | 0.1 |
| 33 kV line (thousand $/km) | 50 | 14 | 0.7 |
| 11 kV line (thousand $/km) | 120 | 10 | 1.2 |
| **Total** | | | **2.4** |

*Source:* ECA and Prorustica (2015).
*Note:* Costs estimates are based on those for similar projects in Ethiopia's 2014 Electrification Master Plan; cost assumptions include connecting villages along the power line (i.e., 33 kV and 11 kV lines and transformers). In reality, the estate may feed back power to the villages from the substation.

Currently in Ethiopia, however, no sugar factory exports its power to the grid because of the country's (i) low electricity tariffs and (ii) unclear regulations on conditions of exporting power to the main grid. A feed-in-tariff (FiT) proposal, which aims to provide incentives to private investors, is expected to become law in 2016 and should clarify those conditions; thus, under future development plans, power sold to the grid will be at the FiT. It is unlikely that sugar estates will sell directly to residential customers; this will be left up to the electricity utility.

### *FINANCIAL ANALYSIS*

The project's financial viability can be analyzed separately from the respective standpoints of the utility and the sugar estate. From the utility's perspective, extending the grid to the sugar estate is not financially viable; the estimated NPV is negative, at US$ –1.5 million (table 5.7). The viability is driven by the amount of power purchased by the utility, the margin between retail tariff and the price at which electricity is purchased from the sugar factory (possibly the FiT), and the cost of extending the grid.

The price at which the utility purchases power from the independent power producer (IPP) is confidential. In the absence of actual data, it is assumed that the utility tariff margin is US¢1 per kWh, which amounts to 40 percent of the domestic tariff.[11]

The project is not viable for the utility, in large part because it does not benefit from sales to the estate, which self-supplies. Subsidies would thus be required for project development. Given the significant financial benefits that will accrue to the sugar estate from the project, one option could be to have the sugar estate contribute to capital costs.

**TABLE 5.7:** FINANCIAL ANALYSIS FROM THE UTILITY'S PERSPECTIVE

| Component | Present Value (million US$) |
|---|---|
| Net revenue from sales | 2.7 |
| Expenses (Opex, losses, depreciation) | 1.8 |
| Capital cost | 2.4 |
| **NPV** | **–1.5** |
| **IRR (%)** | **7.6** |

*Source:* ECA and Prorustica (2015).
*Note:* The discount rate is 10 percent over the 20-year period; of total capital costs, operating costs account for 3 percent, while losses and depreciation each account for 5 percent.

From the sugar estate's perspective, the combination of heating and power from bagasse combustion is a fundamental asset for sugar processing and refining. The project's financial viability depends on the following factors (table 5.8):

- Capital costs, linked to development of the whole estate, including land improvement, buildings and equipment, and staff housing.
- Production costs, including employee wages, seeds, harvesting, loading, transport, maintenance, and electricity costs.
- Expected revenues from sugar sales and power sales.

The project is highly profitable for the sugar estate, with a NPV of US$139 million. As mentioned above, the large financial benefits for the sugar estate create ample scope for a negotiated arrangement of capital cost sharing to improve the utility's financial viability.

**TABLE 5.8:** SUGAR ESTATE CAPITAL COSTS, ASSUMPTIONS FOR PRODUCTION COSTS, AND REVENUES

| Component | Value |
|---|---|
| **Capital costs (million US$)** | |
| Land improvement ($3,500/ha) | 41.9 |
| Buildings and equipment | 80.5 |
| Staff housing ($5,000/house) | 7.0 |
| **Present value of total capital costs** | **129.4** |
| **Production costs** | |
| Average wage ($/month) | 100 |
| Permanent employees (months/year) | 12 |
| Temporary employees (months/year) | 7 |
| Seeds costs ($/ha) | 515 |
| Harvest cost ($/MT) | 6 |
| Loading cost ($/MT) | 2 |
| Transport to sugar mill ($/MT) | 3 |
| Maintenance (% of capital expenditure) | 3 |
| **Present value of total production costs (million US$)** | **311** |
| **Revenue (million US$)** | |
| Present value of sugar sales | 573 |
| Present value of exported power to the grid | 6 |
| **Present value of total revenues** | **579** |

*Sources:* Agritrade; ECA and Prorustica (2015); ESC; IEA; National statistics.

### *ECONOMIC ANALYSIS*

The project's total economic benefits, estimated at about US$410 million, comprise household energy cost savings, sugar estate profits, job creation, and import substitution (table 5.9).

The economic NPV over the period, about US$367 million, equals the sum of the net social benefits linked to the electrification project (figure 5.4), the financial NPV, and the present value of the sugar estate investment cost (table 5.10).

Various factors could hinder the development of such agriculture-power schemes in Ethiopia. The first one is funding availability for grid extension; however, given the project's associated economic benefits, funding from the government, development partners, or even cost sharing with the sugar estates could be sought. Second, for greenfield development, investors face issues about uncertainty over land ownership; despite the government's ability to make quick investment decisions regarding state-owned property, identifying large tracts of high quality agricultural land is difficult in Ethiopia. Third, regulations on exporting power to the grid must be clarified by defining tariff rates that guarantee investors a price for selling generated power from bagasse to the utility. Finally, selling power to the utility carries off-taker risk; delayed payments for power sold or even payment defaults would greatly impact the sugar factory investor.

## SIMULATION STUDY 2. MALI: MINI-GRID EXPANSION FOR PRODUCTIVE USERS

Mali is a regional success in rolling out private mini-grid concessions for rural electrification (map D.8).

**TABLE 5.9:** NET ECONOMIC BENEFITS OF GRID EXTENSION TO THE SUGAR ESTATE

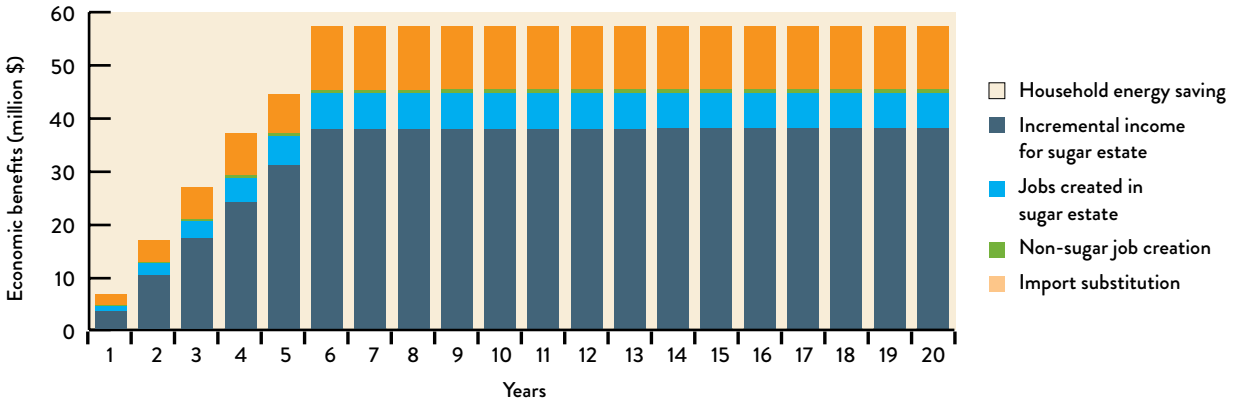
| Benefits | Year 1 | Year 5 | Year 20 |
|---|---|---|---|
| **Household energy savings** | | | |
| Electrification rate (%) | 21 | 85 | 85 |
| Households electrified (no.) | 1,479 | 6,752 | 9,964[a] |
| Savings from grid electrification per household ($/month) | 17 | | |
| **Total savings on energy consumption (million $)** | **0.025** | **0.12** | **0.17** |
| **Incremental income to the sugar estate** | | | |
| Production revenues (million $) | 14.8 | 74.2 | 89.2 |
| Production costs (million $) | 11.0 | 39.5 | 46.7 |
| **Sugar estate's profit (million $)** | **3.8** | **34.7** | **42.5** |
| **Sugar estate jobs created** | | | |
| Monthly salary ($/month) | 100 | | |
| Permanent jobs created (no.) | 933 | 4,663[b] | 5,595 |
| Temporary jobs created (no.) | 1,588 | 7,939 | 9,527 |
| **Total salaries (million $)** | **2.2** | **11.1** | **13.4** |
| **Non-sugar jobs created** | | | |
| Jobs created (no.) | 1,260 | 6,301 | 7,561 |
| **Salaries paid (million $)** | **0.13** | **0.63** | **0.76** |
| **Import substitution** | | | |
| New production of sugar (MT) | 42,000 | 210,000 | 252,000 |
| **Value of import substitution (million $)** | **1.3** | **6.3** | **7.6** |
| **Total economic benefits (million $)** | **7.5** | **52.9** | **64.4** |

*Source:* ECA and Prorustica (2015).

a. The difference in the number of connected households between years 5 and 20 is related to population growth, which is expected to increase by 2.89 percent.

b. Assumes 0.37 permanent job and 0.67 temporary job (working 7 months a year) created by hectare—Estimation based on the number of employees in Metehara sugar factory in Ethiopia.

**FIGURE 5.4:** NET SOCIAL BENEFITS OF GRID EXTENSION TO SUGAR ESTATE (YEARS 1–20)




*Source:* ECA and Prorustica (2015).

**TABLE 5.10:** ECONOMIC NET PRESENT VALUE OF EXTENDING THE GRID TO THE SUGAR ESTATE

| Item | Value (million US$) |
|---|---|
| Financial NPV of Ethiopian Electric Power Corporation (EEPCO) | −1.5 |
| Present value of investment cost of sugar estate | −41.9 |
| Net social benefits | 410.0 |
| **Economic NPV** | **367** |

*Source:* ECA and Prorustica (2015).
*Note:* The discount rate is 10 percent over the 20-year period.

In 2015, it has 255 operating concessions, with a total installed capacity of 22 MW. However, mini-grid operators face key challenges, including the saturated capacity of their schemes and low revenues, which hinder investment in capacity expansion. Limited power-generation capacity has constrained the mini-grids' ability to supply households and serve productive users. The current service level—limited daily hours (typically in the evenings) and tariffs that are higher than on-site diesel generators (usually above US$0.50 per kWh)—are inappropriate for meeting agro-industry power requirements. As a result, productive users in off-grid areas use their own diesel generators as a more competitive power supply option (table 5.11).

**TABLE 5.11:** MALI MINI-GRID EXPANSION FOR PRODUCTIVE USERS AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Capacity expansion of an existing hybrid mini-grid (diesel-solar PV) to serve productive users. |
| **COMMODITIES** | Agro-industrial activities. |
| **DESCRIPTION** | The Koury mini-grid is reaching a point of near saturation as generation capacity is fully taken up by existing household demand. However, small-scale commercial and agro-industrial activities in Koury (milling, water pumping, and bakeries) present significant opportunities for supplying unmet power demand. Attracting powered small businesses as mini-grid customers would require incentives to (i) lower tariffs, (ii) supply electricity during the daytime, and (iii) replace manual equipment with electricity powered machinery. |
| **FINANCIAL VIABILITY** | From the perspective of SSD Yeelen Kura, the rural energy services company, the Koury mini-grid is in a fragile financial situation. However, the capacity expansion project is profitable, thanks to a higher payment rate, additional revenues, and proportionally low capital expenditure and operating expense (with a NPV of €103,000). |
| **ECONOMIC VIABILITY** | The economic NPV for the expansion project is slightly negative (−€18,000) as no significant savings are expected from agro-industrial customers, who currently use individual diesel generators. However, the project could become economically viable if other economic, environmental, and social benefits were considered (e.g., reduction in $CO_2$ emissions, reduced reliance on imported fuels, and exposure to price fluctuations). |

Based on a representative example of an existing mini-grid, this simulation study analyzes how agro-industrial activities may improve mini-grids' financial viability, while benefiting from a more sustainable and competitive source of electricity. Based on the potentially lower costs of hybrid solar photovoltaic (PV) projects, the study explores the potential for attracting agro-industrial power demand to mini-grids. Given that there is no precedent for tying medium- or large-scale industrial processing to private mini-grid projects, an expansion project has been designed to assess the viability of supplying agro-industrial loads. The simulated study also evaluates the potential for adding value to agricultural activities in rural areas through mini-grid supplied power. Powered agricultural activities can indeed improve rural communities' revenues and therefore potentially increase mini-grid operators' profit (box 5.1).

### BOX 5.1: ISOLATED MINI-GRID SYSTEMS IN MALI: EXISTING AND POTENTIAL POWER DEMAND

In Mali, large-scale irrigation schemes are gravity fed, with electric power used only for small diesel or petrol-powered pumps. Four key commodities that could benefit from greater access to electricity are mango, rice, shallot, and shea kernel.

**Mango.** Mali's Bamako and Sikasso regions are particularly favorable for growing mango. But to export larger volumes, Mali must handle various issues related to market transport and product handling, notably reliance on cold chains (e.g., fixed and mobile chilling facilities). Considered a production hub, Sikasso would be the logical location to set up a temperature-controlled mango packing house. Areas outside Sikasso not yet connected to the main grid have limited potential for extending or replacing cold-chain packing-house facilities; such areas are mainly served by isolated mini-grids or diesel gensets.

An alternative value chain to fresh mango is processing mango pulp or nectar. Mali has only lightly exploited this value chain due to the lack of transforming infrastructure, irregular sourcing from small-scale farmers, and distance to markets. Excess mango production can be used for dried mango or canning. However, high start-up costs and working capital would be required; this is not economically viable, given Mali's low margins and small scale.

**Rice.** Mali is a net importer of rice. Its rice production system uses gravity-based irrigation without mechanized bulk water pumping or infield irrigation. On the processing end, rice milling (husking) occurs throughout small-scale private milling operations, using both diesel-powered mobile or fixed husking machines and fixed-site mills. However, Malian milled rice is of low quality, with a high volume of broken rice. In some high production areas connected to the main grid (e.g., the 100,000 ha Office du Niger), larger-scale, fixed-site mills have been developed with higher quality rollers that reduce broken rice, thereby adding value to the volume of rice sold.

In addition to pure processing activities, post-hulling bran-hull biomass is used to generate power for the mill and related activities, as well as lighting on the premises and for staff housing facilities.

**Shallot.** Mali could potentially become a major West African exporter of shallot, thanks to favorable growing conditions. Shallot is grown on small-scale farms across the country, and 90 percent of production ends up in local urban markets. Shallots can be provided fresh or variously processed (e.g., dried, crushed, or machine sliced, [potentially] using solar drying panels or improved solar heaters). Electricity is required for only two processes: (i) pounding and drying and (ii) slicing and drying.

Since consumers prefer the fresh form of shallot, the market for transformed shallots is limited, and higher production costs induced by processing cannot be justified. The main opportunity is extending the market season for fresh shallot, capturing value from price fluctuations due to reduced market volumes. More efficient stocking and drying techniques would make fresh shallot available 4–6 months beyond the regular growing season and

over a year for its dried form. Because storage and drying processes require small amounts of power, there is little opportunity for power to add value to the commodity's value chain, especially in areas not yet connected to the main grid.

**Shea kernel.** Mali is a minor market player in kernels and butter, capturing less than 10 percent of global demand. Penalized for poor quality and yield, unreliable supply, and higher costs, Malian kernel exporters can hardly compete with other West African producing countries. Vegetable oil firms in Europe, India, and Japan dominate the global market, while West Africa accounts for only a handful of industrial extraction facilities, some of which work on a toll basis for global companies. Though Malian farmers have an incentive to produce higher quality kernels, they have little incentive to expand their kernel processing capacity, given the limited potential benefits (Derks and Lusby 2006).

Manual processing of shea fruit includes kernel removal from pits; drying, moulding, and grinding kernels into paste; and kneading paste into separate solids and oils. These activities could benefit from mechanization, but weighed against the required investments, the benefits are not obvious, especially given the low labor costs and limited access to capital.

*Sources:* FAO and Authors.

### *POWER DEMAND FROM MINI-GRIDS*

In Mali, households consume 90 percent of mini-grid electricity, which is mainly used for lighting, with peak load occurring during evening hours. The Koury mini-grid, located in a rural community of Yorosso circle (cercle) in the Sikasso region, is operated by SSD Yeelen Kura, a private operator that manages 21 concessions[12] and has started to hybridize its mini-grids with solar PV. In 2012, Yeelen Kura added 100 kWp of solar PV to the existing 112 kW of thermal capacity, making power available 10 hours a day (typically from 3 P.M. to 1 A.M.). Because of the mini-grid demand profile, the solar output produced by PV generators is stored in batteries, which increases energy losses and capital expenditure (figure 5.5).

The Koury mini-grid currently supplies 180 MWh per year, mostly for households. Out of 3,371 households living in the area, 556 are already connected to the mini-grid, at an average consumption level of about 24 kWh per month.

The opportunities for supplying unmet power demand from small-scale commercial and agro-industrial activities in Koury are significant. Although such activities rely mainly on their own diesel or petrol engines or generators, they represent a total potential energy demand of 7,755 kWh per month—about a 50 percent addition to the existing energy production of the mini-grid power plant (table 5.12). Irrigation is not expected to play a significant role for the mini-grids, given that most irrigation in Mali utilizes gravity fed schemes, and small-scale schemes that require water pumping rely on decentralized pumps spread over large areas.

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

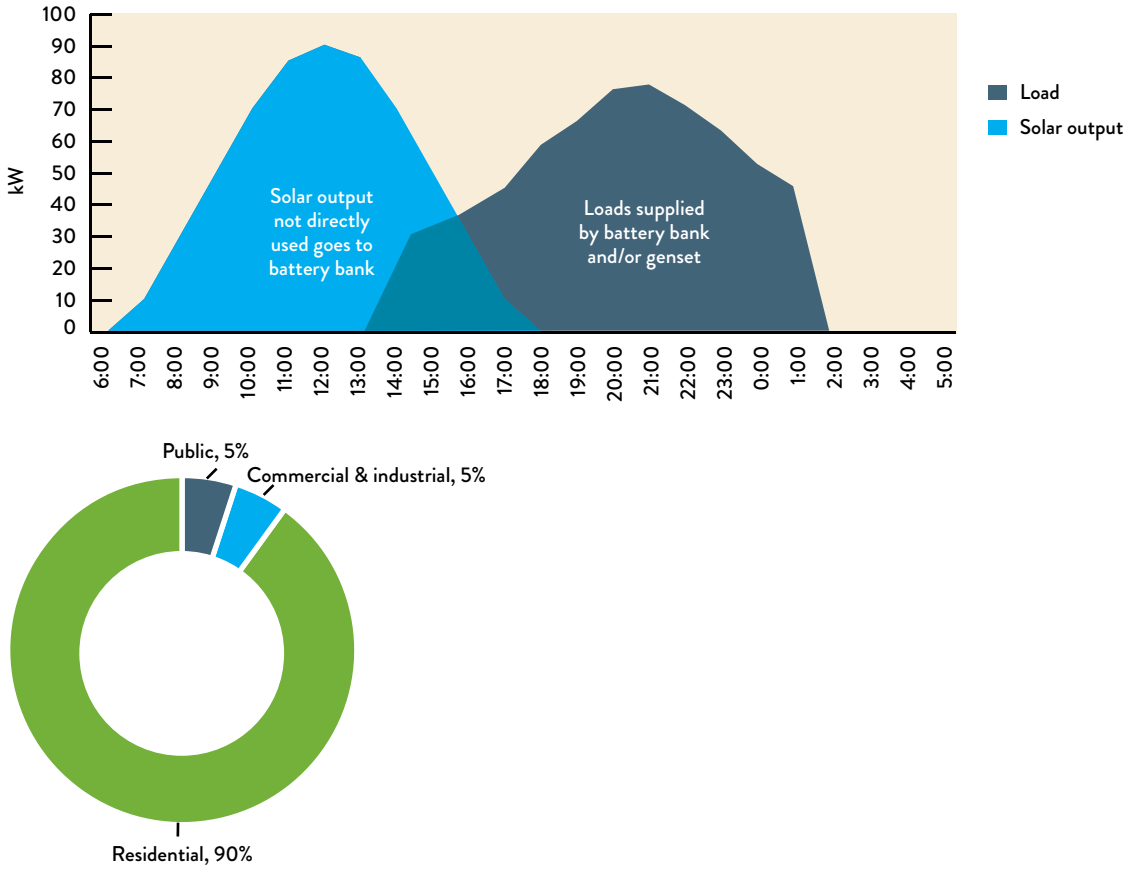
The Koury mini-grid is reaching a near saturation point as generation capacity is fully taken up by current demand. More than 20 percent of the generated electricity is from diesel generators (figure 5.6). The variable cost of thermal generation, at €0.40 per kWh,[13] and the cost of direct consumption (below €0.20 per kWh) suggest the advantages of expanding solar PV capacity.

Notably, expansion of solar PV could enable the electricity provision for productive activities since they require power mainly during the daytime. Direct consumption of solar output would (i) avoid energy losses in the battery bank and (ii) reduce the battery bank size relative to capacity of the solar PV generator.

To attract businesses as mini-grid customers, incentives would be needed to (i) lower tariffs, (ii) supply electricity during the daytime, and (iii) replace manual equipment with electricity powered equipment. Figure 5.7 shows the impact of adding the daytime loads of productive users, along with a 50 kWp matching capacity expansion of the solar PV system (totaling 150 kWp) on the Koury mini-grid load profile.[14]

This capacity expansion is assumed to fall under the existing rural electrification program of the Malian Agency for Development of Household Energy and Rural Electrification (AMADER) and therefore benefits

**FIGURE 5.5:** KOURY MINI-GRID: ELECTRICITY CONSUMPTION PATTERNS



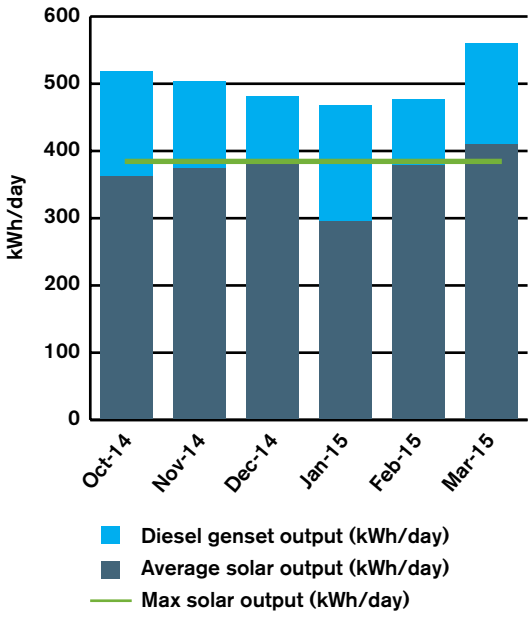

*Source:* SSD Yeelen Kura.

**TABLE 5.12:** POTENTIAL ADDITION OF SMALL AGRO-INDUSTRIAL ACTIVITIES AND OTHER BUSINESSES

| Business Type | Number | Typical Energy Consumption (kWh/month) | Total Consumption (kWh/month) |
|---|---|---|---|
| Milling or grinding (maize, rice, shea kernel) | 6 | 300 | 1,800 |
| Water pumping | 2 | 300 | 2,520 |
| Bakery (electric mixer) | 1 | 300 | 450 |
| Mechanical workshop (welding, grinding, drilling) | 2 | 1,260 | 300 |
| Media center (computer, printer) | 1 | 450 | 135 |
| Petrol station (pumps) | 1 | 150 | 300 |
| Small shops (refrigerators, freezers, TV, lighting) | 10 | 135 | 2,250 |
| **Total** | | | **7,755** |

*Source:* GERES and SSD Yeelen Kura.

**FIGURE 5.6:** ENERGY GENERATION PROFILE AT KOURY SITE




*Source:* SSD Yeelen Kura.

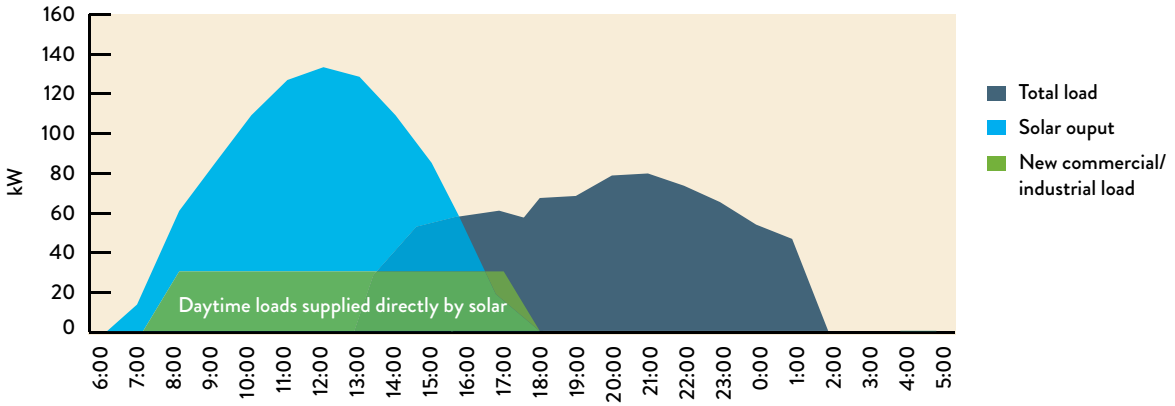
from capital expenditure subsidies, with ownership of infrastructure remaining with the government and the operator regulated under contract.

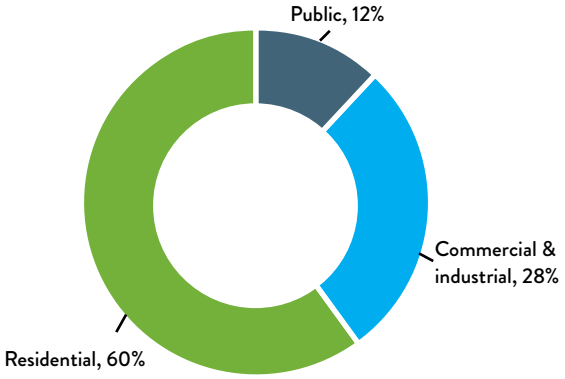
Taking a conservative approach, it is assumed that agro-industrial customers' willingness to pay will be capped at the costs of running individual diesel gensets. This implies that the tariffs needed would be lower than current household tariffs.

### *FINANCIAL ANALYSIS*

From the perspective of SSD Yeelen Kura, the current financial situation of the Koury mini-grid is somewhat precarious (table 5.13, figure 5.8). Although operating expenses are covered by revenues, the 20 percent capital expenditure contribution of the private operator is not recovered through tariffs. In order to achieve a 10–15 percent return, the project receives up to 80 percent of capital expenditure subsidy from the government. Equity investment and reinvestment in capacity expansion and replacement of major parts (e.g., batteries and gensets) cannot be recovered.

**FIGURE 5.7:** KOURY MINI-GRID PROFILE: ADDITIONAL COMMERCIAL AND INDUSTRIAL LOADS




*Source:* SDD Yeelen Kura.

Economies of scale, daytime energy use, and falling solar PV prices imply that the expansion project could be attractive as it allows for additional revenue with relatively low capital expenditure and operating expense. The operating costs will marginally increase due to higher expenses in maintenance and administration, but will be offset by a lower level of generation losses due to direct consumption of solar power (reducing the need for storage) and lower use of thermal generation. Along with the capital subsidy to the developer, this implies a lower average tariff and creates the incentive for new customers to switch from their current diesel generators to daytime electricity consumption from the mini-grid. Largely as a result of the significant capital subsidies, the expansion in generation capacity is financially viable from the perspective of SSD Yeelen Kura, with a positive NPV (table 5.14). However, if viewed from the perspective of AMADER or the Government of Mali, the asset owners, the financial returns are negative (essentially including the subsidy costs in the calculation).

**TABLE 5.13:** CURRENT FINANCIAL SITUATION OF KOURY MINI-GRID

| Item | Amount |
|---|---|
| Households served (no.) | 556 |
| Average total consumption (MWh/year) | 160 |
| Average retail tariff (€/kWh) | 0.55 |
| Payment rate (%) | 80 |
| **Revenues (€)** | **70,500** |
| **Operating costs (€)**[a] | **55,400** |
| **Capital costs before subsidy (€)**[b] | **831,000** |
| **Capital costs after 80% subsidy (€)** | **166,200** |
| **NPV after subsidy (€)** | **(259,700)** |

a. Including corporate overhead and fuel, maintenance, and administrative expenses; excluding depreciation.
b. Including the cost of solar and diesel powered generation and battery storage, as well as costs of the distribution network, civil and electrical works, and engineering; current (2015) costs are used (i.e., €5,300 /kWp, excluding the distribution network).

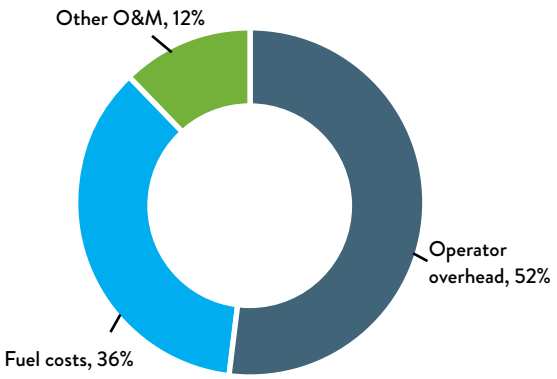
**TABLE 5.14:** FINANCIAL ANALYSIS OF CAPACITY EXPANSION OF KOURY MINI-GRID

| Item | Amount |
|---|---|
| Commercial and industrial customers served (no.) | 20 |
| Average total consumption (MWh/year) | 80 |
| Average retail tariff (€/kWh) | 0.40 |
| Payment rate (%) | 90 |
| **Additional revenues (€)** | **28,800** |
| **Operating costs (€)**[a] | **5,600** |
| **Capital costs before subsidy (€)**[b] | **189,000** |
| **Capital costs after 80% subsidy (€)** | **37,800** |
| **Project cash flows NPV after subsidy (€)**[c] | **103,000** |
| **Project IRR (%)** | **56** |

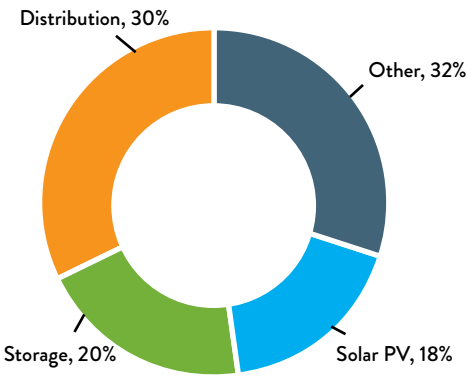
a. Including the cost of fuel and increased maintenance and administrative expenses; excluding depreciation.
b. Including an additional investment of 50 kWp of solar PV; assumes no additional expense in the distribution network.
c. Additional parameters affecting cash flows and thus the calculation of NPV include (i) reinvestment in batteries (every 6 years) and inverters (every 12 years), which are not subsidized; (ii) increased fuel costs, given a PV system degradation rate of 0.5 percent per year; and (iii) a 10 percent weighted average cost of capital (WACC).

**FIGURE 5.8:** OPERATING EXPENSE AND CAPITAL EXPENDITURE DISTRIBUTION

a. Operating expenses




b. Capital expenditures



Similar to most other mini-grid projects in Mali, the Koury mini-grid is not financially viable without large subsidies. While capacity expansion to integrate commercial and agro-industrial loads would improve the financial performance slightly, it is unlikely to be enough to make the grid financially sustainable without subsidies. Some measures that could improve mini-grid performance include implementing better load management practices to reduce energy storage needs, reducing administrative expenses, and enhancing revenue collection through prepaid meters and remote monitoring. Despite these potential improvements, the profitability for hybrid solar-diesel mini-grids would require a revision of the subsidy structure and current tariff levels.

To reach financial viability while serving productive users, capital expenditure subsidy requirements, under assumptions for a greenfield mini-grid similar to Koury, would have to reach 96 percent of a one-off capital expenditure subsidy for initial development and replacement of major parts. With more optimistic assumptions (e.g., a better load management to reduce solar PV losses, improved revenue collection, and lower battery-replacement costs), the subsidy requirement could be reduced to 77 percent of capital investment.[15]

### *ECONOMIC ANALYSIS*

Solar PV capacity expansion to supply productive users has limited economic benefits. For households and existing customers, the cost of supply would remain the same. No significant benefits are expected to accrue to agro-industrial customers as most would not save significantly on electricity costs by switching from marginally more costly individual generators to the mini-grid. This is unlikely to lead to an expansion in processing activity and thus would have little associated economic benefits, as reflected in the slightly negative economic NPV for the expansion project (−€18,000). However, including additional economic, environmental, and social benefits that are not quantified (e.g., reduction in $CO_2$ emissions and other pollutants or reduced reliance on imported fuels and exposure to price fluctuations) could make the project economically viable with a positive NPV. Benefits could also accrue to the agriculture sector if it has suppressed electricity demand, which can be met much easier through mini-grid capacity expansion rather than expansion in the size of the individual generator.

### *MAIN INFERENCES AND INSTITUTIONAL ARRANGEMENTS*

In order for the potential large-scale opportunities to integrate productive users into Mali's mini-grids to succeed, several major barriers need to be overcome (box 5.2). Available financing for rural electrification is a crucial issue for both AMADER and the mini-grid operators. Insufficient and uncertain availability of funding for capital cost grants has limited AMADER, while private operators cannot afford to scale up on their own.

### BOX 5.2: LARGE-SCALE OPPORTUNITIES FOR POWER-AGRICULTURE INTEGRATION IN MALI

Agribusiness development in Mali could have a critical impact on job creation and poverty reduction. With over 40 million ha of arable land and an irrigation potential of 560,000 ha, Mali's agribusiness sector could benefit from favorable agro-ecological conditions and regional food demand. But constraints along the agribusiness value chain (e.g., lack of access to energy and other basic infrastructure, lack of access to finance, and poor sector governance) limit its development. Beyond developing a value-chain strategy, a spatial approach is promoted to boost productivity growth, diversification, and value addition. Since Mali is a vast country, the creation of growth poles, clusters, and trade corridors in the agribusiness sector has real significance. In the Sikasso region, conversion of the Randgold Resources–operated Morila gold mine into an agro-industrial cluster is an example of opportunities to realize large-scale power-agriculture integration.

Currently, the mine's power demand is covered by cumulative available capacity of about 26 MW, with 187,000 MWh of potential production from 10 diesel generators. Once closed and replaced by the agropole in 2017, estimated power needs may drop to 8–10 MW (Randgold Resources estimate), and Randgold Resources plans

(*continued*)

### BOX 5.2: CONTINUED

to hybridize the generation plant and set up a mini-grid aiming to power medium-voltage agribusiness activities, including the following:

- Henhouse (installed capacity of 130 kW with a monthly consumption of 21,000 kWh).
- Juice production and packaging (installed capacity of 1 MW for 4,000 bottles per hour and 30–60 packets per minute).
- Air-conditioned logistic facility (installed capacity of 20 kW with a monthly consumption between 700 kWh in freshness period and 1,250 kWh in peak season).
- Slaughterhouse (installed capacity of 100 kW with a daily consumption of 2,200 kWh).
- Fish preservation units (installed capacity of 200 kW per unit).
- Carton packaging unit (installed capacity of 2.5 MW).
- Other activities (e.g., aquaculture, mango production, and beekeeping).

The mini-grid also aims to connect 100 small- and medium-sized enterprises (SMEs) that require low-voltage, unitary power below 30 kW for transforming and cooling crops (e.g., cereal, shea kernel, and vegetables). Powering SME activities will also facilitate the connection of 15,000 surrounding households and community facilities. This integrated solution optimizes the use of infrastructure to support large-scale agro-industry projects and secure raw materials and supply inputs through a partnership between smallholders and large players. It can also play a role in bringing rural power to the surrounding community.

*Source:* Randgold.

One way to improve the financial viability of mini-grid operators would be through diversification of the service offering to include other energy solutions (e.g., stand-alone systems).[16] Also, clear regulations with scope for tariff-setting flexibility would improve the ability and incentives for supplying productive customers. In addition, differentiated tariffs by customer type or time of use would allow operators to cross-subsidize between customer categories. Finally, access to capital for productive users is critical. Indeed, agribusiness players willing to connect to mini-grids will have to invest in electric machinery to replace manual equipment.

## ENDNOTES

1. The highly stylized setting of the model is thus less appropriate for considering such value chains as milk, poultry, and even floriculture, which have a different spatial distribution of production. While it is possible to adapt the model to these and other settings, it is considered beyond the scope of the present analysis and left for future work.

2. Based on the model assumptions, irrigation load demand is about one-and-a-half times that of all other power demand combined.

3. Assumes an average mill requires 35 kWh to process 1 MT of sugarcane. For other sugar estates in Africa, per hectare power demand could be significantly higher if the potential for gravity fed flood irrigation is not as high.

4. Assumes 3,000 irrigation hours per year.

5. Assumes that the same operating hours as for processing are applied and that a modern inverter driven batch centrifugal consumes about 1 kWh per MT of sugarcane processed.

6. Using a metric of 0.37 employees per ha and considering 4 workers per house (with no family), there are 233 houses in year 1, which rise to 1,399 houses from year 6 onward.

7. The area occupied (300 $km^2$), average rural population density (94 people per $km^2$), and average population growth rate (2.9 percent per year) are used to estimate the surrounding population.

8. On average, each household has 5 members; the number of households totals 5,700 in year 1, rising to 10,077 by year 20.

9. Assumes that total power demand is half that of residential demand and that nonresidential consumers use electricity roughly 4,368 hours a year.

10. A grid connection is essential for exporting power.

11. Domestic tariff is US¢2.3 per kWh.

12. 2015.

13. Analysis was done in Euro (€) currency since the local currency (CFA Francs) is pegged to the Euro, using a diesel price of 650 FCFA per liter (1€ per liter); consumption of 0.33 liters per kWh; and 20 percent in auxiliary losses, lubricants, and other maintenance costs.

14. Assumes no need for further investments in the distribution network or additional diesel generators.

15. Assumes that integration of at least one-third of daytime commercial and industrial loads, 10 percent reduction in solar PV losses from current levels through better load management, 90 percent revenue collection, 20 percent reduction in administrative expenses, and a 20 percent reduction in battery replacement costs within the next 4–5 years due to battery technology development.

16. Partnerships with suppliers of solar pumps or solar mills could also be attractive since many operators are progressively building on an expertise in solar PV technologies.

# Conclusions

## CHAPTER 6

This chapter highlights the study's key findings on Sub-Saharan Africa's potential for leveraging complementary investments in agriculture and electricity to contribute to the region's rural poverty reduction; these include overall results of the study and case studies, along with key learnings from the common challenges encountered by the case study projects (chapters 4 and 5). It then recommends steps that can be taken to maximize the joint benefits of expanded electricity access and increased value added along the agricultural value chains.

## KEY FINDINGS

### *OVERALL RESULTS*

This study finds that creating opportunities to piggyback viable rural electrification onto local agricultural development depends on a variety of site-specific factors (e.g., scale and profitability of agricultural operations, crop, terrain, type of processing activity, and other local conditions). Rural electrification opportunities will be best created by agro-processing activities that generate electricity demand close to rural population centers, generate adequate income to cover electricity supply costs, are sufficiently large in relation to household demand, and have relatively low seasonal variation.

By 2030, electricity demand from agriculture is estimated to double from its level today, to about 9 GW. Between 2016 and 2030, irrigation is expected to provide about three-fourths of the incremental demand (3.1 GW), with agro-processing accounting for the remainder (1.1 GW). The overall magnitude of electricity demand gives a sense of the investment in generation capacity that will be required to meet agricultural needs and the addition to rural electricity demand that is expected owing to the agriculture sector.

For the 13 agricultural value chains selected, electricity demand could increase by 2 GW by 2030, representing nearly half of the 4.2 GW of potential incremental increase in electricity demand from agriculture. Among the value chains examined, poultry has the largest per hectare electricity demand. Together, maize, rice, and cassava account for 83 percent of total incremental demand in agro-processing to 2030. The largest source of electricity demand for the 13 commodities is commercial irrigation, which has the greatest potential to develop large power loads across a range of farm sizes.

### *CASE STUDY FINDINGS*

The case studies show that power supply options for agriculture and rural electrification benefit from economies of scale. Small-scale power systems (less than 5 MW), which may provide a useful source of power service for agricultural processing and household connections, are rarely financially viable without subsidies.[1] When financial viability is not a key driver (or constraint), a full range of activities can benefit from electric power. Once economic benefits are considered, a strong case can be made for providing effective subsidies to cover gaps in financial viability.

The case studies also confirm that irrigation constitutes the largest power demand from agriculture; without it, demand from agricultural activities (except sugar processing) tends to be small. Large land areas are needed to support a major irrigation load. Economic viability is

likely for all except the most expensive sources of power generation for small loads. Power supplies generate proportionally high economic value, primarily through social and indirect economic benefits.

Among the agriculture schemes examined, only large-scale development of irrigation-based agriculture and sugar estates could justify a large grid connection on a purely financial basis. Their requirements—not all of which are readily available in Sub-Saharan Africa—include relatively clear and empty land with good quality soils, reliable supplies of sufficient water, and high quality physical and market infrastructure. Suitable commodities include those typically cultivated on large-scale farms: maize, wheat, sugar, rice, soybean and barley.

The projects show that successful integration of agriculture and power system development requires physical and market infrastructure to facilitate market access for inputs and produce. In Zambia, for example, the strategic location of the Mkushi farming block has improved its development viability. The farming block is situated alongside the main T2 Highway and Tazara Railway, which connect Lusaka and the Copperbelt in Zambia to Tanzania and on to the Dar es Salaam commercial port, providing access to markets for both inputs and produce (chapter 4, case study 3). In Tanzania, the site of the Mwenga mini-hydro generator is situated far from the main TANZAM Highway between Dar es Salaam and the Zambian border; however, the Tunduma, Mufindi Tea Estates, which drove the mini-grid's development, is located only 10–15 km from the main road (chapter 4, case study 2).

**Key learnings from common challenges.** The main barriers faced by the case study projects are linked to the regulatory environment, electrification planning, and institutional and financial capacity. To succeed, projects must be implemented within a stable legal environment that imposes requirements and provides protection. The right degree of regulation must then be found. Viewing the absence of regulations as an opportunity to reduce costs increases risks considerably because of uncertainty. Light-handed regulation of small-scale electricity systems is generally more favorable to developers and operators. In Tanzania, the small power producer (SPP) framework allows private operators to function as power distributors and retailers, charging fully cost-reflective tariffs.[2] This type of regulation should tackle the economic barriers of unaffordability and uneconomic supply. In Kenya, developers have been reluctant to pursue the opportunity to implement electricity distribution and retail schemes because of untested procedures and lack of precedents, notably concerning retail tariff approbation.

Another major barrier to development is the lack of clear electrification plans (e.g., Tanzania and Kenya). Information about future developments of the national grid and concession protection is crucial for dispelling developers' reluctance and avoiding potential friction from tariff differences between customers. The case of large-scale, mini-grid development in Mali shows how regulation and strong government buy-in can, despite large subsidies, allow for development (chapter 5, case study 2). This example also illustrates that clear power regulations are a necessary, but insufficient, condition for successful project development. For example, Tanzania's Mwenga mini-hydro mini-grid—one of the first projects of its kind to deal with regulations about water rights, land access, import laws, and building permits—has entailed significant delays. This experience highlights the need to extend regulations beyond the power sector to include related sectors (e.g., trade, water, land, and environmental management).

For every case study analyzed, the technical and financial capacity of key institutions—the utility, regulator, and rural energy agency—to implement and permit development is perceived as a challenge. The weak financial status of the utilities prevents them from being able to develop financially viable projects without external support. Furthermore, their cash-strapped situation increases the risk of nonpayment for the power supplied by private developers, which negatively impacts project costs and tariffs and, as a result, power affordability. If feed-in-tariffs (FiTs) are not capped at the utility's avoided costs, the situation could worsen, further deteriorating the utility's viability. From the perspective of power-sector regulators, the extra cost and delays resulting from inexperience in negotiating various supply arrangements may be a hindrance to developing private power generation, distribution, and supply.

In **Tanzania,** grid extension planning is generally a transparent and efficient process, largely included in the Power System Master Plan. Although grid densification is currently the priority for the Rural Energy Agency (REA),[3] grid extension projects, such as the one in Sumbawanga, are also part of the plan, considering the potential economic benefits. However, TANESCO (Tanzania Electric Supply Company Limited) has a fragile financial situation, which has consequences for new project investments.

As the mini-hydro project illustrates, dealing with the social and environmental considerations that any project of this nature raises (e.g., water resource management, forestry, village lands, land acquisition, and environmental management) is still lacking in transparency and coordination. Both the regulatory framework and the processes for project development are open to political interference. Coupled with transmission planning, generation capacity must be developed sufficiently and consistently to support grid extension.

Tanzania generally provides developers clear guidance on tariffs, concession security, and system registration; however, the Mwenga experience shows that application of the SPP framework, particularly in setting tariff levels, continues to place unnecessary pressure on developers. For mini-grid developers, especially those that sell power to TANESCO, the risk comes more from the off-taker. Late payments create financial pressure for the operator. Third-party support can therefore help by providing bridging loans. Land access, another obstacle for project developers, can be overcome by developing mutually symbiotic relationships with the local community and district authorities and gaining their support. Project development is still a complex process. The developer, Rift Valley Energy (RVE), expects to sign about 3,000 agreements to access land over which its network runs.

Tariff affordability for consumers continues as one of the most critical issues for mini-grid development. Although RVE is free to set up its tariffs under the SPP framework, pressure from social and political interests continues to make it difficult to do so. The profitability of projects is therefore supported by significant capital subsidies.

In **Zambia,** favorable conditions have facilitated the design and implementation of the Mkushi farming block and the Mwomboshi Irrigation Development and Support Project (chapter 4, case studies 3 and 4, respectively). At a national level, the Mkushi grid-extension process was efficient and transparent; the Zambia Electricity Supply Corporation (ZESCO) led the feasibility study, with the support of a consulting company. Also, land management was clarified by the 1995 Land Act, which gave investors more visibility and reduced the risks of long-term projects. In addition, some solutions were put in place to improve the financial feasibility of both projects. To overcome the utility's cash-strapped situation, the investment costs of grid extension in Mkushi were shared between ZESCO and commercial farmers. Given the extra profits potentially generated by a more reliable power connection, 10 large-scale farmers agreed to fund half of the capital costs.

Beyond these key success factors, some hurdles still need to be overcome. The inability of national generation capacity to support higher peak load and the resulting load shedding create a major risk for farmers. In response, backup diesel solutions were bought to secure production, and irrigation activities were carefully planned to avoid under-voltage. Even though the irrigation project in Mwomboshi will increase peak load slightly, it will require an increase in national capacity in order to reduce risks. Conscious about the critical role played by agriculture in Zambia's economy, central authorities are actively intending to expand the national installed generation capacity so as to limit shortages and load shedding.[4]

In **Kenya,** small-scale, private-sector renewable energy projects have had little success, despite the large number of FiT applications, owing to their high development and transaction costs. Although permits for self-generation are straightforward and allow industrial firms, notably in the agribusiness sector, to lead renewable energy projects, it may take up to three years to acquire licensing and securing of land. The power regulator is working to streamline licensing procedures for projects relying on FiTs. Also, land and way-leave issues can be mitigated thanks to the involvement of project beneficiaries.

A second major concern in Kenya is related to the private sector's involvement in electricity distribution and supply. Currently, Kenya Power and Lighting Company (KPLC) is the only licensed company undertaking distribution and supply activities. The regulatory framework is still unclear on whether other companies are legally allowed to enter this business. Other obstacles concern tariffs and subsidies. Although not explicitly required under the regulations, retail tariffs cannot be higher than KPLC's tariff schedule. This principle could jeopardize the financial viability of any small-scale initiative. Moreover, subsidies are not available for private companies.

## RECOMMENDED ACTIONS TO PROMOTE POWER-AGRICULTURE INTEGRATION

Power utilities in Africa, like those elsewhere in the world, often focus exclusively on their own business, rarely

venturing outside their limited realm of expertise. But a narrow institutional approach—focused only on wires, poles, and consumer billing—means that many of the potential development benefits from electricity remain unrealized. When used by a combination of households, commercial businesses, industry, and agriculture, electricity provides a wide array of benefits and revenue. Ignoring these broader possibilities not only limits the possible benefits for communities and the country overall; most importantly, it neglects the potential revenue for power producers from the increased electricity sales.

### *IMPROVE INSTITUTIONAL COORDINATION*

In order to realize their full potential as providers of electricity service, power companies need to engage with related programs to develop complementary strategies. In the case of agriculture-power integration, this means establishing electricity expansion strategies in collaboration with rural development, agriculture, and other institutions and agencies.

Such complementary strategies can take several forms. One is to provide electricity to those rural areas with the most potential for commercial activities, which is typically the case. For example, electricity can be prioritized in areas with a large irrigation potential, combined with access to markets for agricultural goods. Machinery used in agricultural production, including small threshers, can be promoted as part of a package to encourage electricity use in agriculture. For areas receiving electricity for the first time, agricultural fairs can be set up by local governments to demonstrate the possible machinery that can be used in agriculture.

### *INTEGRATE PLANNING OF POWER, AGRICULTURE, AND RURAL DEVELOPMENT*

Coordination with related institutions and agencies can also benefit the electricity companies. Once a rural development agency realizes that an area is to receive electricity, it may make plans to include those communities in its program, meaning that the region would have access to electricity in conjunction with other inputs important for rural development. Thus, institutional cooperation can work both ways; that is, electricity companies can prioritize certain regions with existing or potentially high levels of agricultural production, while rural development or agricultural agencies can also target areas that will be able to take advantage of the many possible productive use impacts of electricity. The benefits of breaking down institutional barriers between power, agriculture, and rural development programs result in higher revenues for the utility companies and higher levels of development for regions and countries.

### *PROMOTE FARMERS' PRODUCTIVITY*

For their part, the electricity companies can promote internal units responsible for demand-side management and encourage the productive and efficient use of electricity. Productive use units can be responsible for promoting the adoption of productivity enhancing machinery in agriculture, from planting to irrigation and harvest. Such units can coordinate with other organizations, such as farmer associations, nongovernmental organizations (NGOs), and various other local- and regional-level organizations already working closely with farmers to increase productivity.

The barriers to farmers' productively using electricity in rural areas are relatively easy to overcome. They typically include a lack of simple knowledge about available machinery, lack of a local vendor, and inability to purchase machinery on credit. Given the high expense of using diesel-powered engines for grain processing, campaigns could be developed by local governments to promote the substitution of electricity for diesel engines among farmers in areas just gaining access to electricity.

In many countries of Sub-Saharan Africa, lines of credit to farmers and other agricultural entrepreneurs could be augmented by local banks so as to enable the adoption of new machinery (e.g., irrigation pumps, mills, and small stationary threshers). In many cases, existing lines of credit are mainly for seed and other supplies provided at the beginning of the growing season, with loans paid off after harvest. The electricity companies could work with banks and other credit agencies to set up credit lines specifically for the purchase of electric machinery.

## ENDNOTES

1. Exceptions may include hydropower and biomass. Under favorable geographical conditions, low-cost hydropower can be provided; also, biomass can support agricultural activities, but seldom beyond those of the agriculture estate.

2 Especially for systems under 100 kW, for which no approval is required from the Energy and Water Utilities Regulatory Authority (EWURA), Tanzania's sector regulator.

3. Tanzania's rural electrification planning is led by the REA, with the operational support of TANESCO and support of development partners. The July 2014 National Electrification Program Prospectus identified key development centers for connection to the main grid, which will not be effectively initiated before 2016. While the prospectus suggests that some flexibility in identifying additional centers could be considered in order to develop synergies between power and agriculture, such uncertainty can be unhelpful to planners of rural electrification projects.

4. In addition to these technical issues, environmental considerations must be taken into account. The impacts of these projects on the environment, especially those that involve dam construction, have a non-negligible significance.

# ANNEXES

# Annex A: Business Models for Agricultural Development

Attaining productivity increases by focusing on small-scale agriculture and small- and medium-sized agribusiness enterprises, as compared to larger scale commercial systems, is a major challenge. Larger scale farming provides economies of scale in production and input supply, including finance. This is particularly observable for relatively large, uneven investments (e.g., machinery, irrigation, and electricity installation) or working capital needs. Smaller farms tend to be less efficient when collateral requirements affect their ability to raise working capital (Collier and Dercon 2009).

However, this does not mean that one farming system should entirely preclude the other as there are examples of successful crop-specific, small-scale projects, particularly in the higher value commodities. Meeting growing demand will require improved performance of informal value chains and their linkage with formal value chains to gain much needed capital, knowledge and skills, and market contacts. Achieving this will require a more flexible approach to farming systems, currently being evaluated, whereby farming is seen as a business, with small-scale farmers and their communities forging stronger linkages with modern agribusiness. The key is to ensure economies of scale around aggregated small-scale farmer models linked to larger commercial agribusiness. For example, new integrated small-scale farmer models are being tested in northern Ghana with the development of a commercially run, professionally managed maize farmers association, Masara N'Arziki. Such small-scale farmers associations are being developed with the technical help and financial support of commercial inputs and commodity marketing companies; Masara N'Arziki currently has more than 10,000 small-scale members producing over 100,000 MT of maize for local and regional markets.

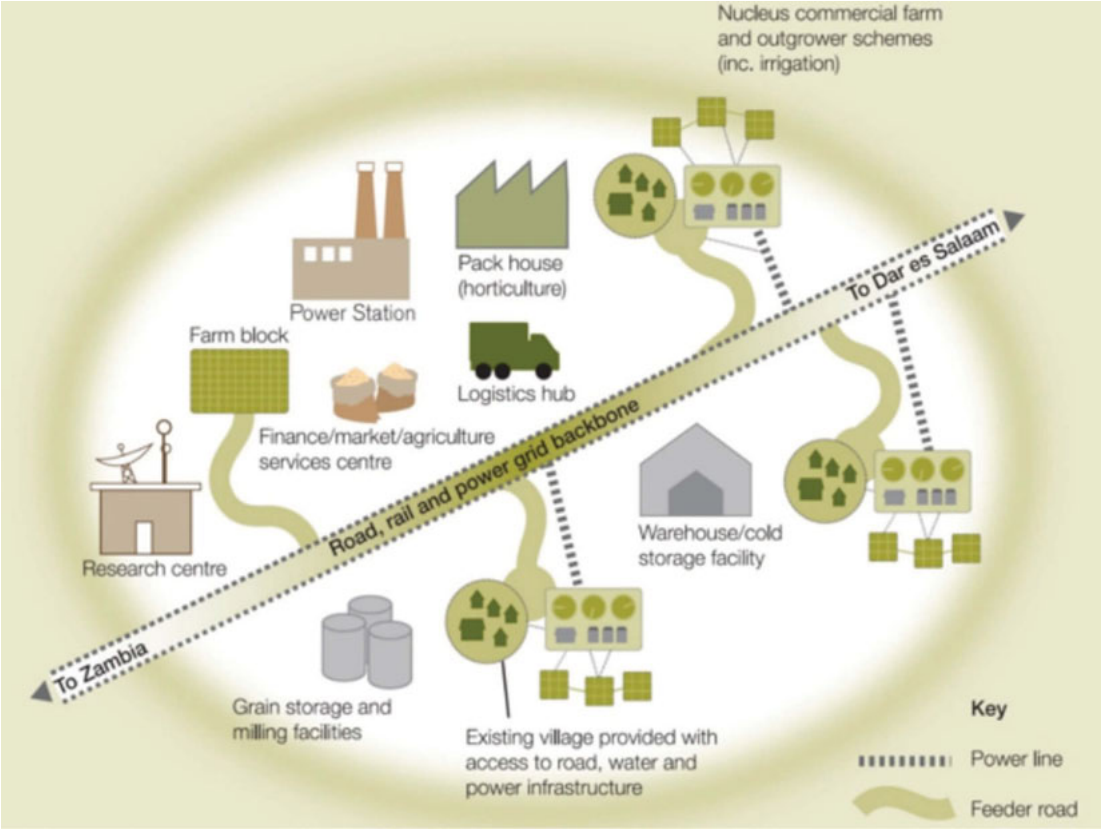
Other models that create scale include the **nucleus farm hub and outgrower models**. These allow small-scale and emergent farmers to benefit from access to infrastructure, including irrigation, lower cost inputs, processing and storage facilities, finance, and markets. Adjacent villages can be linked to water and power supplies at low marginal cost. In cases where nucleus farms and outgrower schemes incorporate community-owned land on a leasehold basis, local residents can be given an equity share in the farming business, as well as access to low-cost irrigation. Likewise, farmer producer associations can be integrated into commercial value chains through outgrower or contract farming models.

Other evolving agribusiness models enable the **"crowding in"** of both public and private **investment into defined areas** of a country. Due to economies of scale, farmers and agribusinesses are most likely to be successful when they are located in proximity of each other and related service providers. Such programs as the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) is focusing initially on 5–6 **clusters** within the southern corridor where there is potential, over time, for profitable groupings of farming and processing to emerge.[1] Each cluster requires investment along the full agriculture value chain. Some of these investments are public goods (e.g., rural infrastructure and electrification) that must come from the **government and its development partners**; others can expect to earn a financial return and will come from the **private sector** (figure A.1).

Building on existing operations and planned investments, the clusters are likely to bring together agricultural research stations, larger nucleus farms and ranches with outgrower schemes, commercially focused farmer associations (like those described above), irrigated block-farming operations, processing and storage facilities, transport and logistics hubs, and improved "last mile" infrastructure to farms and local communities.

When occurring in the same geographical area, these investments result in strong synergies across the agriculture value chain, helping create the conditions for a competitive, low-cost industry. Similar corridor programs are operational in Mozambique (e.g., Beira Agricultural Growth Corridor), while others, such as the Lakaji Corridor in Nigeria, are still in the design stage.

**FIGURE A.1:** EXAMPLE OF AN AGRIBUSINESS CLUSTER




*Source:* SAGCOT Investment Blueprint, AgDevCo, and Prorustica.

The aim of creating simultaneous coordinated investments can also be found in the concept of **growth poles**. Rather than being oriented around addressing identified market failures, growth pole projects center on exploiting opportunities that already exist. The underlying assumption about the benefits of growth poles is that they increase market size so that it becomes profitable for firms to invest, with the resulting higher wages and economies of scale. Notable agriculture-related growth pole programs include those now being developed in Burkina Faso (e.g., Bagre Growth Pole Project) and the Democratic Republic of the Congo (e.g., Western Growth Poles Project). The Western Growth Poles Project also includes development of a special economic zone to provide land equipped with critical infrastructure and a more conducive business environment for investors and private-sector operators.

The forces driving the evolution of the design and development of these types of programs are the demands of modern agribusiness and commercial agriculture for new technology, finance, and logistics. To ensure their success, larger agricultural systems are needed, be they stand-alone commercial farming and agribusiness enterprises or those linked to business focused, integrated small-scale organizations. All of these agricultural systems require viable and reliable power sources. The primary power requirement of commercial agribusiness clusters is **irrigation**, which can increase yields, reduce risk, and allow for winter cropping and **post-harvest processing and storage** activities; locating these activities closer to production can reduce transport costs and allow for increased value capture closer to the point of production.

With a focus on particular regions for agribusiness development in place, the aim of governments should be

to **encourage anchor investments that require reliable sources of power**. Building up a critical mass of such investments should lead to a trigger point, whereby investments in grid extension and cluster electrification are financially and economically feasible. Reaching this tipping point will allow for the "crowding in" of additional related investments into the region to exploit the value-chain opportunities and economies of scale. These activities, in turn, will lead to **opportunities to electrify local businesses and community customers**, whose low levels of power consumption would not otherwise have justified electrification.

## ENDNOTE

1. Kilimo Kwanza Executive Committee, *Investment Blueprint* (Dar es Salaam: SAGCOT, 2011).

# Annex B: Agriculture Fuels for Power Generation

In addition to providing demand for power, certain agriculture activities provide a supply of power. Agricultural products that may be used as fuels for power generation can be categorized as direct burning fuels or fuels that are the product of chemical conversions. This annex outlines three of the more common forms of power supply from agricultural activities.

## BIOMASS

Biomass is biological material derived from living or decaying organisms. In the context of biomass energy, the term often refers to plant-based material; however, biomass can apply equally to animal- and vegetable-derived material. As it is growing, biomass takes carbon out of the atmosphere, and returns it as it is burned. Biomass for energy can include a wide range of materials. High-value material, such as good quality large timber, is unlikely to become available for energy applications. However, resources of residues and waste could potentially become available, in quantity, at relatively low cost. In the context of Sub-Saharan Africa, the main categories include agricultural residues from harvesting and processing and high-yield crops grown specifically for energy applications. Plant-based material include**s wood (sawmill waste), nutshells, agricultural wastes (e.g., rice husks), corn stover, and cassava peels.**

An assessment for the West African Economic and Monetary Union (UEOMA) countries suggests that agricultural residues amount to about 10 metric tons (MT) of stubble per ha of maize, 5 MT of dry matter per ha of sorghum, 4 MT of straw, 2.5 MT of bran per ha of rice, and 2 MT of tops per ha of groundnut and cowpea (UEMOA 2008). In many countries, these are sources for traditional, as well as modern, utilization of biomass energy.

## BAGASSE

Bagasse—the fibrous matter that remains after sugarcane or sorghum stalks are crushed to extract their juice—is used as a biofuel in many sugar estates around the world. In sugar production, every 10 MT of cane crushed produces nearly 3 MT of wet bagasse. The high moisture content of bagasse, typically 40–50 percent, is detrimental to its use as a fuel. For electricity production, it is stored wet, and the combination of the mild exothermic reaction resulting from the degradation of residual sugars, along with exposure to air, light, and heat, dries the bagasse pile slightly.

Bagasse is used primarily as a fuel source for sugar mills. When burned in quantity, it produces sufficient heat energy to provide both electricity and heat (including steam) to supply all the needs of a typical sugar mill, with energy to spare. At some sites, surplus electricity is sold to third parties (including feeding in to main grids).

## BIOGAS

Anaerobic digestion is a natural process, whereby plant and animal materials (biomass) are broken down by microorganisms in the absence of air. The process begins when biomass is placed inside a sealed tank or digester. Naturally occurring microorganisms digest the biomass, which releases a methane-rich gas (biogas) that can be used to generate renewable heat and power. The remaining material (digestate) is rich in nutrients, so it can be used as a fertilizer.

A biogas plant can be fed with such crops as maize silage or biodegradable wastes, including sewage sludge (animal and human) and food waste.

Four types of technology can be used to convert the chemical energy found in biogas into electricity. In biogas conversion, the chemical energy is converted into mechanical energy in a controlled combustion system. The mechanical energy activates a generator, producing electrical power. Gas turbines and internal combustion engines are the most common technologies used in this type of energy conversion.

At the village level, biogas plants can be built to convert livestock manure into biogas and slurry, the fermented manure. For small-scale farmers, the technology is feasible for those with livestock producing 50 kg of manure per day, an equivalent of about 6 pigs or 3 cows. This manure is collected and mixed with water and fed into the plant.

# Annex C: Description of Processing Activities

## POST-HARVEST AND PRIMARY PROCESSING

**Cleaning drying**. Many of the basic drying techniques rely on solar energy through sun drying (e.g., such cereals as wheat and maize). Slightly more rigorous drying technologies use energy input for heating boilers; this energy may be in the form of electricity, but often is biomass (farm waste) or liquefied petroleum gas (LPG). The latter techniques are more common for fruits, vegetables, and meats with a high moisture content (i.e., about 60–80 percent) which must be reduced to a range of 10–25 percent to prevent spoilage.

**Milling**. Mills are used for processing in the value chains of maize, wheat, and rice. Smaller mills may be powered with diesel or electricity, and larger units with electricity only. For maize, the main choice of milling is either a plate mill or hammer mill (often supplied by India and China, and increasingly from local craftsmen). The plate mill can grind both wet and dry products, while the hammer mill is restricted to dry products. Hammer mills are the more prevalent of the two although plate mills are popular in West Africa and Sudan and operate with a greater component of shear than compression. As a rule of thumb, about 1 kW can mill 25–30 kg of produce per hour. Hammer mills have a power requirement in a range of 2–50 kW, while motor-driven plate mills generally demand less power; 0.5–12 kW is usually sufficient. Larger scale hammer mills, with a capacity of 4.5–5 MT per hour, have a power consumption of approximately 75 kW; for fully integrated milling systems, with a capacity range of 2.5–25 MT per hour, power demand is 120–650 kW. These systems can operate year-round, often at nearly constant rates.

The power demand of wheat mills ranges from 20 kW for smaller units up to 600–700 kW for larger ones. Small-scale rice mills can remove the hard husk and polish the kernel. A full rice processing production line (excluding the polisher), with a daily output of 20–30 MT, has a total power demand of approximately 38 kW, whereas a processing line with polishers requires 60–90 kW.

Commercial-scale mills are usually found along main roads with access to national grid power supplies. Diesel power supplies are too expensive for commercial operators to remain competitive, and other sources of power can be unreliable. In many countries, a mill may have a backup diesel generator to compensate for the unreliability of national grid supplies.

**Cold storage**. Control temperature storage is used to reduce the temperature of foods and flowers post-harvest. Cooling or chilling a food product reduces the risk of bacterial growth and allows longer storage of produce without spoilage.[1] In principle, this process enables farmers in relatively remote locations to harvest and store produce for shipment to large demand centers beyond the local markets (including exports). A cold chain is thus a necessary asset for many high-value agricultural products (e.g., milk and dairy products, fish and other seafood, fruit and vegetables, meat and prepared foods) and high-value horticulture and floriculture industries, especially those that are export-oriented. Large storage hubs are often centrally located at transportation centers; however, more localized facilities are often necessary since products deteriorate quite rapidly post-harvest and must be cooled/dried or processed immediately.[2] While grid power is more cost effective, alternative energy sources, including solar power, can be used.[3] For commodities transported fresh to market, cooling systems are often temporary or movable, with commodities packed straight into refrigerated reefers before being moved within days. Reefers can be plugged into any power supply for the short term, and, once in transit, are often powered with diesel gensets.

**Cassava processing**. Roots and tubers (e.g., cassava, potatoes, and yams) have high moisture content, which makes them hard to store and bulky to transport. Cassava is the most perishable of the roots and tubers and can deteriorate within a couple of days of harvesting. This implies that cassava is mostly sold in processed form, and processing facilities and machinery need to be located at relatively short distances from the agricultural lands. The more important traditionally processed products include dried chips, flours/starches, and gari. Most small-scale

chippers and graters are petrol driven, with capacities of 1 MT per hour and a power drive of 3.5 hp, equivalent to 2.6 kW. Large-scale cassava factories are usually located in the vicinity of cassava farms.

**Meat processing**. The core processing equipment consists of hoists for lifting, which can be operated manually or electrically; meat grinders; bowel cutters; cooking vats; smokehouses; and chillers. Refrigeration is generally the most energy-intensive activity in meat-processing facilities. Other uses of electricity include on-site water pumping for washing, electrical elevators, and hoists and stunning guns, with scalding tanks (electrical heating) for pig processing. Modern abattoirs consume energy in livestock holding; slaughtering and processing; monitoring and testing; cleaning; and packing.

**Oil extraction**. Oil extraction from a variety of oilseeds (e.g., sunflower, soybean, sesame, palm oil, and groundnut) results in significant value addition to the final product. While smaller scale extraction is done using a manual press, larger scale commercial systems use motorized presses that rely on electric input. Oil filter presses are used for larger, electricity-powered oil-extraction systems for sunflower, groundnut, and soybean. Once cleaned and de-hulled, the seed is placed under increasing pressure as it is conveyed through a tapered chamber (expelling). Mini extruders, typically with a capacity of 125 kg per hour, require a power drive of about 10 kW, while 400 kg per hr power requirements are approximately 23 kW. Capacity depends on the quality and type of seed (e.g., groundnut capacity is 120–180 kg per hour, compared to sunflower capacity of 280–320 kg per hour using a similar 15–18.5 kW motor).

## SECONDARY PROCESSING

**Thermal treating**. Thermal treating of foods (either heating or cooling) is necessary to destroy microorganisms that could adversely alter food properties or deactivate enzyme action and optimize the retention of certain quality factors at minimum cost, including such processes as pasteurization (e.g., of milk and some fruit juices) and sterilization. Heat exchangers are used on a wide variety of products, including pasteurization of cheese, milk, and other beverages; ultrahigh temperature sterilization; bottled water treatment; and heating of soups, sauces, and starches.

**Canning, bottling, and packaging**. A growing number of foods are packaged to increase their shelf life. Prior to packaging (or canning or bottling), food may be processed (by juicing, peeling, or slicing) to increase value and prevent deterioration (through pasteurization, boiling, refrigeration, freezing, or drying). Each of these processes creates demand for electricity. Packing requires electricity to run machines for vacuum sealing, heat sealing, and bottling; in larger facilities, electricity is needed to power conveyor belts, as well as to run filling, weighing, wrapping, boxing, coding, and printing equipment.

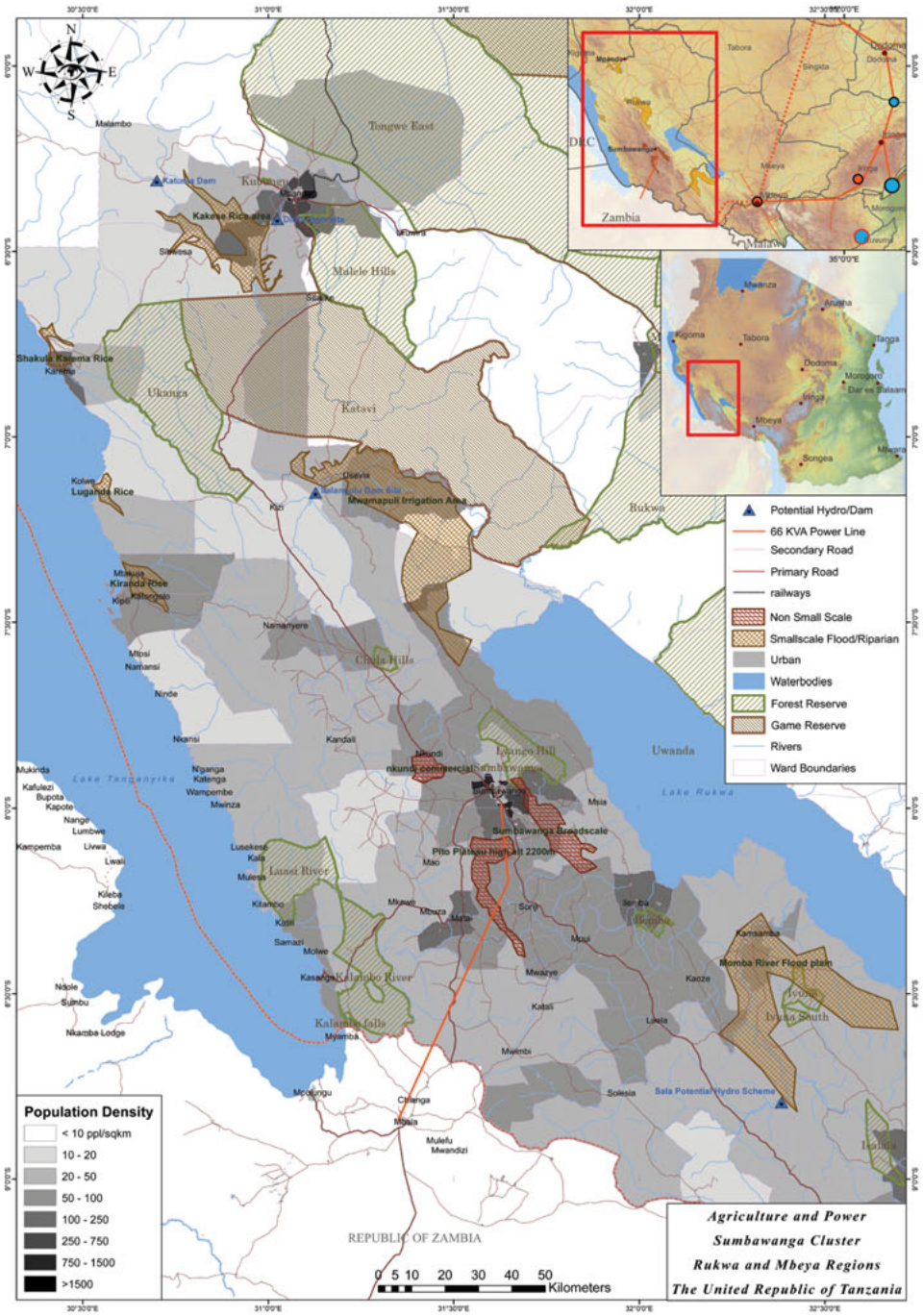
Many of Sub-Saharan Africa's canning and bottling factories are situated in areas where electric power is available and reliable.[4] Modern packing lines require reliable electricity supplies to operate efficiently. As with other secondary processing plants, packaging plants are often supplied with main grid power. The power requirements for juicing and canning is quite low. For example, a juicing machine that can process up to 5 MT of raw fruit per hour may have a peak power load of 5–22 kW. A canning machine with a per-hour capacity of 250 cans (approximately 125 kg) has a power-load range of 5.5–7.5 kW.[5] Given the scale efficiencies of larger facilities, it is difficult to extrapolate to determine the load of a much larger commercial plant without information on the capacity and power demand.

## ENDNOTES

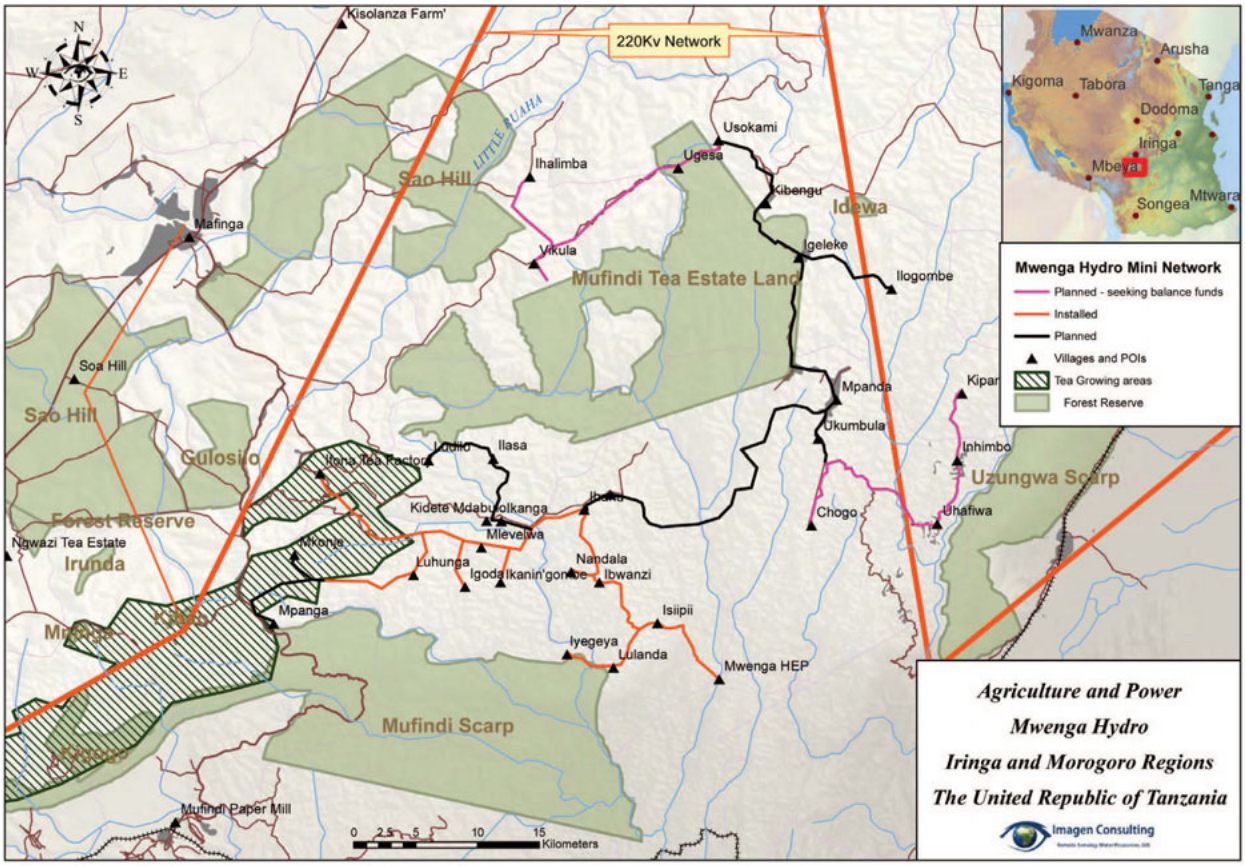
1. Rapid chilling—also known as flash freezing—lowers this risk even further.
2. For some products, the shelf life may be diminished by a factor of eight times the length of delay between harvesting and cooling.
3. With peak demand during daylight hours matching the generation profile of solar power, freezing systems can be switched off overnight when outside temperatures are cooler.
4. Notable canned foods prevalent in Sub-Saharan Africa include pineapple, grapefruit, and tomato.
5. References come from data on plants available for sale on Alibaba.

# Annex D: Maps of Case Study Project Areas

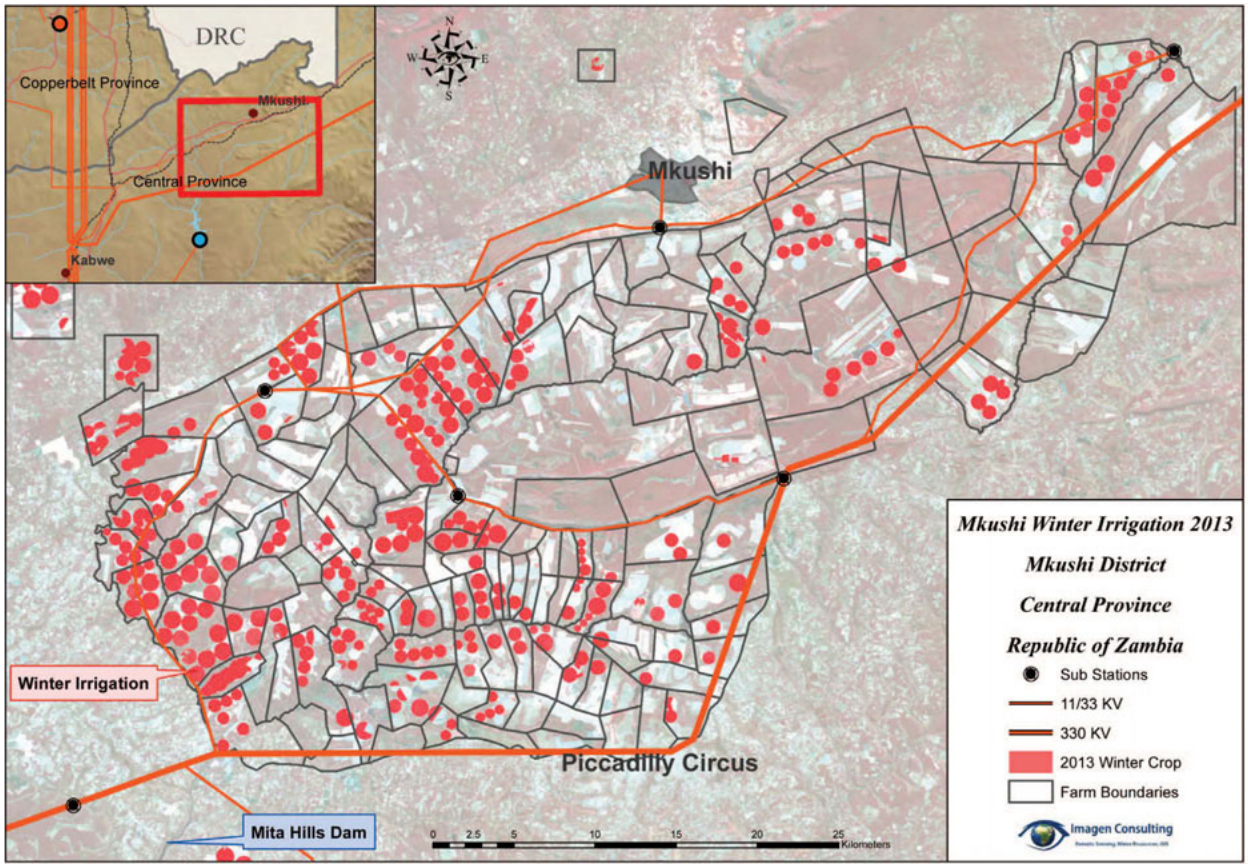
**MAP D.1:** TANZANIA: POWER AND AGRICULTURE IN THE SUMBAWANGA AGRICULTURE CLUSTER



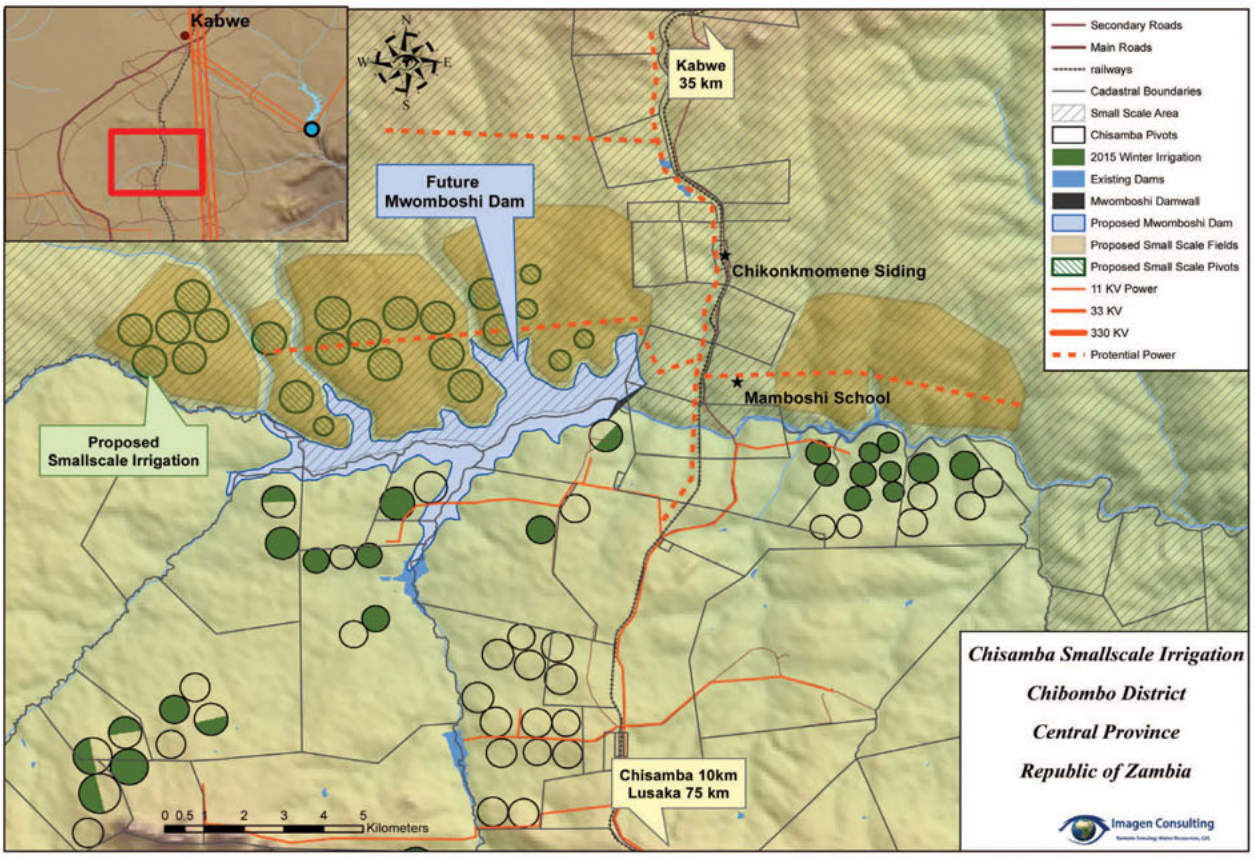
**MAP D.2:** TANZANIA: MWENGA MINI-HYDRO MINI-GRID



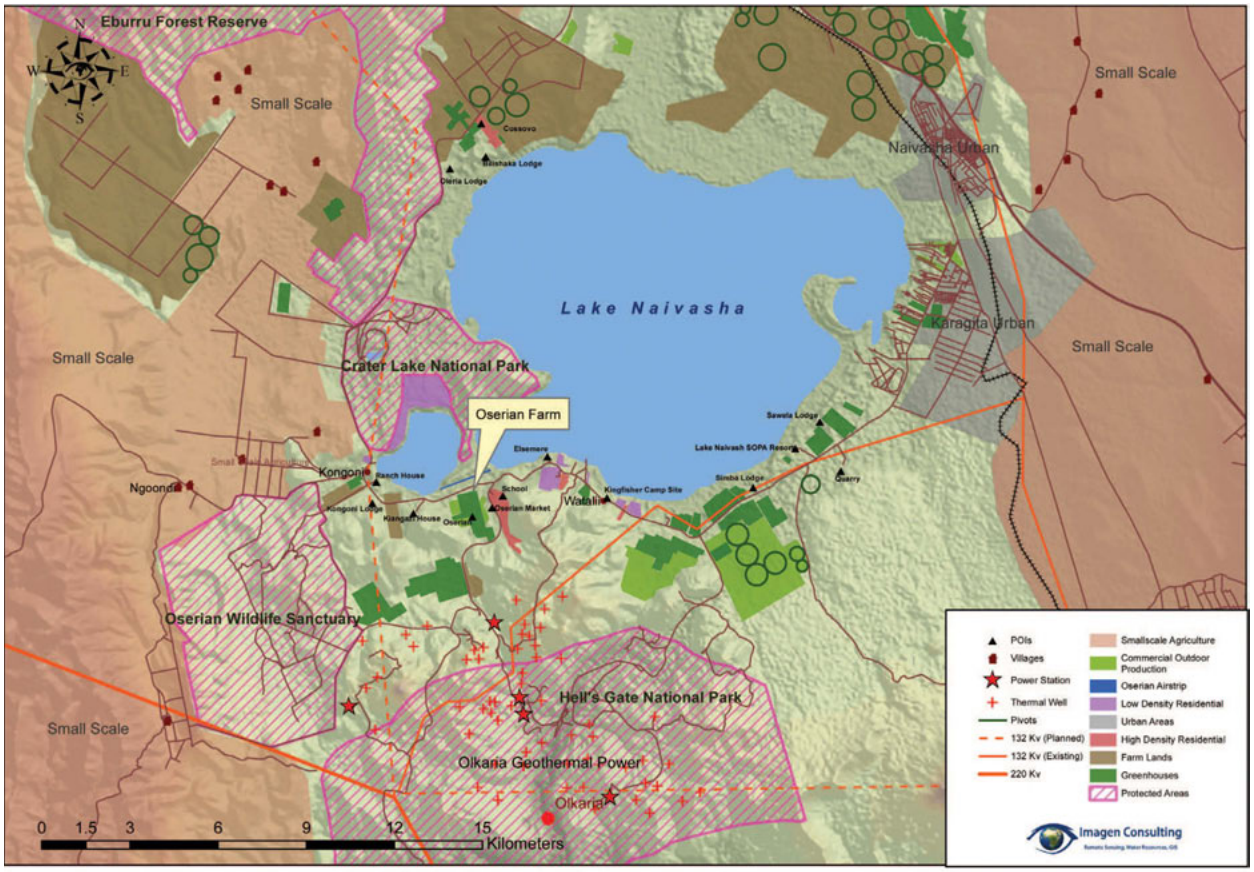
**MAP D.3:** ZAMBIA: MKUSHI FARMING BLOCK



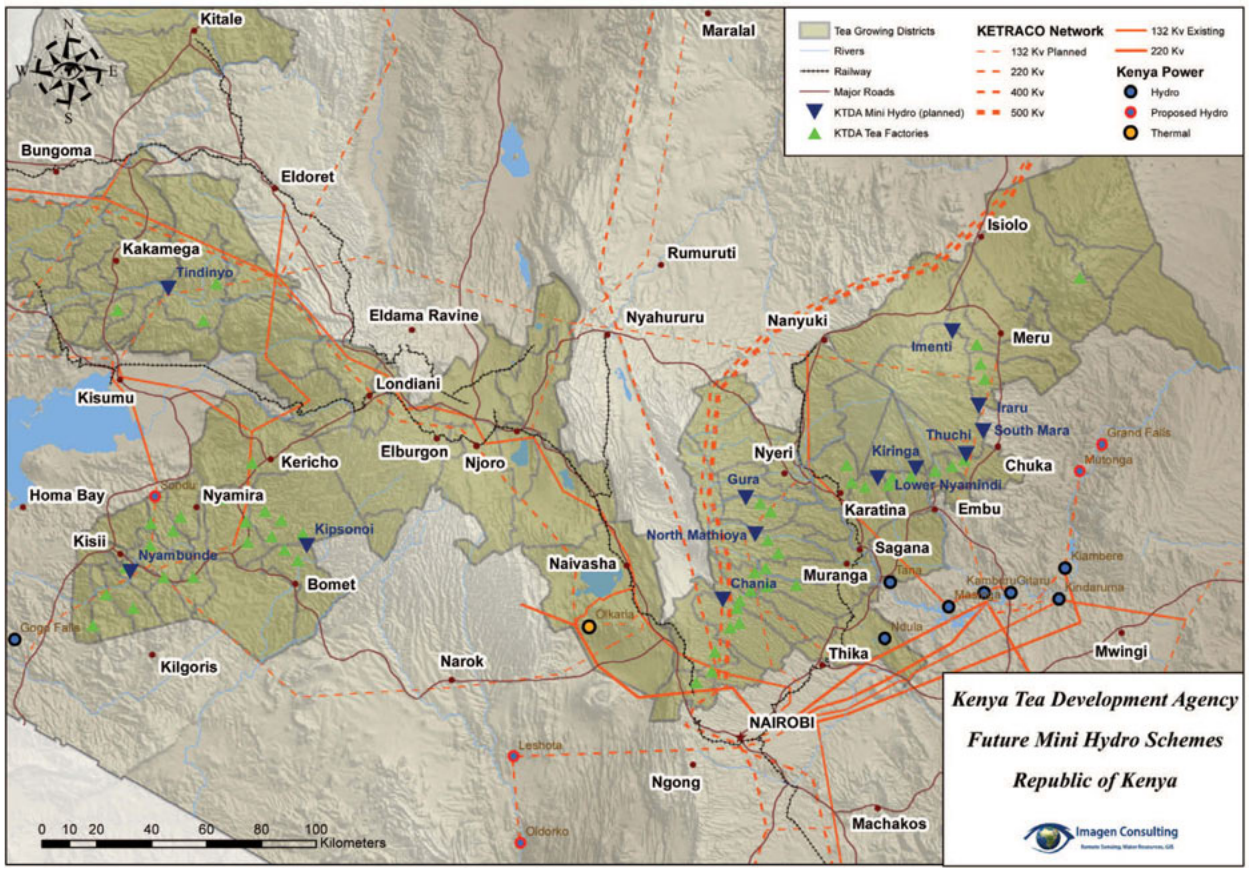
**MAP D.4:** ZAMBIA: MWOMBOSHI IRRIGATION DEVELOPMENT AND SUPPORT PROJECT



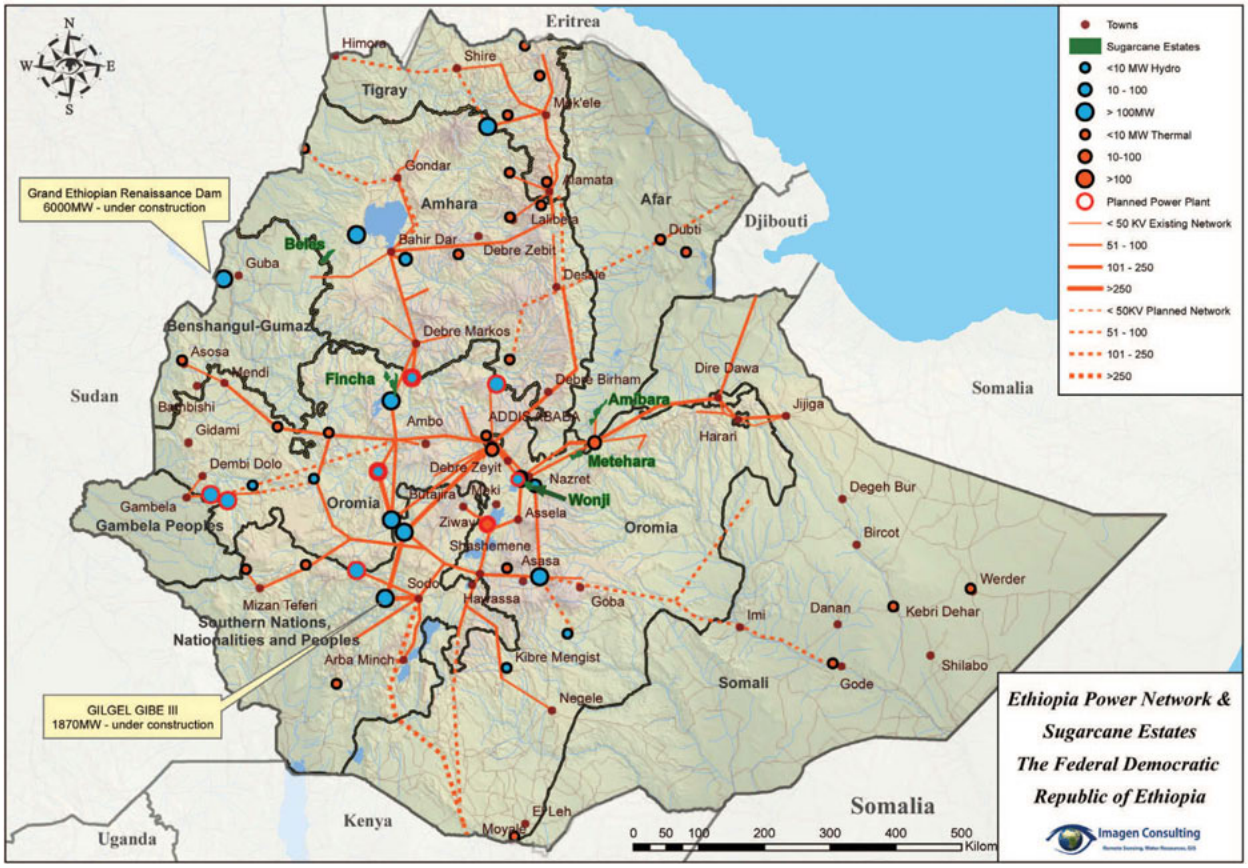
**MAP D.5:** KENYA: OSERIAN FLOWERS AND HARNESSING GEOTHERMAL POWER



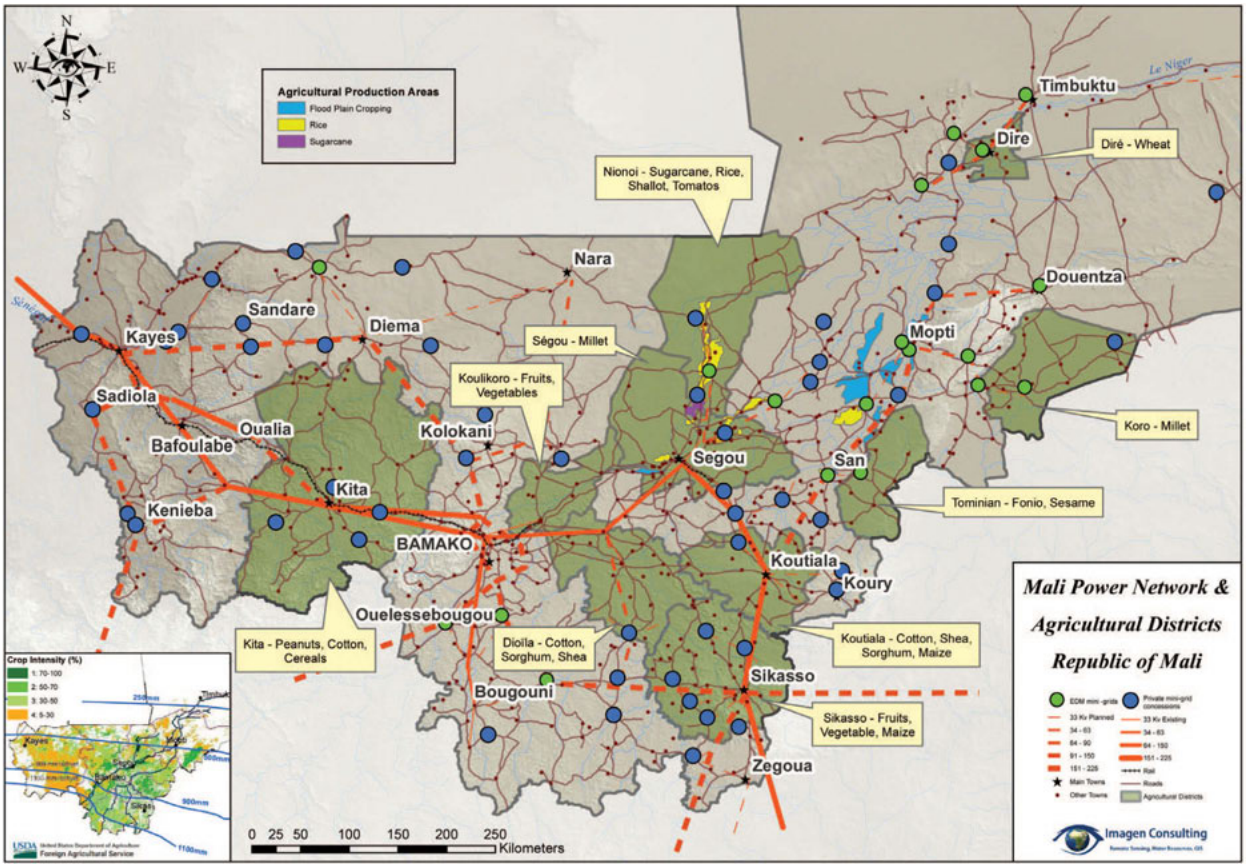
**MAP D.6:** KENYA TEA DEVELOPMENT AGENCY HOLDINGS MINI-HYDRO MINI-GRIDS



## **MAP D.7:** ETHIOPIA: SUGAR ESTATES



**MAP D.8:** MALI: POWER NETWORK AND AGRICULTURAL DISTRICTS



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The majority of households and enterprises in rural Africa cope without electricity, compromising socio-economic welfare and firm productivity. Africa, characterized by low electricity consumption and ability to pay, makes rural electrification commercially unviable.

Agriculture as the most important value added industry in rural areas presents a significant opportunity to improve commercial viability of grid and off-grid projects. This study explores the nexus between power and agriculture, challenges in scaling-up, and recommendations to harness this opportunity.

ESMAP

Africa Renewable Energy Access Program (AFREA)

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# Double Dividend: Power and Agriculture Nexus in Sub-Saharan Africa

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Kabir Malik
Andrew Tipping
Juliette Besnard
and John Nash

ESMAP
Africa Renewable Energy Access Program (AFREA)
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# Foreword

The greatest challenge to increasing electricity access in Sub-Saharan Africa is how to make electricity provision financially viable in low-demand rural households. The presence of commercially attractive customers—typically those that have relatively large and stable electricity demand for revenue generating purposes—can help reduce the barriers to accelerating grid and off-grid approaches to rural electrification. By aggregating anchor-load demand with that of households and businesses, it may be possible to extend the grid or create opportunities for mini-grids and other decentralized options.

African agriculture has tremendous potential to raise rural welfare through agricultural transformation. It is estimated that productivity growth in agriculture—which predominates the livelihoods of the subcontinent's rural poor—could be several times more effective than growth in other sectors in reducing rural poverty. Furthermore, there is a growing commitment among African governments toward sustainable and inclusive agricultural development.

Developing energy intensive agricultural processes, such as large-scale irrigation or milling activities, can not only increase agricultural productivity, but can also increase the commercial viability of electricity provision. The large-farm, agribusiness model practiced over the past 20 years has a continuing strategic role to play in promoting growth in Africa. At the same time, subsistence, smallholder farms, which account for most of Sub-Saharan Africa's agriculture, are key to stimulating the rural economy and uplifting the poor. Energy, along with investments in other complementary infrastructure and services (e.g., roads, transport links to markets, and access to finance), is a critical input for supporting Africa's agricultural transformation. Without access to affordable and reliable electricity, farmers will continue to face constraints to productivity growth and thus lag behind their counterparts in more prosperous regions of the developing world.

Against this backdrop, this study explores opportunities for synergy between the goals of rural electrification and agricultural transformation in Sub-Saharan Africa. It shows that leveraging complementary investments in agriculture and electricity can yield double dividends in terms of poverty alleviation. Aligning electricity investments with agricultural development can maximize joint benefits from the expansion of rural electricity access and the increase in value added along the agricultural value chains, both of which are directly linked to improved quality of life and poverty alleviation in rural communities.

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# Abbreviations and Acronyms

| | |
|---|---|
| **ABC** | Anchor Business Community |
| **AMADER** | Malian Agency for Development of Household Energy and Rural Electrification |
| **CAADP** | Comprehensive Africa Agriculture Development Programme |
| **CAGR** | compound annual growth rate |
| **CHP** | combined heat and power |
| **CSR** | corporate social responsibility |
| **CTC** | cutting, tearing, and curling |
| **DRC** | Democratic Republic of the Congo |
| **ECA** | Economic Consulting Associates |
| **EEPCO** | Ethiopian Electric Power Corporation |
| **EFB** | empty fruit bunch |
| **ESC** | Ethiopian Sugar Corporation |
| **EWURA** | Energy and Water Utilities Regulatory Authority |
| **FFB** | fresh fruit bunch |
| **FiT** | feed-in tariff |
| **GDP** | gross domestic product |
| **GP** | global practice |
| **GTAP** | Global Trade Analysis Project |
| **IPP** | independent power producer |
| **IRR** | internal rate of return |
| **KPLC** | Kenya Power and Lighting Company |
| **KTDA** | Kenya Tea Development Agency |
| **LCOE** | levelized cost of electricity |
| **MSMEs** | micro-, small-, and medium-sized enterprises |
| **NPV** | net present value |
| **ODA** | official development assistance |
| **PV** | photovoltaic |
| **REA** | Rural Energy Agency (Tanzania) |
| **RVE** | Rift Valley Energy |
| **SAGCOT** | Southern Agricultural Growth Corridor of Tanzania |
| **SDG** | Sustainable Development Goal |
| **SE4ALL** | Sustainable Energy for All |
| **SHS** | solar home system |
| **SMEs** | small- and medium-sized enterprises |
| **SSA** | Sub-Saharan Africa |
| **TANESCO** | Tanzania Electric Supply Company Limited |
| **ZESCO** | Zambia Electricity Supply Corporation |

# Executive Summary

**Increasing access to modern electricity services in Sub-Saharan Africa is one of the main development challenges facing the world over the next two decades.** Inclusion of the target to "ensure access to affordable, reliable, sustainable, and modern energy for all" in the Sustainable Development Goals (goal 7) has brought a sharper focus to accelerating electricity access in the historically underserved regions of the world—most notably Sub-Saharan Africa. Two out of every three people in Sub-Saharan Africa live without electricity, a reality that is inconsistent with the modern world. The majority of this population without access to electricity is rural and poor. Rural electrification efforts in the region have not achieved sufficient progress in increasing electricity access as these areas are typically commercially unattractive, characterized by sparsely distributed customers with low electricity consumption and ability to pay, and a high cost of service to extend the grid. Rural enterprises and households thus must cope without electricity, relying instead on expensive, poor quality backups (e.g., diesel, kerosene or other oil-based sources), thereby stunting productivity, limiting development outcomes, and imposing harmful environmental impacts. The rural economies are overwhelmingly dependent on agriculture; in fact, agriculture and agribusiness comprise nearly half of Africa's gross domestic product (GDP). These enterprises require electricity to grow to their potential, while the expansion of rural energy services needs consumers with consistent power needs to serve as a reliable revenue source.

**Can agriculture and energy come together in Sub-Saharan Africa to offer a double dividend with benefits to enterprises, households, utilities, and private-sector service providers?** This is the central question of this study. That is, can energy intensive activities along the agriculture value chains provide significant revenues to the power utilities and increase the financial viability of rural electrification? Combining agricultural load with other household and commercial power demand could increase the feasibility of extending the grid or creating opportunities for independent power producers and mini-grid operators. Drawing on a suite of case studies, this study offers insights on what it would take to operationalize the opportunities and address the challenges for power-agriculture integration in Africa.

## WHAT IS THE SCALE OF OPPORTUNITY OF POWER DEMAND FROM AGRICULTURE?

**Historical performance of agriculture in Sub-Saharan Africa has been wanting.** The share of agriculture in GDP has declined from 20 percent in 2000 to 14 percent in 2013.[1] A very small percentage of Africa's agricultural production undergoes industrial processing.[2] In high-income countries, processing adds about US$180 of value per ton of agricultural produce, compared to only $40 in Sub-Saharan Africa; this disparity is aligned with the small size of Sub-Saharan Africa's agribusiness sector relative to on-farm agriculture. In addition, for more than four decades, the region's share in global agricultural export markets has been on the decline.

**There are reasons to believe that agriculture productivity could turn the tide**. Trends in economic growth and urbanization fuel the demand for food, as do continuing improvements in infrastructure and the benefits of lower oil prices. The potential urban market for agricultural goods and commodities is projected to reach US$1 trillion by 2030. There are a number of underlying structural incentives to promote agriculture. The region has 45 percent of the world's total suitable land area for expanding sustainable agricultural production. Past gains in commercial crops (e.g., cashews, tea, and sesame seeds) indicate that the region can increase its agricultural productivity. But seizing this opportunity will require farmers and agribusinesses to ramp up production

**FIGURE ES.1:** ENERGY INTENSIVE ACTIVITIES ACROSS AGRICULTURE VALUE CHAINS

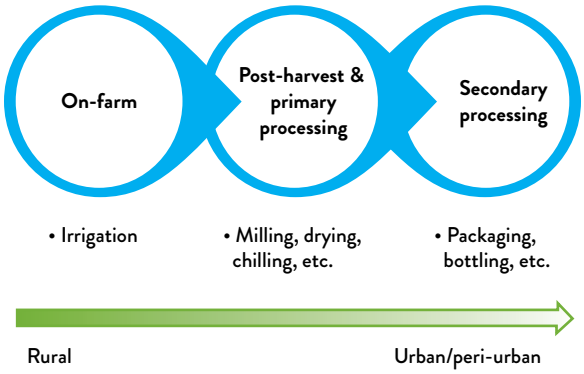
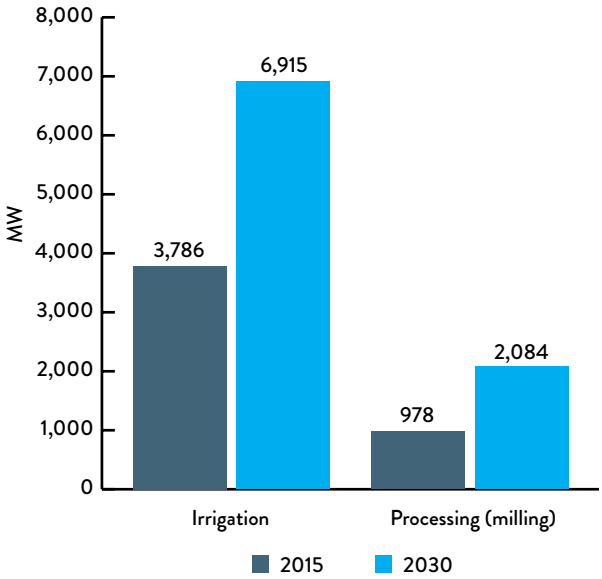



**FIGURE ES.2:** ESTIMATED POWER DEMAND FROM AGRICULTURE IN 2030




and develop agriculture value chains to enhance processing, logistics, market infrastructure, and retail networks.

**Electricity is an important enabler for the agriculture sector to realize its growth potential, especially for power intensive value chains.** The need for electricity is distributed across the life of the crop—from mechanized irrigation to processing for final consumption (figure ES.1). The power demand for irrigation primarily comes from (i) sourcing bulk water from a water body (e.g., a dam or river) and (ii) distributing it over the cultivated area. Bulk water pumping is typically the major source of demand and depends on the vertical and horizontal distances of the scheme from the water source. Demand from distribution systems varies by the types of irrigation system, which range in scale from manual to surface flooding and localized ones to center pivots. Post-harvest and primary processing (e.g., milling and drying) and secondary processing (e.g., packaging and bottling) represent a growth area. It is clear that milling is likely to increase significantly owing to the expected demand growth for such grains as maize, wheat, and rice. Similarly, such staples as cassava are expected to experience increased demand for processing due to their perishable nature and use as an industrial input in the manufacture of other products (e.g., glue in the case of cassava). Creating opportunities to piggyback viable rural electrification onto local agricultural development will depend on the scale and profitability of agricultural operations, crops, terrain, types of processing activity, and other site-specific local conditions.

**By 2030, the region's electricity demand from agriculture is estimated to double from its level today, to about 9 GW.** The estimated incremental demand between 2015 and 2030 is 4.2 GW (figure ES.2). Irrigation would provide about 75 percent of agriculture's demand, with the rest coming from agro-processing. The irrigation demand estimate assumes full exploitation of economically viable, potential areas for new or rehabilitated irrigation development, totaling nearly 6.8 million ha. This would be dominated by small-scale scheme development in the Gulf of Guinea and rehabilitation of existing schemes in the Sudano-Sahelian region. The agro-processing demand estimate is based on the electricity requirement for a typical processing activity (milling), and thus does not capture demand from the potential development of other processing activities or storage.

**For 13 major agriculture value chains, electricity demand could increase by 2 GW (from 3.9 GW in 2013 to 6 GW in 2030).** This represents nearly half of the 4.2 GW of potential increase in electricity demand from agriculture calculated for Sub-Saharan Africa. The 13 products are maize, rice, cassava, wheat, oilseed (soybean), horticulture (pineapple), sugarcane, oil palm, dairy, poultry, tea, floriculture (roses), and cotton (lint). These were selected on the basis of their nature and magnitude of power use for irrigation and processing, growth potential, and ability to serve as significant loads for electricity systems. Of the value chains studied, the per-hectare

electricity demand is largest for poultry, because the process is more intensive, using less land for a much larger yield. Other value chains with significant per-hectare demand are floriculture (roses), tea, and sugarcane. Together, maize, rice, and cassava add to about 83 percent of the total incremental demand in agriculture processing to 2030. For the 13 commodities analyzed, commercial-scale irrigated farming is the largest source of electricity demand. Commercial irrigated agriculture, which is highly mechanized, has the largest potential for developing large power loads across a range of farm sizes.

## WHAT ARE THE CASE STUDY LESSONS ON ECONOMIC AND FINANCIAL VIABILITY?

**This study analyzes eight case studies—six actual and two simulated—in five countries of Sub-Saharan Africa; these provide important lessons on the benefits and risks of large power loads, supply options, and viability.** In **Tanzania**, the first case study is the Sumbawanga Agriculture Cluster, a concept-stage project located in the country's Southern Agricultural Growth Corridor of Tanzania (SAGCOT). The second case in Tanzania is the successful Mwenga Mini-Hydro Mini-Grid Project, which supplies the Mufindi tea estate and surrounding households in the country's Southern Highlands. In **Zambia**, the first case is a grid extension to the ongoing Mkushi Farming Block Project, stretching over 176,000 ha of land in the country's Central Province. The second case study in Zambia is the Mwomboshi Irrigation Development and Support Project (IDSP), which is developing integrated irrigation agriculture based around a recently built water storage dam on the Mwomboshi River. In **Kenya**, the first case examines floriculture development by the Oserian Development Company Limited (ODCL), a pioneer in using heat from geothermal wells for internal power generation and consumption. The second case in Kenya focuses on the Kenya Tea Development Agency (KTDA) mini-hydro mini-grids. The two simulated case studies are in Ethiopia and Mali. The **Ethiopia** study centers on a sugar estate with self-generated power from bagasse and the opportunity of selling the power surplus to the main grid. The **Mali** study analyzes capacity expansion of an existing hybrid mini-grid (diesel-solar PV) to serve productive users (tables ES.1 and ES.2).

**Irrigation is typically the largest source of power demand, along with processing activities in specific instances.** Irrigation usually has a larger load requirement than agro-processing activities, especially in cases of supply to a given area (e.g., Tanzania's Mufindi Tea Estate). Irrigation development and electrification can significantly help increase the viability of rural electrification. Taken alone, the smaller loads of agro-processing activities (e.g., milling and extrusion) may not be sufficient to justify rural electrification investments, except when they provide a viable source of electricity generation (e.g., sugar) or have a large and consistent load requirement (e.g., tea). If the volumes of produce can benefit from powered irrigation, supplemented by economies of scale, the load from the production could be significantly larger.

**Irrigation and processing are often linked.** In many instances, increase in yields from irrigation is an important prerequisite for the development of large-scale processing activities (as seen in Zambia). This cause-and-effect relationship between irrigation and processing was also observed in the cluster concept (e.g., SAGCOT in Tanzania). Increase in the scale of processing activity could lead to a significant increase in the power demand.

**Successful integration of agriculture and power system development requires physical and market infrastructure, which facilitate market access for inputs and produce.** Viable rural electrification relies on a healthy and profitable agriculture sector. Better infrastructure and market access improve agriculture revenues, spurring further expansion in production and associated electricity demand. In Zambia, for example, the strategic location of the Mkushi farming block along a major international highway (T2 Highway and Tazara Railway, which connects Lusaka and the Copperbelt in Zambia to the port at Dar es Salaam) has improved its development viability. The location of the farming block allows access to markets for both inputs and produce. In Tanzania, the Sumbawanga agriculture cluster benefits from access to shared infrastructure and services, including market access. This helped increase the viability of the agriculture sector as a creditable customer for electricity suppliers.

**The seasonality of power demand from the agriculture sector can be a significant constraint**

**TABLE ES.1:** SUMMARY OF ONGOING OR PLANNED CASES OF POWER-AGRICULTURE INTEGRATION

| Project | Tanzania | Tanzania | Zambia | Zambia | Kenya | Kenya |
|---|---|---|---|---|---|---|
| Name | Sumbawanga Agriculture Cluster | Mwenga Mini-Hydro Mini-Grid | Mkushi Farming Block | Mwomboshi Irrigation Development and Support Project (IDSP) | Oserian Flowers and Geothermal Power | Tea Development Agency Holdings Mini-Hydro Mini-Grids |
| Overview | Expansion of electricity supply to support the development of an agriculture cluster and surrounding households through main power grid extension. | A 4 MW hydro mini-grid connected to the main grid. Main local anchor load is Mufindi Tea Estates and Coffee Limited; 1,300 households connected in surrounding communities. | Extending a transmission line into a farming area with significant agricultural potential. | Grid upgrade and grid extension to support irrigation development and household electrification. | Expansion of the estate's geothermal generation capacity and distribution network to power the farm's operations and distribution within the estate. | Development of hydropower plants powering tea factories and staff housing and selling surplus power to the grid. |
| Commodities | Maize, sunflower, finger millet, paddy, sorghum | Coffee, tea | Wheat, soybean, tobacco, soya, vegetables, coffee | Tobacco, wheat, poultry, maize, sunflower, horticulture (tomatoes, onions, bananas) | Floriculture | Tea |
| Financial Viability | The project is marginally financially unviable as a stand-alone project. | The financial viability of the project depends critically on the ability to sell excess power to the main grid. Despite financial viability, capital subsidies were provided to keep local electricity tariffs low. | From a purely financial point of view and as a stand-alone project, grid extension to Mkushi was profitable for the farmers but not for the utility; sharing of capital costs was however an appropriate and successful approach to project financing. | Positive financial NPV, estimated at US$1.1 million. | With a positive financial NPV, the planned expansion project of 0.4 MW and electrification of 2,000 households is financially viable. | Evaluation of a sample project, North Mathioya, shows that the project is financially viable, with a NPV of US$3.3 million; revenues accrue from the sale of power to the grid and cost savings by tea factories. |

| Project | Tanzania | Tanzania | Zambia | Zambia | Kenya | Kenya |
|---|---|---|---|---|---|---|
| Economic Viability | Economic benefits would be significant (US$134 million), justifying the project; they come mainly from households' cost savings, small-scale irrigation benefits, and margin uplift from market access. | Economic benefits are positive (US$9 million); they come from households' energy cost savings, reduced reliance on diesel backup for the tea estate, and job creation from newly electrified businesses. | Thanks to households' energy cost savings, increased yields from irrigation on small-scale farms, and job creation; the project's economic NPV was positive (US$46 million). | Positive economic NPV was estimated at US$2 million for the power line extension, mainly from greater irrigated tomato and maize production. | Positive economic benefits were estimated at US$2.5 million; the main economic benefit is based on increased household electrification and thus savings due to lower energy consumption costs (e.g., less use of kerosene and no more payment for cell phone charging services and disposable batteries). | The same project is evaluated as economically viable, with a NPV of US$10 million; direct and indirect rural electrification impacts include electrification of staff housing, reduced connection costs for surrounding households, and development of stand-alone home systems. About 30,000 households will benefit from electricity connections. |

**to viability.** Large seasonal differences in electricity dependent agricultural activities will impact the cost recovery of electricity supply investments. In such cases, it is important to consider ways to mitigate the impact of a variable load. One option, especially in the case of mini-grid or captive generation, is the ability to sell excess power to the grid (e.g., Mwenga mini-hydro in Tanzania and KTDA mini-hydro development in Kenya).[3] During the post-harvest season, an increase in the post-harvest processing activity may complement electricity demand from irrigation. In addition, irrigation itself may reduce seasonality in agricultural production and thus electricity demand by allowing for multi-cropping (e.g., Mkushi in Zambia).

**When considering agricultural anchor loads, it is more risky for the investment to depend on a single large customer since any negative shock to the customer would negatively affect operating revenues of the electricity supplier.** As such, agricultural clusters (e.g., Sumbawanga in Tanzania) can increase the viability of rural electrification. Cluster development has load diversity by design and thus is less risky than relying on a single anchor load. If there is a private electricity supplier and private off-takers, any such risk will be priced into the supply contract, thus increasing the price of electricity for all customers. In such cases, diversified cluster development can also help reduce the price of electricity. In some such instances, the public sector can also help mitigate this risk through a grid connection and a feed-in tariff (FiT), subsidies to increase the customer base, or guarantee/insurance instruments.

**Large-scale development of irrigation-based agriculture and sugar estates with excess generation can justify a main grid connection on a purely financial basis.** Requirements for this—not all of which are readily available in Sub-Saharan Africa—include relatively clear and empty land with good quality soils, a reliable

**TABLE ES.2:** SUMMARY OF SIMULATED CASES OF POWER-AGRICULTURE INTEGRATION

| Project | Ethiopia: Power Generation from Sugar Estates | Mali: Mini-Grid Expansion for Productive Uses |
|---|---|---|
| Overview | Self-generation of power from bagasse and sale of power surplus to the main grid. | Capacity expansion of an existing hybrid mini-grid (diesel-solar PV) to serve productive users. |
| Commodity | Sugar | Agro-industrial activities |
| Financial Viability | From the utility's perspective, extending the grid to the sugar estate is not financially viable since the net present value (NPV) is negative—because it does not benefit from sales to the estate, which self-supplies; however, from the standpoint of the sugar estate, it is highly profitable (US$139 million). | From the perspective of Yeelen Kura, the current financial situation of the Koury mini-grid is fragile; however, the capacity expansion project is profitable thanks to a higher payment rate, additional revenues, and proportionally low capital expenditure and operating expense (NPV of €103,000). |
| Economic Viability | The economic NPV for the whole period is positive (US$367 million), thus justifying project development. | The economic NPV for the expansion project is slightly negative (−€18,000) as no significant savings are expected from agro-industrial customers (currently using individual diesel generators); however, it could become economically viable if other economic, environmental, and social benefits are considered (e.g., reduction in $CO_2$ emissions, reduced reliance on imported fuels, and reduced exposure to price fluctuations). |

supply of sufficient water, and high quality physical and market infrastructure. Suitable commodities include those typically cultivated on large-scale farms: maize, wheat, sugar, rice, soybeans, and barley.

**The main grid has certain fundamental advantages that may make it the most viable option, even in cases where it is located at a distance.** The multiple generation sources connected to the main grid help mitigate the risk of power failure and enable the utility to minimize costs by balancing supply profiles to match demand. In contrast, a smaller isolated system based on a single generation source may not be amenable to different load profiles and is at a greater risk of failure due to shutdowns of the sole generation facility. In addition, due to economies of scale in generation and the ability to spread fixed costs over a wider set of consumers, electricity from the main grid tends to be cheaper than that from a smaller system. At the same time, the size of electricity load required to ensure viability of grid extension increases with the capital costs incurred for the extension, which, in turn, is related to distance. The Sumbawanga cluster (Tanzania) and the Mkushi farming block (Zambia) cases show that grid extension is the more viable option.

**Despite the advantages of the main grid, mini-grids may still offer the least cost solution to reach unserved consumers, overcome grid unreliability, and leverage private-sector funds to accelerate rural electrification.** Case studies in mini-hydro mini-grids developed under the Mwenga (Tanzania) and KTDA (Kenya) projects show how unreliable grid supplies have led to the development of alternative generation sources. However, the more typical case is establishing mini-grids in greenfield areas and access-deficit countries setting up policies and regulations to create a level playing field and mitigate uncertainties for private-sector, mini-grid operators. The two main concerns are (i) the ability to be financially sound, either through charging cost recovery tariffs or receiving government subsidies and (ii) having regulations that specify what happens when the large grid reaches the mini-grid areas.

**A number of options exist to make projects financially viable.** First, to benefit from economies of scale, the local generation capacity can be increased beyond the level of local demand, and surplus power can be sold to the grid. This option is particularly relevant in countries that have introduced FiT programs set above the utility's avoided costs. Selling excess power makes it possible to lower the per megawatt cost, but relies on the ability to sell excess generated power. For example, the capacity of Tanzania's Mwenga mini-hydro mini-grid is greater than what the tea estate requires; therefore, the surplus is sold to the utility and nearby rural customers. Another option, as is done for the main grid extension projects in Zambia (i.e., Mkushi and Mwomboshi), is to require beneficiaries to partially finance projects and share the development costs with major customers. Farmers partially contribute to capital costs in exchange for receiving power. A further option is load balancing across beneficiary categories, which enables the spread of fixed costs, especially capital costs, across a larger pool of customers with diverse peak-load profiles.

**The role of subsidies to cover some costs should be highlighted.** All of the distributed schemes have received subsidy payments to decrease the level of cost recovery through retail tariffs. This contributes toward ensuring maximum capacity development, increasing the project's net present value (NPV), improving tariff affordability for customers, and attracting private-sector participation. Subsidies are particularly necessary for most privately developed, small-scale projects under 5 MW. By subsidizing household connections, which also tend to be financially unviable, developers can be encouraged to expand their customer base to capture additional subsidies, prioritizing smaller customers close to each other rather than larger ones.

**National policy targets based on economic net benefits, rather than financial viability, drive investments in rural electrification.** For all the cases studied, the estimated economic viability was high. Power for agricultural use enables the development of previously unviable activities, which increases yields and lowers production costs. The benefits to households and businesses include savings on energy expenditures, better health, and improved educational outcomes. Wider benefits accrue from higher incomes and improved quality of life. However, subsidies are needed to make the schemes financially viable. All of the distributed schemes analyzed received subsidies to bridge the gap between actual retail tariffs and the levels required for full cost recovery.

## HOW CAN COMPLEMENTARITIES IN POWER AND AGRICULTURE BE HARNESSED?

**To realize the full potential of agriculture-power integration in Sub-Saharan Africa, the region's policy makers and power companies must think about demand creation.** Governments should coordinate strategies in the power sector with complementary strategies on rural development and agricultural extension. The experience of agriculture corridors, clusters, and growth poles should be analyzed and applied on a wider scale. In addition, power companies should coordinate with other related agencies and institutions to maximize complementarities. Electricity can be prioritized in areas with large irrigation potential, combined with access to markets for agricultural goods. The sale of agricultural machinery, including irrigation pumps and small threshers, can be promoted as part of a package to encourage electricity use in agriculture. In the process of developing expansion plans, power companies should account for the electricity needs of, and benefits to, both smallholder and commercial scale farmers.

**Leveraging complementarities in rural development across sectors would likely result in higher revenues for the utility companies and deliver greater economic benefits to rural areas.** While power companies can prioritize regions with existing or potentially high levels of agricultural production, rural development or agricultural agencies can target areas that are able to take advantage of the many productive use benefits of electricity. The utilities can create internal units responsible for encouraging the productive and efficient use of electricity. Productive use units can be responsible for promoting electric machinery in agriculture, from irrigation to harvest and post-harvest. Banks and other financial institutions should be incentivized to set up credit lines for farmers and agricultural entrepreneurs to purchase agricultural machinery. Given the high expense of using diesel powered engines for grain processing, campaigns by local government could be developed to promote electricity as a substitute for diesel engines among farmers in areas just gaining access to electricity.

**Coordinated planning encompassing geospatial efforts and multi-agency inputs is necessary.** A geospatial map with information about future developments of the national grid, as well as layered data on agriculture and other rural infrastructure, is important to understand where the load clusters are. These are the areas where feasibility studies of mini-grid developments could be carried out for potential future tendering. Clarity in site identification and the regulatory environment is also useful for mini-grid developers and concessioners to allay fears on what happens when the grid arrives. Such integrated maps, possibly housed in a national institution, can also support more transparent decision making on infrastructure expansion and integrated rural development approaches.

**Policy makers can support a stable regulatory environment for electricity suppliers.** To succeed, projects must be implemented within a stable legal environment that imposes requirements and provides protection. Light-handed regulation of small-scale electricity systems is generally more favorable to developers and operators. For example, Tanzania's small power producer (SPP) framework allows private operators to function as power distributors and retailers, charging fully cost-reflective tariffs. This type of regulation should tackle the economic barriers of unaffordability and uneconomic supply. Regulation must also extend beyond the power sector to tackle interactions with related sectors. Tanzania's Mwenga Mini-Hydro Mini-Grid Project, one of the first projects of its kind, encountered significant delays when negotiating regulations over water rights, land access, import laws, and building permits. Also, information about future developments of the national grid and concession protection is crucial for dispelling developers' reluctance and avoiding potential friction from tariff differences between customers.

**Supporting the financial health of key sector institutions, central to the World Bank policy dialogue in the electricity sector, is important for this agenda as well.** The weak financial status of the utilities prevents them from being able to develop financially viable projects without external support. Furthermore, their constrained cash flows increase the risk of non-payment for the power supplied by private developers, which negatively impacts project costs and tariffs and, as a result, power affordability. If FiTs are not capped at the utility's avoided costs, this situation could worsen, further deteriorating the utility's viability. From the perspective of power sector regulators, the extra cost and delays resulting from inexperience in negotiating various supply arrangements may be a hindrance to developing private-sector power generation, distribution, and supply.

**Finally, rapid changes over the last few years in small-scale generation and distribution technology, especially solar PV, have created opportunities to test new models for viable rural electrification and power-agriculture integration.** Recent technological advancements and reduction in small-scale generation costs have led to heightened interest in viable isolated mini-grid development models, such as those based on shared solar PV systems and DC distribution lines. Compatible product development (e.g., TVs, refrigerators, solar pumps, and grain mills) is enabling increased productive use of electricity and increased aggregate electricity demand from such mini-grids to further improve their viability. While there is limited experience of such mini-grids in operation (which thus explains why they are not reflected in our findings), this is a dynamic space with tremendous current interest and significant future potential to spur greater opportunities for power-agriculture integration.

## ENDNOTES

1. Authors' calculation from the World Development Indicators (WDI) database.

2. Korwama (2011) estimates that 30 percent of agricultural produce in Sub-Saharan Africa is processed, compared to nearly 98 percent in some developed countries.

3. Apart from the mitigating impact of seasonal variation, the ability to sell excess power to the grid also helps to invest in large generation capacity and reduce costs due to economies of scale in generation.

# Agriculture and Power Nexus

## CHAPTER 1

Agriculture predominates the livelihoods of the rural poor in Sub-Saharan Africa; thus, higher growth in the agriculture sector, especially through increased productivity, is instrumental in reducing the incidence of extreme poverty in the region. Diao et al. (2012) estimate that the decline in national poverty rates is up to four times higher for agriculture-led growth, compared to growth led by nonagricultural sectors (e.g., 4.3 times higher for Kenya, 3.1 for Rwanda, 1.6 for Nigeria, and 1.3 for Ethiopia). Similarly, ongoing research using the Global Trade Analysis Project (GTAP) model of world trade finds that productivity growth in agriculture, compared to growth in other sectors, is nearly three times as effective in reducing poverty.

Agriculture and agribusiness comprise most income generating activities in Sub-Saharan Africa's largely rural economies (box 1.1), together accounting for nearly half of its gross domestic product (GDP) (figure 1.1). Agricultural production is the most important sector, averaging 24 percent of the region's GDP. Agribusiness input supply, processing, marketing, and retailing contribute another 20 percent (World Bank 2013). Thus, transformation of the agriculture sector through improved productivity and incomes can simultaneously help achieve both robust economic growth and poverty reduction. In other developing regions, agricultural transformation has resulted in declining numbers of the poor. Thus, for Sub-Saharan Africa, where poverty rates have remained stubbornly high, utilizing agricultural transformation to tackle poverty in rural areas—where more than 70 percent of the region's poor live—is a critical part of any poverty reduction strategy.

For both agricultural and nonagricultural households, electricity is needed to raise living standards,[1] as well as enable broader economic development. Lack of access to reliable and affordable electricity in Sub-Saharan Africa constrains development of on-farm and off-farm economic activities, as it does for other manufacturing and services firms. Rural electrification can raise productivity and income when farmers switch from manual to electricity powered inputs and small industries begin using electric tools and machinery. Access to reliable electricity supply can increase productivity along the agriculture value chains and enable increased production and income generation for the farm sector and the rural economy as a whole.

### BOX 1.1: TERMINOLOGY CLARIFICATION: AGRICULTURE AND AGRIBUSINESS

**Agriculture** refers to on-farm production. It includes crops and livestock but not floriculture, fisheries, or forestry. Although much agriculture in Africa is oriented to sustaining livelihoods, this study focuses on commercial farming, recognizing that commercial farmers in Sub-Saharan Africa are overwhelmingly small and medium in scale.

**Agribusiness** denotes organized firms—from small- and medium-sized enterprises to multinational corporations—involved in input supply or downstream transformation. It includes commercial agriculture involving some transformation activities (even if they are basic). It includes smallholders and microenterprises in food processing and retail to the extent that they are market oriented. Indeed, these producers and enterprises comprise the bulk of agribusiness activity in Africa today.

*Source:* World Bank 2013.

The United Nations Sustainable Development Goals (SDGs), adopted in September 2015, set a target for universal access to affordable, reliable, and modern energy services by 2030 (SDG 7). The acknowledgment of modern energy access as a development goal builds on the momentum created by the Sustainable Energy for All (SE4ALL) initiative, which has galvanized the international community into action to achieve concrete energy related targets.[2] Under SE4ALL, the three goals to be achieved by 2030 are: (i) universal access to modern energy services, (ii) doubling the share of renewables in the global energy mix, and (iii) doubling the growth rate of energy efficiency.

## HIGH POTENTIAL FOR AGRICULTURAL TRANSFORMATION

Historically, agriculture in Sub-Saharan Africa has underperformed despite the region's comparative advantage stemming from abundant land and water resources. However, recent developments have created more favorable conditions for an agricultural transformation. Today there is an expectation that well-informed policies and investments can put agriculture on a higher growth path to achieve its vast potential and raise rural welfare.

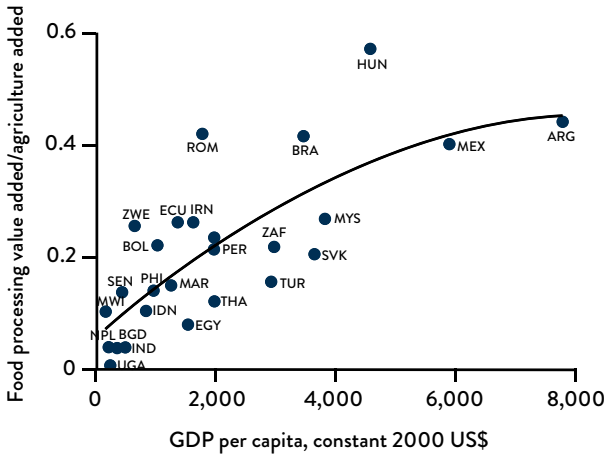
### *PAST PERFORMANCE: A MISSED OPPORTUNITY*

Agricultural growth has typically lagged behind that of other sectors in Sub-Saharan Africa. Vulnerability to weather shocks, limited use of modern tools and inputs, low levels of processing, poor development of rural financial markets, and market access barriers have all hindered agricultural growth and kept agricultural productivity and incomes low. Between 2000 and 2013, the share of agriculture in GDP declined by 6 percentage points (from 20 percent to 14 percent).[3]

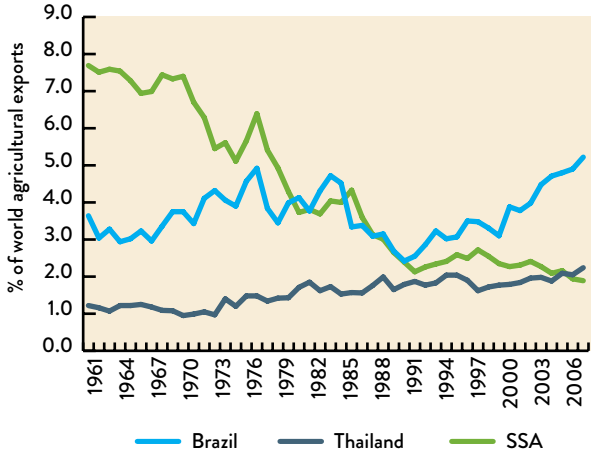
Only a small percentage of the region's agricultural production undergoes industrial processing.[4] For the world's high-income countries, processing adds about US$180 of value per ton of agricultural produce, compared to only $40 for Sub-Saharan Africa. This is related to the small size of the agribusiness sector compared to on-farm agriculture in Sub-Saharan Africa relative to other regions. For developing countries, including those in Sub-Saharan Africa, the ratio of value added in agribusiness to that of farming is typically 0.6. This ratio increases to 2.0 for transforming countries (mainly in Asia), 3.3 for urbanized countries (mostly in Latin America), and 13.0 for the United States, indicating significantly more value created in the downstream agribusiness sector than on-farm production for countries outside Africa. These comparisons reflect the positive correlation between the relative importance of agribusiness and economic growth: both per capita GDP growth (figure 1.1a) and human development indices (da Silva et al. 2009).

**FIGURE 1.1:** HISTORICAL PERFORMANCE IN AGRICULTURE

a. Ratio of food processing to agricultural value added




b. Market share of global exports




*Sources:* World Bank 2008, 2013.

*Note:* In figure 1.1a, three-letter codes represent the following countries: ARG = Argentina, BGD = Bangladesh, BOL = Bolivia, BRA = Brazil, ECU = Ecuador, EGY = Egypt, HUN = Hungary, IDN = Indonesia, IND = India, IRN = Iran, MAR = Morocco, MEX = Mexico, MWI = Malawi, MYS = Malaysia, NPL = Nepal, PER = Peru, PHI = Philippines, ROM = Romania, SEN = Senegal, SVK = Slovak Republic, THA = Thailand, TUR = Turkey, UGA = Uganda, ZAF = South Africa, ZWE = Zimbabwe.

For more than four decades, Sub-Saharan Africa's share in global agricultural export markets has been on the decline. By the early 1990s, the region's share had fallen to about 2 percent, 5–6 percentage points lower than in the 1960s. Meanwhile, other important agricultural exporters, including Brazil and Thailand, have seized market share despite having a tiny fraction of Africa's land area, especially in the case of Thailand (figure 1.1b).

African imports of agricultural products have skyrocketed due to the gap between regional demand and supply. From the 1990s to the 2000s, the balance of trade in food staples for Europe and Central Asia, South Asia, and East Asia and the Pacific moved from deficit (i.e., imports exceeding exports) to surplus; however, for Sub-Saharan Africa, this gap greatly expanded. While food trade deficits are expected in regions without a comparative advantage in food production, such as the Middle East and North Africa, they are symptomatic of a missed opportunity in Sub-Saharan Africa, which is endowed with abundant natural resources for efficient production.

### *INVESTMENT FUNDING CHALLENGES*

Investment funding for the agriculture sector, especially primary production, is limited by perceived high risks and low returns. Poor infrastructure on farms and along the supply chains, low access to credit and product markets, and other regulatory hurdles have kept returns from agricultural investments in Sub-Saharan Africa below potential. Over the past decade, the increased inflows of commercial finance, especially foreign direct investment (FDI), have been vastly inadequate. Official development assistance (ODA) has helped, in part, to fill the gap. In 2003–12, ODA for agricultural projects in Sub-Saharan Africa rose 121 percent (from US$1.1 billion to $2.5 billion). Over the same period, the share of aid allocated to the agriculture sector in Sub-Saharan Africa grew from 37.4 percent to 40.3 percent, the highest share increase for the period (Development Initiatives 2015).

The high costs of connecting agricultural land to backbone infrastructure in Sub-Saharan Africa cannot be easily absorbed by most medium-sized farming businesses, let alone small-scale farms. But without these "last-mile" infrastructure investments, the region's farmers cannot increase their productivity. Furthermore, without access to concessional funding, the establishment costs of an outgrower program, especially those involving provision of infrastructure services to small-scale farmer organizations, can be prohibitive, explaining why so few of the nucleus farm and outgrower models have been successfully established.

### *AN IMPROVING OUTLOOK*

The high yield gap between Sub-Saharan Africa and other regions underscores the large potential for Africa to catch up with the productivity frontier (World Bank 2013). The increasing prominence of the agriculture sector among policy makers, the private sector, and the development community has been driven, in part, by the recognition of decades of prior neglect of the sector by governments and donors, as well as the urgent need to mobilize small-scale farmers to increase food production in order to avoid food security challenges in the near term.

Over the past decade, African governments have demonstrated a renewed and growing commitment toward agriculture. The improving policy environment, led by the Comprehensive Africa Agriculture Development Programme (CAADP) (box 1.2), high investor interest, and technological advances that ease implementation of necessary reforms, particularly in land administration, have created excellent conditions for an agricultural transformation.[5]

The outlook for agricultural development in Sub-Saharan Africa is improving.[6] Economic growth and urbanization have fueled an increase in food demand in Sub-Saharan Africa. In addition, continued improvements in infrastructure and the benefits of lower oil prices have resulted in increased domestic food production. Although recent declines in agricultural prices may dampen price incentives for agriculturalists, they may further increase food demand and thus induce farmers to grow food and other agricultural commodities for the market.

## MAJOR APPROACHES TO AGRICULTURAL DEVELOPMENT

There are two major approaches to agricultural development in Sub-Saharan Africa. The first is a cluster approach, which focuses on particular areas with a high level of infrastructure access and development potential. This generally involves support for large farms and commercialized agriculture as growth poles. The second approach is smallholder agriculture, which centers on support for smallholder farmers to increase their productivity and access to markets. These two approaches differ in their implications for electricity supply in rural areas.

### *CLUSTER APPROACH*

Over the last 20 years, one rural development trend in multiple countries across Africa has focused on integrated

### BOX 1.2: AFRICA'S VISION FOR AGRICULTURE: CAADP GOALS

The Comprehensive Africa Agriculture Development Programme (CAADP), initiated in 2003, strives to improve country frameworks to support agricultural development. The CAADP's initial 2015 target, extended through 2025, envisions that the continent should achieve the following goals:

- Attain food security in terms of both availability and affordability and ensure access of the poor to adequate food and nutrition;
- Improve the productivity of agriculture to attain an average annual growth rate of 6 percent, with particular attention to small-scale farmers, especially focusing on women;
- Have dynamic agricultural markets among nations and between regions;
- Integrate farmers into the market economy, including better access to markets, with Africa to become a net exporter of agricultural products;
- Attain more equitable wealth distribution;
- Become a strategic player in agricultural science and technology development; and
- Practice environmentally sound production methods, featuring a culture of sustainable management of the natural resource base (including biological resources for food and agriculture) to avoid their degradation.

*Source:* CAADP 2012.

infrastructure and social development for specific areas. This cluster or corridor development approach has significant implications not only for the development of agriculture, but also for how electrification and other types of institutions develop plans to serve such areas (annex A).

Clusters are geographic concentrations of interconnected companies, including intermediate goods suppliers, service and infrastructure providers, and associated institutions in a particular product space or sector. Clusters benefit from geographical agglomeration economies that may result from the proximity between intermediate and final goods suppliers, labor market pooling, and knowledge spillovers (Marshall 1890; Krugman 1991). Despite falling transportation and communication costs, clusters continue to be relevant today due to the underlying benefits of increased firm productivity, innovation, and formation of new businesses (Porter 1990). Transportation growth corridors, a closely related concept, places the significant economies of scale of infrastructure development at the center of the benefits from spatial agglomeration.

In the case of agriculture, clusters can affect development in several ways. Improved access to infrastructure can lead to increased productivity of farms and companies within a concentrated economic area. As opposed to remote rural areas, these clusters of economic activity benefit from joint access to necessary infrastructure services, linkages to upstream and downstream activities, and connectivity to markets. Better connectivity to markets and access to infrastructure, including electricity, are likely to induce agricultural intensification. Both large-scale and smallholder agriculture will benefit from increased productivity induced by spillovers, greater connectivity, and reduced transaction costs. The ability to serve wider markets for their goods and services will create greater incentives to innovate.

The cluster approach brings together agricultural research stations, nucleus large farms and ranches, commercially focused farmer associations, irrigated block farming operations, processing and storage facilities, transport and logistics hubs, and improved "last-mile" infrastructure to farms and local communities. When occurring in the same geographical area, these investments result in strong synergies for agricultural growth, helping create the conditions for a competitive and low-cost industry.

The essential elements of a cluster approach include the following:

- Having a long-term strategy for agricultural development, recognizing that transformation occurs over an extended period (e.g., 10–20 years);
- Understanding and leveraging vertical and horizontal linkages between farms and other businesses to maximize value addition;
- Commissioning robust analysis of the constraints on commercial agriculture and recommending how these can be addressed;
- Establishing an independent public-private partnership organization to help coordinate and target

agricultural development programs and public investments; and

- Leveraging government and development partner resources to catalyze socially and environmentally optimal private investment.

Electricity is one of the fundamental requirements for cluster or corridor development. Investments in electricity infrastructure must adequately account for long-term demand growth due to increased demand from large farmers, small farmers, farm service businesses, and other tertiary development in such growth areas. Accounting for medium- to long-term demand growth will allow benefits to accrue from economies of scale and thus can lower costs to end consumers.

### *SMALLHOLDER AGRICULTURE*

Most agriculture in Sub-Saharan Africa today involves smallholder farms, usually characterized by landholdings of less than 2 ha, with a subsistence orientation. While the large farm, agribusiness model has an important role to play in promoting agricultural growth in Africa, smallholder agriculture is key to revitalizing the rural economy and tackling poverty.

The question is what role should smallholder or family farms play, in contrast with large farms, in striving for productivity transformation in Sub-Saharan Africa. In agricultural economies, which describes most of Sub-Saharan Africa, smallholder agriculture comprises the majority of employment and production. With rising demand for staple food crops and high-value commodities resulting from rapid urbanization in the region, an increase in smallholder productivity can arise from easing constraints on access to credit, infrastructure, and markets. Targeting the development of smallholder agriculture is also an effective way to reduce rural poverty. Thus, smallholders in Sub-Saharan Africa have a critical role to play as a source of agriculture competitiveness. The World Bank (2009) finds that "contrary to expectations, few obvious scale economies were found in the production systems analyzed for the CCAA study. Compared with those of large commercial farms, family farms and emerging commercial farms were typically found to have lower shipment values at the farm level and/or final distribution point (shipment values reflect production and delivery costs). Large commercial farms can play an important strategic role by contributing to the achievement of the critical mass of product needed to attract local and international buyers, but the value chain analysis shows that investments in smallholder agriculture can be an important source of competitiveness in their own right. An additional benefit of smallholder led agricultural growth is the much higher level of second-round demand effects that occur when income gains are realized by smallholder households, as opposed to large commercial farms."

Hazel et al. (2007) make the case for development of the smallholder sector, pinpointing the importance of infrastructure development to support it. "The case for smallholder development as one of the main ways to reduce poverty remains compelling. The policy agenda, however, has changed. The challenge is to improve the workings of markets for outputs, inputs, and financial services to overcome market failures." The point is that numerous factors can support smallholder agriculture, including the coordinated efforts of farms, the private sector, nongovernmental organizations (NGOs), and government. Support can take the form of agricultural research, agricultural extension, and infrastructure development (e.g., roads and provision of electricity).

Given the "competing barriers" to agricultural development, the provision of electricity infrastructure, by itself, is unlikely to make an appreciable difference. Electricity investments must be coordinated with interventions targeting agricultural development (e.g., improving agricultural inputs and technology adoption; agricultural extension services; research on smallholder farming practices; and other infrastructure, including roads, markets, and water supply). The combination of these inputs will increase the growth of agricultural production and have a multiplier impact on the rural economy.

In short, it is not the role of electricity institutions to promote agriculture; rather, their role is to support agriculture in conjunction with other programs. This may seem a daunting task from a policy perspective, given that, in most governments, electricity, agriculture, rural development, and water institutions reside in isolated "silos." However, in countries with successful rural electrification programs, electricity companies have often found ways to deal with such silos, mainly through outreach and coordination (Barnes 2007). For example, in Tunisia, the main electricity company (STEG) had regular meetings with rural development agencies and coordinated expansion plans to provide electricity in communities that were receiving other development inputs.

Coordinated planning of rural electrification would require a change in the way the electricity companies operate, taking into account expected growth in energy-intensive agricultural activities and development

programs in the pipeline. To do this, electricity companies need to develop an effective information sharing mechanism with relevant agriculture sector stakeholders. This could involve reaching out to relevant agricultural agencies; promoting productive uses of electricity; and understanding future growth and development trends, especially with regard to smallholder agriculture. Electricity access for agriculture and rural businesses could effectively be promoted as part of an overall strategy to support small farmers through a variety of activities (e.g., development of farm cooperatives to purchase and market local farm goods; machine rental; and agricultural extension, including advice on irrigation practices, seeds, and fertilizers).

## AGRICULTURAL GROWTH TO RAISE RURAL WELFARE: REASONS FOR OPTIMISM

There are four main reasons to believe that agriculture in Sub-Saharan Africa is poised for growth that can contribute significantly to raising rural welfare. First, relative to much of the rest of the world, the region's land and water—the major natural inputs necessary for growing crops and raising livestock—are underutilized, creating a huge potential for agricultural growth (figure 1.2). Of the world's total land area suitable for sustainable production expansion—that is, non-protected, non-forested land with low population density—Sub-Saharan Africa has the largest share by far, accounting for about 45 percent.[7] In the case of Latin America, which accounts for only 28 percent of land suited for production, 73 percent of that amount is located within six hours' travel time to the nearest market, compared to just 47 percent in Sub-Saharan Africa—a result of the subcontinent's generally poor state of infrastructure (Sebastian 2014). Sub-Saharan Africa also has significant untapped water resources. Only 2–3 percent of the region's renewable water resources are being utilized, compared to 5 percent worldwide (World Bank 2013). Its irrigation intensity, one of the lowest in the world, represents only 5 percent of total cultivated area, compared to 37 percent for South Asia and 14 percent in Latin America (World Bank 2008). Despite an absolute abundance of water resources, lack of irrigation development and storage capacity has limited the availability of water in certain basins, resulting in water stress. Also, the uncertainties related to climate change raise concerns about future water availability (box 1.3).

Second, despite Africa's overall decline in the share of agricultural exports, a recent disaggregated view tells a more nuanced story. Since the early 1990s, Africa has held its own for some cash crops (e.g., cocoa, rubber, fruits and vegetables, and tobacco) and has even gained market share for others (e.g., cashew, tea, and sesame seed), showing some evidence of its productive potential.

Third, Sub-Saharan Africa is poised for demographic transition and wealth creation, reflecting the growing aspirations of its people. According to the United Nations, between 2013 and 2050, the region's population will more than double, from about 900 million to 2.1 billion (United Nations 2013). While one-third of its population is already living in urban areas, this proportion should increase to 50 percent by 2035. Globally, urban food markets are set to increase fourfold, exceeding US$400 billion by 2030 (World Bank 2013). For Africa's 11 biggest economies, the middle class, defined as those earning at least US$450 per month, tripled between 2000 and 2014 (from fewer than 5 million people to 15 million). Over the next 15 years, these numbers may rise by a further 25 million (Standard Bank Research 2014).

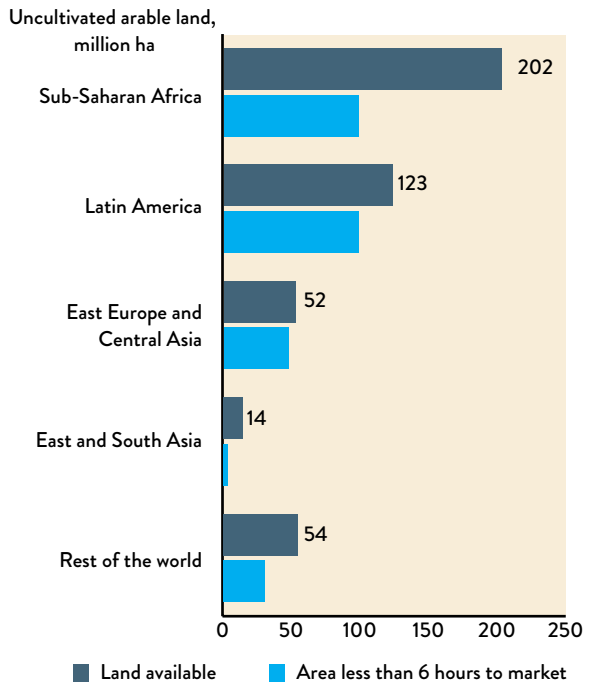
Sub-Saharan Africa's rapid population growth, accompanied by robust economic growth, is creating a huge regional urban market for agricultural goods. A recent World Bank study on agribusiness predicts that the market for agricultural goods and commodities could reach US$1 trillion by 2030 (figure 1.3). It states that "the majority of the increase in food consumption will occur in cities. Based on the United Nations' projections of urbanization and assuming that the per capita value of food consumption is 25 percent higher in urban areas than rural areas, the urban market is set to expand fourfold in 20 years" (World Bank 2013). This expansion in regional demand will create an enormous opportunity for African agriculture and agribusiness.

Fourth, agriculture is critical for managing the urban transition that Africa will undergo. To date, this process has been driven to a large extent by populations being pushed out of rural areas, rather than cities attracting a workforce by acting as growth poles. It would be a more positive process were it driven by improving economic opportunities in the cities that would gradually pull in rural residents, rather than declining conditions and periodic disasters in rural areas that push residents out. The latter situation often leads to conflict and waves of migration that cities find difficult to absorb, typically leading to expanded slums. The objective of a transition strategy—of which electrification is a key element—is thus to enhance living conditions and economic opportunities in rural areas.

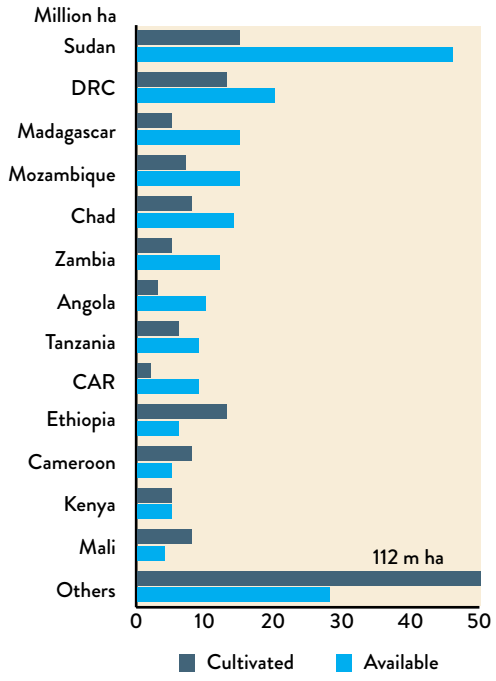
In this context, agriculture and agribusiness can play a critical role in jump-starting the economic transformation through development of agro-based industries in

**FIGURE 1.2:** LAND AND WATER RESOURCES POTENTIAL IN SUB-SAHARAN AFRICA

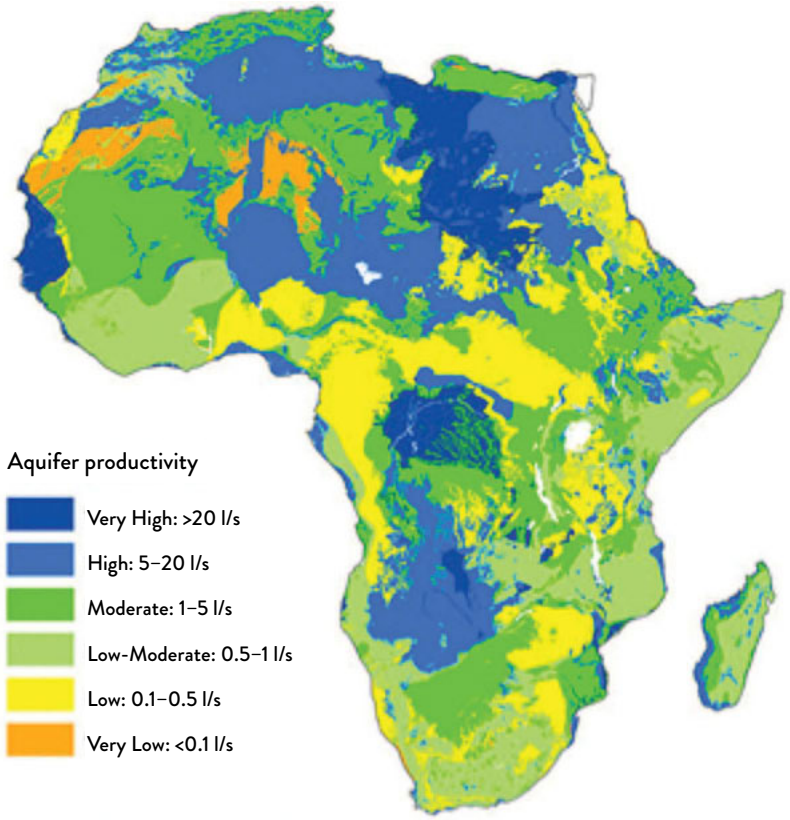
a. Land potential, by world region




b. African countries with largest available land resources




c. Aquifer productivity in Africa



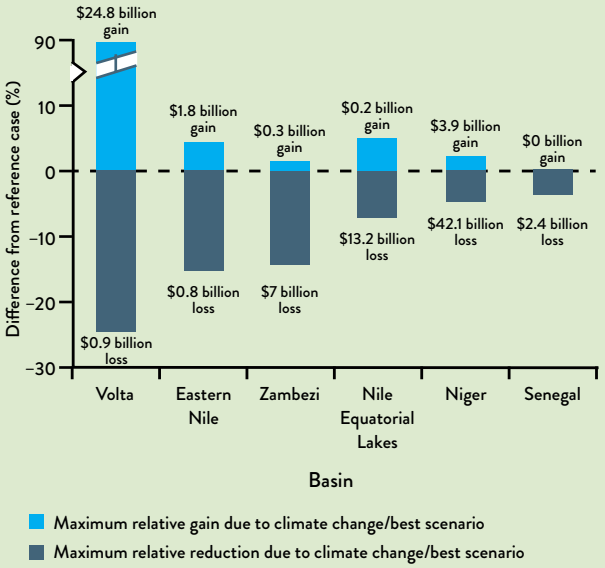

*Sources:* World Bank and Schaffnit-Chatterjee 2014 (figure 1.2 a, b); British Geological Survey (figure 1.2c) (http:// www.bgs.ac.uk/research/groundwater/international/africanGroundwater/maps.html).

## BOX 1.3: MAKING AFRICA'S POWER AND WATER INFRASTRUCTURE CLIMATE RESILIENT

Uncertainty over water availability for productive uses is a critical issue facing Sub-Saharan Africa's infrastructure investments, especially long-lived infrastructure (e.g., irrigation schemes, dams, and power stations). Variations in annual rainfall and monthly rainfall distribution, along with temperature changes due to drier or wetter climates, could put power and water infrastructure at risk, affecting operation and cost over their life span. Beyond impacting the technical performance of infrastructure, uncertainty about drier or wetter futures could significantly modify its financial viability, incurring losses or gains. In a drier scenario, for example, shortfalls in irrigated production could raise demand for food imports, and thus increase food prices (figure B1.3.1).

Cervigni et al. (2015) highlight significant disparities across Africa's seven main river basins: Congo, Niger, Nile, Orange, Senegal, Volta, and Zambezi. The study estimates that, in dry scenarios, loss in irrigation revenue could range between 5 and 20 percent for most basins. For wet estimates, revenue gains could reach 90 percent for the Volta basin, but would be vastly less (1–4 percent) for the other areas. Under the driest scenarios, unmet irrigation demand could drop by more than 25 percent in the Zambezi basin. The magnitude of impact will depend on the willingness and ability of decision makers to integrate climate projections and their uncertainty into the planning and design of power and water infrastructure.

**FIGURE B1.3.1:** CHANGES IN IRRIGATION REVENUES FROM CLIMATE CHANGE, 2015–50 (PRESENT VALUE)

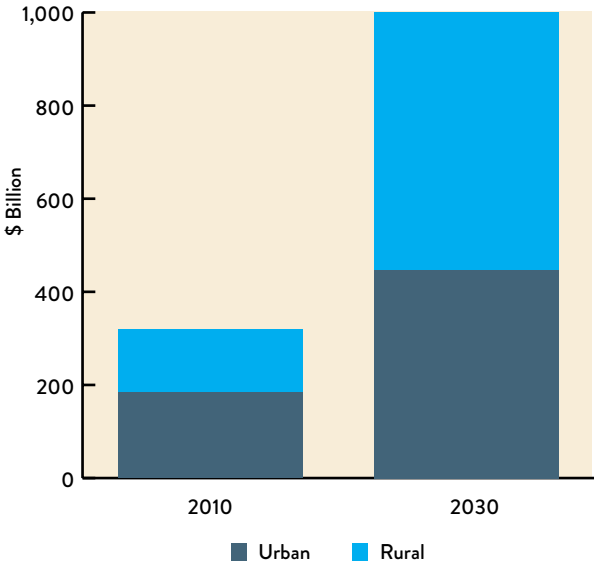



*Note:* The bars reflect, for each basin, the range of economic outcomes across all climate futures; that is, the highest increase (light blue bars) and highest decrease (dark blue bars) of irrigation revenues (discounted at 3 percent), relative to the no-climate-change reference case. The outlier bar corresponding to the Volta basin has been trimmed to avoid distorting the scale of the chart and skewing the values for the other basins. Estimates reflect the range, but not the distribution, of economic outcomes across all climate futures. Each basin's results reflect the best and worst scenarios for that basin alone, rather than the best and worst scenarios across all basins. The Congo and Orange basins are excluded because the effects on irrigation are minimal.

Africa's need to tap its irrigation potential represents a window of opportunity to make power and water infrastructure climate resilient. Although such a paradigm shift will take time, practical steps to integrate climate resilience can be undertaken now. For example, Cervigni et al. (2015) recommend defining and promoting technical standards for integrating climate change into project planning and design and launching training programs targeting relevant stakeholders.

*Source:* Cervigni et al. 2015.

**FIGURE 1.3:** PROJECTED VALUE OF FOOD MARKETS IN SUB-SAHARAN AFRICA




*Source:* World Bank 2013.

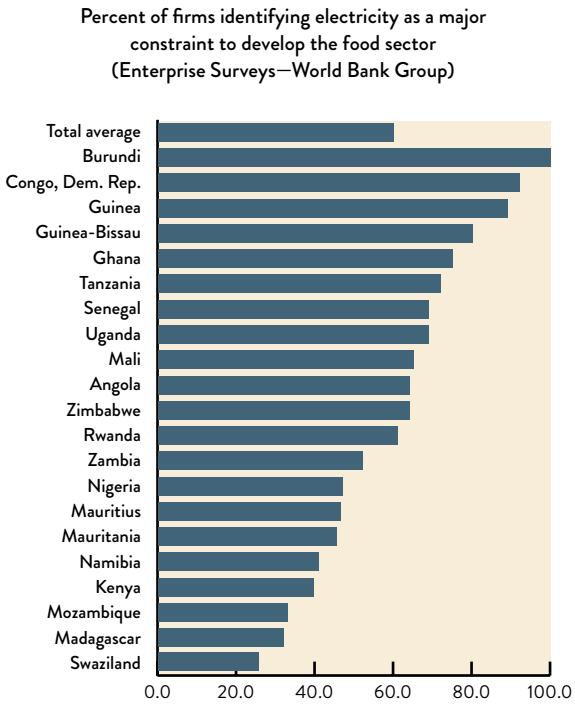
a vibrant agricultural sector. Investments in agricultural productivity can spur the development of downstream agribusiness; in turn, agribusiness investments stimulate agricultural growth through the provision of new markets and development of a vibrant input supply sector. Micro-, small-, and medium-sized enterprises (MSMEs) comprise the bulk of Sub-Saharan Africa's agriculture-related value chains. In West Africa, for example, three-fourths of agriculture-related firms are micro or small enterprises (Staatz 2011).

Taking advantage of this opportunity requires that both farmers and agribusinesses ramp up production, while becoming more competitive; otherwise, the ballooning demand will be filled by imports. This requires developing agriculture value chains and agribusiness to enhance processing, logistics, market infrastructure, and retail networks, all of which require electricity.

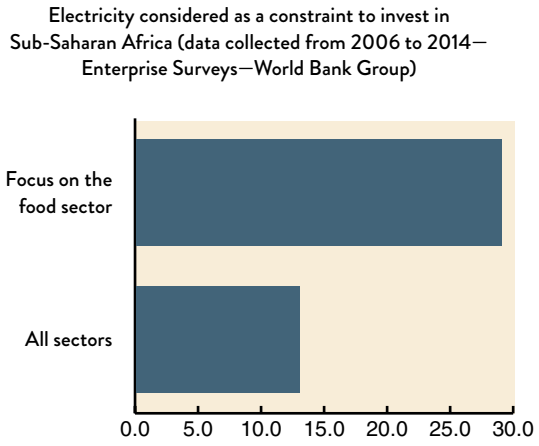
However, electricity remains a critical constraint to the development of the agro-industrial sector. According to data from WBG enterprise surveys, the majority of firms in many countries of Sub-Saharan Africa identify lack of electricity access as a major obstacle (figure 1.4a).

**FIGURE 1.4:** ELECTRICITY AS A CONSTRAINT TO FOOD-SECTOR DEVELOPMENT IN SUB-SAHARAN AFRICA

a. By country




b. Comparison with other sectors




*Source:* WBG 2015 (http://www.enterprisesurveys.org/).

In fact, the fraction of firms in the food sector that consider electricity a constraint to investment is significantly higher than the average fraction in all other sectors (approximately 29 percent, compared to less than 15 percent) (figure 1.4b).

Successful commercial agriculture is typically characterized by the following elements:

- Ample **suitable land**, with **benign climate** conditions and **reliable water availability**.
- **Private-sector participation** in sector development, with higher skills levels and access to international capital and markets, **with strong government support** (e.g., through a favorable policy and regulatory environment and publicly funded research and development and infrastructure).
- Affordable and reliable **access to supporting infrastructure**, in the form of reliable electricity supply, transport links to markets, and irrigation in drier climates (often powered by grid-based electricity).
- **Clusters** of large-, medium-, and small-scale commercial farming, processing, and services firms concentrated in discrete geographical areas. Taken together, the result is a reduction in costs of production through economies of scale, making prices more competitive for regional and global markets, and ultimately increasing the profitability of agricultural activities.

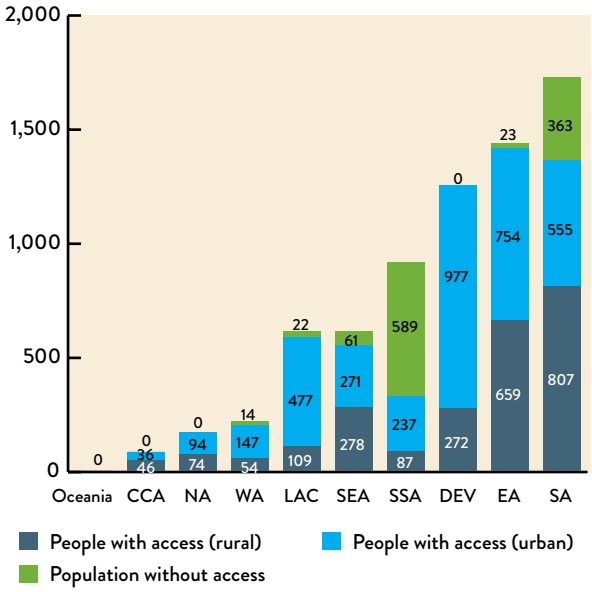
## RURAL ELECTRIFICATION HAS LAGGED BEHIND

A majority of Africans—nearly 600 million people—live without electricity; instead, they rely on kerosene or dry-cell batteries as coping mechanisms. The latest estimates peg Sub-Saharan Africa's electrification rate at 35 percent overall, with 69 percent in urban areas and just 15 percent in rural areas (figure 1.5a). Viewed from space, the picture of Africa's nightlights, showing large sections of perpetual darkness, is a stark contrast to the rest of the developing world, and the evolving disparity is enormous (figure 1.5b).

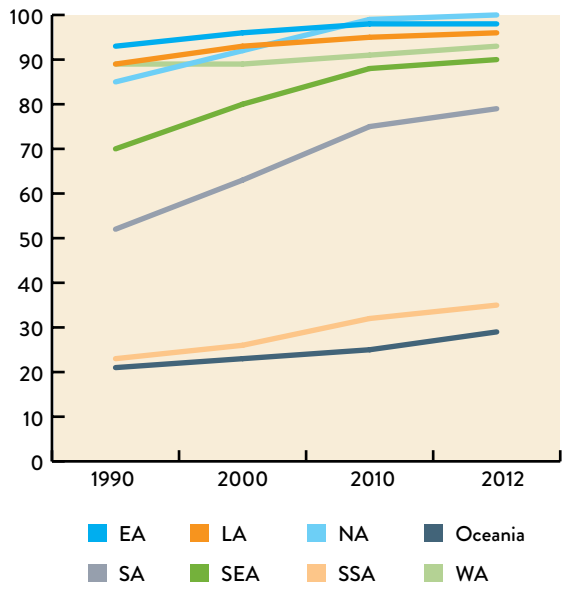
Historically, the region's population growth has outpaced the rate of expanding electricity access, and the gap in rural areas is enormous. Amid a population increase of 202 million, only 59 million people have received electricity. If business as usual continues, by 2030, Sub-Saharan Africa will be the world's only region with an increase in the number of people without electricity

**FIGURE 1.5:** ELECTRIFICATION RATE, BY DEVELOPING REGION

a. Millions of people with and without access, 2012




b. Evolution of access (%), 1990–2012




*Source:* IEA and World Bank 2015.

*Note:* CCA = Caucasus and Central Asia, EA = East Asia, LA = Latin America, NA = North Africa, SA = South Asia, SEA = Southeast Asia, SSA = Sub-Saharan Africa, and WA = West Africa.

access. Furthermore, the urban/rural disparity in electricity access is set to widen as most expansion is likely to occur in densely populated urban areas (IEA and World Bank 2015).

The biggest challenge to rural electrification in the Sub-Saharan Africa region is the lack of commercial viability of expanding connections. Low population density, coupled with the limited purchasing power of most rural consumers, implies that, in many cases, investment in rural grid extension is cost-prohibitive. This problem is compounded by the poor financial health of the region's distribution utilities, owing to a combination of factors (e.g., low consumer base, historical mismanagement, inadequate tariffs, high generation costs, and high rates of technical and nontechnical losses). The high cost of supply, coupled with low tariffs, puts an inordinate strain on sector finances.

This situation, in turn, traps the sector in a self-reinforcing cycle of low investments in expansion and improvement, resulting in an expensive, poor quality electricity supply, circling back to low investments. Thus, many of the region's countries are stuck in a cycle of low generation capacity, excess demand, and inadequate mobilization of private-sector investment. Breaking this negative cycle requires a multipronged approach customized to the financial, economic, and political realities of particular countries. Least-cost grid expansion, wherever viable, should be creatively complemented by a decentralized off-grid strategy based on distributed generation in the form of mini-grids, micro-grids, or stand-alone systems.

## AGRICULTURE AS AN ANCHOR LOAD FOR RURAL ELECTRIFICATION

In recent years, African governments, donors, and the private sector have been reviewing the success stories of such countries as Brazil and Thailand in an attempt to replicate or adapt agribusiness and rural electrification development models that take individual country characteristics into consideration. In the case of India, the most notable example, rural electrification was strongly linked to the promotion of high-yield crop varieties and the spread of irrigated agriculture, facilitated by electric water pumps with subsidized or free electricity. Here it was clear that the financial viability and reliability of rural electrification were linked to promoting productive uses.

The financial viability of agricultural anchor loads rests on the ability to use electricity to generate an increase in agricultural value added and incomes. Generally, the most dramatic changes in agricultural development due to rural electrification have resulted from increased irrigation. With greater access to electricity, it is more cost-effective for farmers to irrigate their fields since electric pumps require low maintenance and are more efficient than diesel alternatives. Irrigation also allows farmers to produce multiple crops in a single year and improve the productivity of existing farms. These advantages lead to higher crop yields and incomes.[8]

This relationship has most often been documented in India, which historically has emphasized the use of irrigation pumps and new agricultural technologies to improve agricultural productivity (Barnes, Peskin, and Fitzgerald 2003). While efforts to improve rural development through electrification have been relatively successful in some countries, the question is whether this experience is applicable to Africa, with its low levels of existing irrigation.

The productive impact of rural electrification depends heavily on several enabling factors: government policy, infrastructure, and complementary development programs. Electrification is an important enabler for the development of rural businesses (e.g., small commercial shops, grain mills, sawmills, and brickworks); however, it cannot produce an explosion of economic activity in the absence of roads and access to finance and markets. If these complementary conditions are inadequate, the growth of rural economies, especially agriculture, will likely remain lethargic and may, in turn, adversely impact the viability of the rural electrification program.[9]

One potential solution to address the region's rural electrification challenge is having an *anchor load*, defined as large consumers that offer power utilities a consistent and substantial source of revenue, which offsets a portion of the fixed costs of electricity supply to rural households. Anchor loads help ease the constraint posed by the low demand profile of rural customers. Guaranteed demand from anchor-load customers ensures the power producer or utility a certain level of revenue, and may help to defray the fixed costs of rural electrification through demand aggregation (along with household and commercial demand in neighboring communities of the anchor load). In short, an anchor load helps overcome the problem of low demand, which constrains the viability of rural electrification.

In some developing countries, the Anchor Business Community (ABC) model is being piloted, using cellphone towers and mining companies as anchor loads.[10] In this context, the supply options range from self-supply

by the agribusiness to intermediate arrangements with an independent power producer (IPP) to grid extension. A recent study that analyzed the integration options between power and mining established a typology of power sourcing options for mines (Banerjee, Romo, and McMahon et al. 2015).

Agriculture can potentially fit into this category of anchor load to sustain small-scale supply arrangements with commercial establishments (including irrigation) and households in rural areas. In this way, electricity demand along the agriculture value chains, as well as commercial/household electricity demand, can create opportunities for the IPPs and mini-grid operators. In addition to demand aggregation, supplying both households and agro-processing may create load balance; the demand of households and agro-processing peak at different times of the day, which can help to disperse capital and maintenance costs over a larger set of consumers.

The development of anchor loads can benefit both centralized and decentralized approaches to rural electrification. In the case of grid extension, promoting the development of relatively large anchor customers in off-grid areas could tip the balance in terms of the economic viability of extending the grid to connect to the anchor load and bringing the grid closer to communities without electricity access. In current-day industrialized economies, such anchor customers as mills and factories were an integral part of the electrification experience. In Sub-Saharan Africa too, national grid expansion plans tend to prioritize district commercial centers and areas with factories or other large commercial customers. Beyond demand from the anchor customer, grid extension can be made viable through the potential to sell electricity back to the grid (in cases where there is an in-house generation facility).

Grid extension may not be viable if anchor customers are not large enough or are located in relatively remote areas. In such cases, smaller isolated grid systems or mini-grids can be used to save on costs associated with transmission infrastructure. Mini-grids can be developed by aggregating demand from the anchor load and surrounding communities, with electricity generation and distribution undertaken through a context-specific combination of a small, in-house power producer and anchor business or public utility.

For both on- and off-grid access solutions, the presence of an anchor-load customer greatly improves the financial viability. In principle, activities along agriculture value chains require electricity and thus might serve this role. The electricity consumption of activities along the various agriculture value chains, aggregated with commercial/household electricity demand, can potentially make it feasible to extend the grid or create opportunities for small IPPs and mini-grid operators. In addition to demand aggregation, supplying both household and agro-processing demand may create a balanced daily load profile, helping to disperse capital and fixed operating costs over a larger set of consumers.

In addition to providing anchor loads, agricultural production can provide fuel for off-grid solutions in rural areas (annex B). Agricultural by-products can serve as cheap sources of locally available fuel for biomass electricity generation; they can be derived from various types of processing (e.g., cotton, groundnut, soybean, wheat, and other cereals), but the most common ones are rice husks and sugarcane waste (i.e., field waste and bagasse).

Such opportunities are now being commercially harnessed in various countries and regions of the world. For example, India has created a business model to serve rural households using husk power, whereby agricultural residue (e.g., rice husks, mustard stems, corn cobs, and certain grasses) is cost-effectively converted into electricity. In this study, the scope of agriculture's role is limited to that of an anchor load in rural areas of the Sub-Saharan Africa region.

## STUDY PURPOSE AND METHODOLOGY

Rural electrification is at a crossroads in Sub-Saharan Africa; for many countries, the challenge is overwhelming, but opportunities are also emerging. It is up to governments, the private sector, and international communities in the region to decide how these opportunities will be harnessed for the benefit of Africans living in the dark. Recently, the WBG's Energy and Extractives Global Practice in the Africa Region commissioned a series of studies to explore potential solutions to the challenge of bringing power to Africa. This study, which follows on the recent initiatives of Banerjee, Romo, and McMahon et al. (2015), Hussain et al. (forthcoming), and Hosier et al. (forthcoming), is designed as a joint effort between the Energy and Extractives, Agriculture, and Trade and Competitiveness Global Practices. It also complements the ongoing analytical work of the Latin America and Caribbean region on energizing agriculture.

This study's overall aim is twofold: (i) to identify potential synergies between agriculture value chains and rural electrification expansion and (ii) to examine the challenges in harnessing this potential. Its specific

objectives are to (i) conduct an evidence-based analysis of the extent of the potential of power-agriculture integration for specific case studies on agriculture value chains; (ii) assess alternative supply arrangements (business models) for providing electricity to the combined power demand of agriculture and local commercial and residential demand; (iii) analyze barriers and institutional mechanisms that will create the enabling conditions for private-sector participation in this space; and (iv) identify operationally relevant opportunities for piloting this concept.

This work builds on two background studies prepared by the consulting consortium of Economic Consulting Associates (ECA) and Prorustica in 2014–15, which involved field visits and stakeholder discussions in the countries covered. The first study analyzed the landscape for rural electrification centered on agricultural activities, while the second examined a set of eight case studies on powered agribusiness activities from across Sub-Saharan Africa (Ethiopia, Kenya, Mali, Tanzania, and Zambia). The primary focus of the landscape study was on power consumption of agricultural activities within value chains, identifying where sufficient demand from the activity makes it possible to provide an economic or socioeconomic rationale for an electrification project that may then be extended to support surrounding communities. The case studies comprised both national grid-connected activities and those powered by distributed generation systems. They included power schemes that had already been developed, as well as those in progress or proposed. The cases covered a range of commodities (e.g., fruits, floriculture, maize, sugar, tea, vegetables, and wheat).

Since agriculture is a dispersed activity with varied scales of production, results of this analysis need to be considered with the following caveats. First, although the study provides an estimate of power demand from agriculture in 2030, it was unable to capture the location of this demand, the extent to which it can be met by simply increasing the generation capacity of national grids (i.e., the grids already extend to production and processing areas), and whether alternative power sources (e.g., isolated electricity mini-grids) are the most viable supply options. Second, the study was unable to capture the necessary financial viability of power supply with reference to the price that the agricultural activities could afford to pay for power.

The rest of this report is organized as follows. Chapter 2 presents the context of power needs from agriculture, while Chapter 3 reports on the detailed analysis of power needs by selected value chains. Chapter 4 discusses power supply arrangements for a suite of case studies in three countries, encompassing technical, economic, and financial analysis. Chapter 5 reviews the potential for harnessing power-agriculture synergies and provides alternative integration scenarios using two simulated case studies. Finally, Chapter 6 summarizes the study's key findings and recommends actions required to promote power-agriculture integration.

## ENDNOTES

1. Households that connect to the electricity grid benefit immediately from better household lighting. With brighter light in the home, children spend more hours studying, adults have more flexible hours for completing chores and reading books, and home-based businesses remain open longer in the evenings, producing more items for sale. Once rural families connect to the grid, television sets, fans, and an array of other household appliances gradually become more affordable (Barnes 2014).

2. The SE4ALL initiative was launched by the United Nations (UN) in 2011. It is co-chaired by the UN Secretary General and World Bank Group (WBG) President; SE4ALL helped place energy access explicitly on the global development agenda, thus filling the gap left by the Millennium Development Goals (MDGs), which did not include any energy access goals.

3. Authors' calculation from the World Development Indicators (WDI) database.

4. Korwama (2011) estimates that 30 percent of Sub-Saharan Africa's agricultural produce is processed, compared to nearly 98 percent in some developed countries.

5. Focusing on the enabling environment, WBG (2016) measures regulations that impact firms in the agribusiness sector. It collects and reports data on 18 indicators for 40 countries across the world; the indicators capture aspects related to production of inputs and market enablers to help policy makers better understand barriers to growth and transaction costs imposed by the regulatory environment.

6. Africa's economy has been expanding at a relatively high rate. Following a very strong decade from the beginning of this century, growth in 2015 was more modest, at 3.7 percent (World Bank 2015). Growth rates over the next several years are projected at well above 4 percent.

7. About two-thirds of this area is spread over eight countries: Angola, Democratic Republic of the Congo (DRC), Madagascar, Mozambique, South Sudan, Sudan, Tanzania, and Zambia (World Bank 2013; Deininger and Byerlee 2011).

8. The impact of electricity will be lower in areas that use gravity-fed irrigation since the value added by electricity is likely to be relatively minor. The main impact will be realized by farmers using agricultural pump sets or other forms of mechanized irrigation.

9. A recent WBG study states that electricity access is critical to promoting a more commercialized agriculture sector in the developing world; it emphasizes the importance of rural electrification as an enabling condition for agribusiness development, and discusses indicators on electricity access, reliability, and affordability (WBG 2015).

10. In the ABC model, anchor customers are the main off-takers for the generated power. Business refers to small local businesses and shops; community refers to households, farming needs (including irrigation), and local institutions.

# Power Needs of Agriculture

## CHAPTER 2

Agricultural transformation in Sub-Saharan Africa implies a shift away from household subsistence farming toward a more market-oriented farming sector that is effectively able to supply demand across the world. Achieving this transformation involves increased use of modern farming inputs, greater value addition through post-harvest processing, and access to markets through transportation and storage.

Electricity is a key input required to create greater value added in the agriculture sector through enabling irrigation, processing, and storage. Growth in agricultural incomes is directly dependent on farmers' ability to increase their yields through irrigation, processing of produce to retain a greater proportion of the value added along the full supply chain, and proper storage of produce to prevent spoilage. A growing agriculture sector will thus produce greater demand for electricity along its value chain, from both on- and off-farm activities. Agricultural transformation, through increasing rural electricity demand, can thus go hand-in-hand with an expansion in rural electricity access.

A structural shift in agricultural markets is set to induce demand for electricity from agriculture. With growing domestic and export markets for agricultural products, the need for increased agricultural productivity will necessitate greater on- and off-farm mechanization of agricultural and agribusiness practices. In addition, economic growth is set to create markets for new products and higher value commodities for urban markets and as intermediate inputs for various industries, especially in the food sector.

Electricity demand from agriculture stems from the various processes along the agriculture value chain—from on-farm irrigation and off-farm grain milling to larger secondary processing (e.g., pulping and packaging) that caters to higher value urban and export markets. An increase in an irrigated area to reach its estimated potential and improving existing irrigation practices will require electricity for water pumping. The mechanization of basic milling or grinding that is largely done manually will require electricity to run machines. Storage of high-value perishables awaiting transport to demand centers will require electricity for chilling; and such processing activities as pulping, drying, heating, and packaging will also demand electricity.

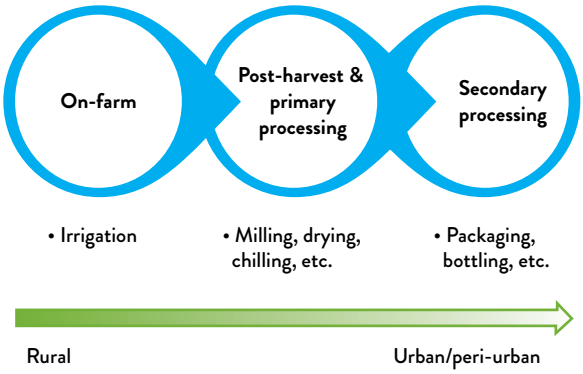
This chapter explores the synergy between agricultural growth and rural electrification and provides initial estimates of power demand from agriculture in 2030. The value generated by agricultural activities that demand electricity can help tip the scales of commercial viability of rural electrification interventions.

### POWER NEEDS ACROSS THE AGRICULTURE VALUE CHAIN

Electricity input is vital for the adoption of modern productivity enhancing technologies and thereby the integration of small-scale farming into high-value and export-oriented value chains. The implications for electricity demand from such a shift in the agriculture sector of Sub-Saharan Africa will be determined by the extent to which modern techniques are adopted at each stage along the value chain and the scale of each activity. In addition to electricity requirements, the potential of various crops to gain from irrigation and processing activities can vary widely.

Depending on crop characteristics and target markets, value chains differ in post-harvest processing and preservation requirements. This creates differing on- and off-farm demand for electricity for each value chain. In order to examine the nature of electricity use along

**FIGURE 2.1:** POWER NEEDS ACROSS AGRICULTURE VALUE CHAINS




agriculture value chains, the sources of growth in future electricity demand can be divided into three sources, as follows (figure 2.1 and annex C):

- The potential for expanded irrigation, which is the primary **on-farm** source of electricity demand.
- The potential growth in **post-harvest and primary processing** activities from both new and existing production; activities include cleaning/drying, milling, cassava processing (chipping), chilling and cold storage, meat processing, and oil extraction.
- The potential growth in **secondary processing** activities that cater mainly to urban markets and provide intermediate inputs to other production processes; activities include thermal treating, canning, bottling, and packaging.

These several activities are presented in decreasing order of rural presence. Virtually all irrigation occurs in rural areas, and post-harvest and primary processing usually occur shortly after the rural harvest, depending on scale. Secondary processing is more likely to take place near trading hubs and demand centers in urban or peri-urban areas, although, under appropriate conditions, some smaller-scale operations can be viable in rural areas. The prevalence of irrigation potential in rural areas and the benefits across value chains imply that irrigation is the largest potential source of power demand from agriculture in Sub-Saharan Africa.

### *IRRIGATION POTENTIAL*

The irrigation intensity in Sub-Saharan Africa is the lowest in the world; only 6 percent of the region's cultivated land is irrigated, compared to 44 percent in Asia (FAO 2005). Irrigation intensity and technique vary across the region. Powered irrigation systems are prevalent in Southern and East Africa, and are emerging in West Africa. To a large extent, West Africa and the Sudano-Sahelian region utilize small-scale irrigation systems, which tend to be gravity fed.

Like other powered activities in agriculture, the electricity requirements of powered irrigation equipment depend on system scale, form of irrigation, and specific geographic conditions—the latter factor making it difficult to develop accurate estimates of electricity use for irrigation. The two primary power demands for irrigation are (i) sourcing bulk water from some water body, such as a dam or river and (ii) distributing it over the cultivated area.

Irrigation systems commonly used in Sub-Saharan Africa range in scale from manual systems to surface flooding and localized systems to center pivots. Manual systems, including simple buckets to support small-scale farmers, require no power. Surface flooding and localized systems (e.g., stationary drip schemes and pressurized systems, such as sprinklers[1]) require power to source the bulk water that cannot be accessed by gravity only. Center pivots may require power for bulk water supply, as well as for pressurizing water for the system and possibly for system mechanics (e.g., motors to rotate the pivot span).

In all four cases, power demand is related to system scale, but will vary per unit of area covered. In each case, pumping bulk water comprises the major demand and will depend on the vertical and horizontal distances of the scheme from the water source (table 2.1).

For irrigation systems that use gravity to redistribute water, power may only be required for bulk water pumping into storage (if needed). The most efficient pumping systems do this to meet infield demand, running nearly continually. But some systems may design their capacity with larger pumps so as to require pumping for fewer hours within a day. This design is inefficient from the viewpoint of electricity supply, as it would require a greater peak generation load.

Benefits from irrigation come from increased yields and reduced weather-related risks. Enhanced irrigation practices may thus result in large benefits from increased crop yields, leading to higher farm revenues. Giordiano et al. (2012) find that Sub-Saharan Africa has considerable area under small-scale irrigation or improved agricultural water management. The study estimates that investments in dry-season irrigation for rice could potentially increase yields by 70–300 percent. The same study estimates that investment in relatively low-cost motorized pumps, benefiting 185 million across the Sub-Saharan Africa region, could generate net revenues of up to US$22 billion a year.

**TABLE 2.1:** POWER DEMAND FOR IRRIGATION, BY SYSTEM TYPE

| System Type | Cultivation Methods Supported | Crops Supported | Power Components | Estimated Power Demand/Unit (kW/ha)[a] | Typical Area Coverage[b] |
|---|---|---|---|---|---|
| Surface flooding (furrow and paddy systems) | Small- and large-scale commercial. | Rice, sugarcane, tomatoes, citrus. | Possibly bulk water, infield pumping. | 0.5–0.9 | 600 $m^2$–20,000 ha |
| Micro irrigation (drip and trickle) schemes | Small-scale and intensive commercial. | Floriculture, horticulture, seedling propagation, citrus, vegetables, potatoes. | Possibly bulk water, infield pumping. | 0.5–0.9 | 600 $m^2$–20 ha |
| Micro jet irrigation | Some small-scale, mostly large-scale commercial. | Floriculture, horticulture, citrus, macadamia, some tree crops. | Possibly bulk water, infield pumping. | 0.5–0.9 | 5–50 ha |
| Portable impact sprinkler systems (drag-line and hand-move) | Small- and large-scale commercial (broad-scale). | Floriculture, horticulture, grain crops, tobacco, bananas, sugarcane, potatoes. | Possibly bulk water, infield pumping. | 0.5–0.9 | 600 $m^2$–20,000 ha |
| Center pivot | Small- and large-scale commercial (broad-scale). | Wheat, barley, soya, maize, groundnuts, sorghum, paprika, tobacco, sugarcane, rice. | Possibly bulk water, infield pumping. | 0.7–2.2 | 9–150 ha (65 ha per pivot is typical on farms of 50–5,500 ha) |

*Source:* ECA and Prorustica (2015).
*Note:* The categories provided in this table are general as no two schemes are identical.
a. Assumes an average distance of 300 m from the water source to the irrigation scheme.
b. Indicates the system scale commonly seen in Sub-Saharan Africa.

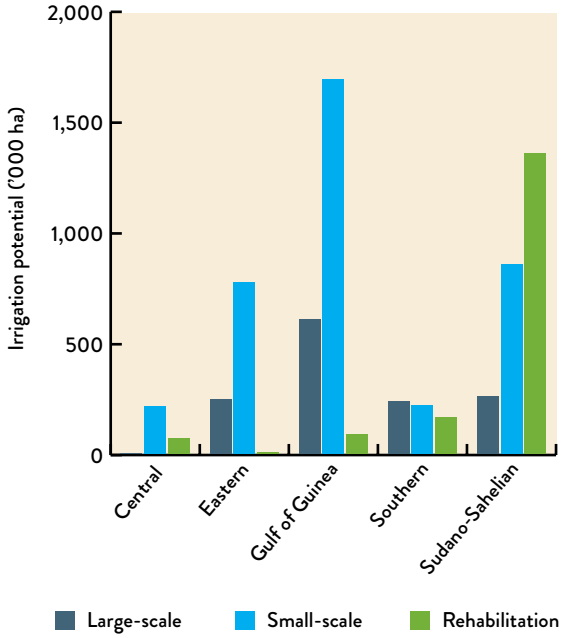
Irrigation offers distinct seasonal advantages for crop production as it can help overcome rainfall variability and even temperature extremes by maintaining adequate levels of soil moisture year round. In the summer, the primary advantages are greater reliability of water supply (i.e., reducing the impact if rainfall is less than expected) and the ability to plant crops early without waiting for rains. In the winter, when rains are not expected, irrigation is indispensable for cropping, allowing for the production of wheat and other winter crops and more crop cycles per year for rice. Therefore, annual use of irrigation allows year-round cropping.

The extent of irrigation and the associated electricity is likely to be characterized by some amount of seasonality. The magnitude of the seasonal variation in irrigation depends on crop choice, weather variations, and irrigation and farming practices. Despite this, multi-cropping, along with the nearly constant need of water supply for efficient cropping (especially under drip irrigation), does reduce seasonal variation to a certain extent.

Africa's grossly underutilized agricultural potential should be tapped by significantly growing the area under cultivation to cover most economically viable areas. You et al. (2009) developed estimates of potential increase in irrigable area in the region using detailed topographical data and economic parameters (figure 2.2). The study found that both large- and small-scale irrigation schemes can be economically developed in Africa, with economic internal rates of return (IRRs) exceeding 12 percent.[2] Investments in irrigation over this cut-off could potentially increase irrigated areas by 7.7 million ha, with 5.8 million ha coming from small-scale schemes.

Countries with the greatest potential for large-scale investment are Ethiopia, Mali, Mozambique, Nigeria, Sudan, Tanzania, Zambia, and Zimbabwe (You et al. 2009).

**FIGURE 2.2:** POTENTIAL NEW OR REHABILITATED IRRIGABLE LAND IN SUB-SAHARAN AFRICA




*Source:* You et al. 2009.

All of these countries have more than 100,000 ha of potential, based on existing or projected development of mainly multipurpose water-storage reservoirs. Except for Southern Africa, small-scale irrigation projects in Sub-Saharan Africa are generally estimated to have higher IRR than large-scale irrigation. This implies that economically viable, small-scale irrigation projects could increase in area under irrigation to a greater extent than large-scale projects (table 2.2).[3]

By far, the greatest potential is found in Nigeria, which accounts for more than 2.5 million ha or nearly half of suitable hectares. Such countries as Cameroon, Chad, Ethiopia, Mali, Niger, South Africa, Sudan, Tanzania, Togo, and Uganda each has at least 100,000 ha of potential.

To begin to tap this potential, the CAADP Program for Investment in Agricultural Water targets region-wide expansion of the irrigated area by 3 million ha, approximately doubling the current area by 2030 (World Bank 2013). In some areas, this expansion could be carried out even more quickly: the World Bank's proposed Sahel Irrigation Initiative has a goal of "doubling the irrigated areas in Sahel in five years through improved public policies and increased private-sector involvement." Much of this irrigation would be gravity fed, but some of it, especially small-scale irrigation, would require pumping for transport and/or extraction. And there is an additional synergy: the development of hydroelectric power sources can often be combined with irrigation projects.

**TABLE 2.2:** POTENTIAL INVESTMENT NEEDS FOR LARGE-SCALE, DAM-BASED AND COMPLEMENTARY SMALL-SCALE IRRIGATION SCHEMES IN SUB-SAHARAN AFRICA

| Region | Large-scale Irrigation | | | Small-scale Irrigation | | |
|---|---|---|---|---|---|---|
| | Increase in Irrigated Area (million ha) | Investment Cost (million US$)[a] | Average IRR (%) | Increase in Irrigated Area (million ha) | Investment Cost (million US$)[a] | Average IRR (%) |
| Sudano-Sahelian | 0.26 | 508 | 14 | 1.26 | 4,391 | 33 |
| East | 0.25 | 482 | 18 | 1.08 | 3,873 | 28 |
| Gulf of Guinea | 0.61 | 1,188 | 18 | 2.61 | 8,233 | 22 |
| Central | 0.00 | 4 | 12 | 0.30 | 881 | 29 |
| Southern | 0.23 | 458 | 16 | 0.19 | 413 | 13 |
| Indian Ocean Islands | 0.00 | 0.00 | n.a. | 0.00 | 0.00 | n.a. |
| **Total** | **1.35** | **2,640** | **17** | **5.44** | **17,790** | **26** |

*Source:* You 2008.

*Notes:* The average value for IRR was weighted by the increase in irrigated area. Benin, Chad, and Madagascar have no profitable, large-scale irrigation; n.a. = not available.

a. These estimates are one-time investment costs rather than annualized figures.

### *PRIMARY AND SECONDARY PROCESSING*

Electricity is a vital input in value-added processing activities, such as post-harvest cleaning and drying to remove moisture and prevent spoilage (e.g., for cereals and legumes), milling (e.g., of maize, rice, and cassava), and crushing. Specific processing activities for high-value agricultural products also rely on electricity inputs (e.g., wet-processed coffee using machinery for pulping). Furthermore, electricity can improve storage of produce through cold chains, thereby reducing income loss from spoilage and increasing the ability to specialize in high-value perishable products (e.g., dairy, meats, fruits, and vegetables). It is estimated that about 30 percent of agricultural produce is wasted due to spoilage. Cold storage and drying can reduce this figure substantially. Electric fans for air precooling, ice-making machines and hydro-coolers can improve cooling efficiency in cold storage rooms.

Though difficult to estimate accurately due to the dispersed potential, primary and secondary processing represent a significant growth area in Sub-Saharan Africa. The expected demand growth for grain milling is likely to increase significantly (e.g., maize in Nigeria, wheat in Zambia, and rice in Tanzania). Similarly, increased demand for processing of cassava—a widely produced and consumed staple in many countries (e.g., Angola, Democratic Republic of the Congo, Mozambique, Nigeria, and Uganda)—is expected due to its perishable nature and use as an industrial input in the manufacturing of glue.

Additional primary and post-harvest processing (if developed to full potential), together with the activities discussed above, could significantly change the rural electricity markets. Table 2.3 summarizes the various activities that can serve as anchor loads for rural electrification, along with the value chains they are part of and examples of countries where they are present and likely to grow.

The creation of opportunities for viable rural electrification on the back of local agricultural development will depend on various site-specific factors, including the scale and profitability of agricultural operations, crop, terrain, type of processing activity, and other local conditions. Rural electrification opportunities will be best served by agro-processing activities that generate electricity demand close to rural population centers, generate enough income to cover electricity supply costs, are sufficiently large in relation to household demand,[4] and have relatively low seasonal variation.

## AGGREGATE ELECTRICITY DEMAND FROM IRRIGATION AND PROCESSING

By 2030, we estimate that electricity demand from agriculture could double from today's level, reaching about 9 GW. This is a simplified estimate as the varied nature of product value chains and associated irrigation, processing, and storage activities makes it impossible to develop a comprehensive, region-wide estimate. The demand emerges from considering the potential increase in irrigation and post-harvest activities. Assumptions about increased development of irrigation and processing potential, unit electricity use, and accompanying growth in crop yields underlie this estimation. Growth in agricultural production catering to domestic and export demand and accompanying movement up the agriculture value chain are expected to increase electricity demand from irrigation and post-harvest processing.

By 2030, about 3.1 GW in additional electricity demand is expected from the development of irrigation potential across Sub-Saharan Africa (figure 2.3). Given the region's significant underutilized water resources, along with the ubiquitous benefits from irrigation across most value chains, it is expected that irrigation will account for a significant portion of electricity demand from the agriculture sector.[5] The estimated demand from irrigation is based on fully exploiting potential areas for new or rehabilitated irrigable areas, totalling nearly 6.8 million ha.[6] This area is dominated by small-scale scheme development in the Gulf of Guinea (with more than 1.5 million ha in Nigeria alone) and rehabilitation of existing schemes in the Sudano-Sahelian region (with over 1 million ha in Sudan) (table 2.4).[7]

Figure 2.3 shows that about an additional 1.1 GW is expected from the development of the region's agro-processing potential. Power demand from the development of agricultural processing activity is based on increased growth in both primary crop production and the proportion of crops that are processed. Currently, the percentage of crop production processed through electrified value chains is quite low (conservatively estimated at 10 percent). By 2030, this percentage is expected to grow to 15 percent as a result of the increased participation of small-scale farmers in formal value chains.

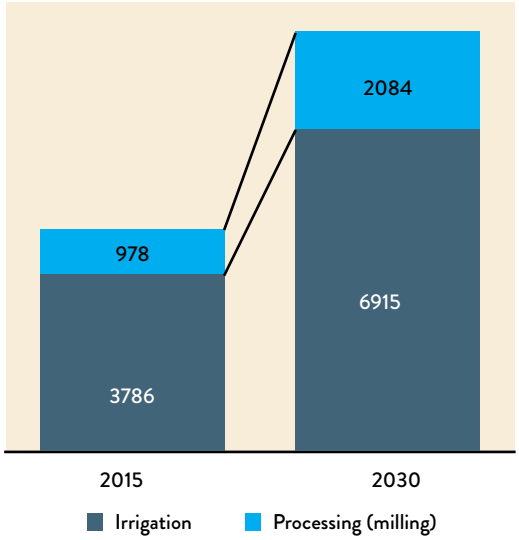
Given the varied nature of processing activities by type, scale, location, and technology, the estimate is based on the electricity requirement of a typical processing

**TABLE 2.3:** KEY POWER-INTENSIVE AGRIBUSINESS ACTIVITIES

| Activity | Value Chains Supported | SSA Countries/ Regions Where Activity Occurs | Scale of Power Demand/ Supply | Growth Potential of Value Chain and Activity |
|---|---|---|---|---|
| New **large-scale irrigation** | Maize, rice, wheat, oilseed, sugarcane, tea, floriculture | Most countries | Single areas can demand > 15 MW of capacity. | Many areas that can be supported likely to require farms of > 250 ha; crop choice depends on market prices. |
| Substitute **power for diesel** in small-scale milling | Maize, rice, cassava, oilseed | Most countries | In unconnected rural towns, demand unlikely to exceed 500 kW for the whole town. | Many towns in agricultural areas will have this demand; risky as anchor load for electrification. |
| New **large-scale milling** | Maize, rice, wheat, oilseed, sugarcane, oil palm, tea, cotton | Most countries | Demand can be > 1 MW from a single mill. | Widespread opportunity. Reliant on base supply from commercial estates; crop choice depends on market prices. |
| **Milking and cold storage** | Dairy | Few countries | > 800 kW peak demand. | Small markets in SSA; climatic conditions not ideal for dairy farming. |
| **Cold storage** | Floriculture, export vegetables | Ethiopia, Kenya, and Uganda (floriculture and export vegetables); Rwanda and Tanzania (export vegetables) | 10 MWh/ha per year. | Continued demand for floriculture in Europe, leading to agribusiness growth in select countries; challenges with horticulture through demand for high quality, competitive retail markets driving down margins and tariff restrictions in European markets. |
| **Biomass**-fueled generation | Rice, oil palm | Many countries (rice); West Africa and East and Southern Africa | Can provide > 10 MW of power (ha/ton). | Beyond Africa, export market for rice is challenging and unreliable for palm oil. Water intensity restricts locations; depends on reliable supply of biomass from commercial estates. |
| **Bagasse**-fueled generation | Sugarcane | Eastern and Southern Africa (South Africa) | Can provide > 10 MW of power (70 kWh/MT of sugarcane, or 243 kWh/MT of bagasse). | Large market for crop, but price-dependent. Water intensity restricts locations; depends on reliable supply of bagasse from commercial estates. |

*Source:* ECA and Prorustica (2015).

**FIGURE 2.3:** ESTIMATED ELECTRICITY DEMAND (MW) FROM AGRICULTURE FOR SUB-SAHARAN AFRICA IN 2030




*Source:* ECA and Prorustica (2015).

activity (milling) and thus does not capture the electricity demand from the potential development of other processing activities or storage.

In 2012, the Food and Agriculture Organization of the United Nations (FAO) estimated crop production at about 852 million metric tons (MT). Assuming a growth rate of 2.4 percent annually (Alexandratos and Bruinsma 2012), crop production would reach 1.3 billion MT by 2030 (table 2.5). The power demand from crop production is estimated by assuming that processed crops will consume, on average, the amount of power needed for an average wheat mill in Zambia—some will have greater consumption and others less. This "average mill" is assumed to handle 8 MT per hour, operating year round at 16 hours per day and 6 days a week. This would result in approximately 40,000 MT per year and have a power capacity demand of 400 kW.

The total estimated electricity demand from agriculture is indicative of the scale of the opportunity for rural electrification to benefit from agricultural growth potential. The overall magnitude of electricity demand provides

**TABLE 2.4:** METHOD FOR CALCULATING POWER DEMAND FROM IRRIGATION

| Category | Prominent Countries with Irrigable Area (thousand ha) | Estimated Proportions/ Power Use | Estimated Power Use (kW/ha) | Estimated Power Use (MW) |
|---|---|---|---|---|
| Large-scale | Ethiopia (191)<br>Nigeria (609)<br>Sudan (238)<br>Zimbabwe (142)<br>Total = 1,352 | Much of East and Southern Africa requires bulk-water pumping, West Africa less so; 50% requires bulk-water pumping and 50% just infield equipment. | 1.2 kW/ha for area requiring bulk water, 0.7 kW/ha otherwise | 1,285 |
| Small-scale | Cameroon (170)<br>Chad (231), Mali (219)<br>Nigeria (1,538)<br>Tanzania (196)<br>Uganda (445)<br>Total = 3,754 | Most schemes are very basic in riparian areas; 40% requires power, and 60% is entirely gravity fed with no power. | 0.7 kW/ha for area using power, 0 otherwise | 1,051 |
| Rehabilitation | Somalia (135)<br>Sudan (1,064)<br>Total = 1,688 | Most rehabilitation consists of gravity fed, colonial-era schemes; 10% is large-scale with bulk water, 30% large-scale without, 20% small-scale with power, 40% small-scale with no power. | 0.7 kW/ha for area using power, 0 otherwise | 793 |

*Sources:* You et al. (2009); ECA and Prorustica (2015).

**TABLE 2.5:** POWER DEMAND FOR CROP PROCESSING

| Year | Primary Crop Production (million MT) | Crops Processed (%) | Processed Production (MT) | Number of 400-kW Mills Required | Total Power Demand (GW) |
|---|---|---|---|---|---|
| 2012 | 852 | 10 | 85.2 | 2,129 | 0.851 |
| 2030 | 1,306 | 15 | 196.0 | 4,893 | 1.960 |

*Sources:* FAO; Alexandratos and Bruinsma (2012); ECA and Prorustica (2015).

a sense of the investment in generation capacity that will be required to meet agricultural needs and the addition to rural electricity demand that is expected, owing to the agriculture sector. The latter informs the likely viability of accounting for agricultural growth in rural electrification strategy and planning.

## ENDNOTES

1. Some sprinklers are pressurized, while others are solely gravity operated.

2. Conditional on having initial investment costs at best-practice levels and if market access, complementary inputs, extension of credit, and a supportive policy and institutional environment are in place.

3. The higher IRR for small-scale irrigation is due to the existence of large amounts high-potential rainfed cultivation located far from large-scale developments that could be profitably converted into small-scale irrigation (You et al. 2009).

4. Although even a relatively small agricultural load can potentially help to push aggregate demand in a given area over the threshold of economic and financial viability.

5. In the context of climate change, the future availability of water will depend critically on improvements in water management practices and planning (box 1.3). World Bank (2016a) predicts that, under business as usual, water management in Southern and East Africa will not experience negative effects on GDP, while other parts of Sub-Saharan Africa could experience about a 6 percent fall in GDP in 2050.

6. You et al. (2009) classifies areas based on their anticipated IRR on irrigation investment. The numbers reported here are based on an anticipated 12 percent return, which is a typical benchmark for such projects.

7. You et al. (2009) was published before the independence of South Sudan and thus classifies the whole of Sudan together.

# Power Needs in Selected Value Chains

## CHAPTER 3

Agricultural production in Sub-Saharan Africa is fairly diversified, and no single cereal crop predominates across the region. In terms of production quantity, maize is the most important, followed by sorghum, millet, and rice; the importance of each crop varies by individual countries. In West and Central Africa today, cereals comprise less than 20 percent of agricultural value added (compared to 35 percent for Asia prior to the Green Revolution), with the remainder coming from other staples (especially roots and tubers), horticulture, export crops, and livestock (Schaffnit-Chatterjee 2014).

Owing, in part, to diversity in agricultural production, agriculture value chains also vary widely across the region and even within countries. Value chains vary by length, technologies utilized, value added, and markets served.[1] Many value chains operate in both informal and formal markets, with the former catering to low-income, domestic consumers and the latter catering to higher income urban and export markets (World Bank 2013).

The value chains for the region's bulk commodities (e.g., maize and rice) are primarily informal, in contrast to more market-oriented, semi-processed and consumption ready products. As a commodity moves along the value chain to the ultimate market and consumer, hygiene and quality standards become more stringent. Such commodities as sugar, tea, and oil palm are processed virtually at the point of primary production, while other commodities (e.g., fruits, vegetables, and livestock products) must be processed within a relatively short period before they deteriorate. Still others have parallel value chains; that is, for the same commodity, some value chains focus on lower end consumers in domestic markets, while others are more formal, with strong processing and stringent quality control.

The need for post-harvest electricity input varies, depending on the nature of the crop, the type of value chain (or targeted market) and local conditions. A case in point is Kenya's dairy sector: 86 percent of the country's milk supply is driven by small-scale farmers and small- and medium-sized enterprises (SMEs), with milk being sold to small-scale vendors. Parallel to this, larger dairy farms with either integrated dairy herds and/or formal links to dairy farmer cooperatives provide pasteurized milk and processed dairy products via cool chains for sale to higher income urban consumers through supermarkets (World Bank 2013).

This chapter examines potential electricity use along 13 selected value chains. Electricity demand from on-farm activities and rural processing presents an opportunity for the development of anchor loads to spur rural electrification. The source of electricity may vary on a case-by-case basis, and opportunities for biomass based generation for particular value chains (e.g., oil palm and sugar) are highlighted. In addition, bottom-up estimates of potential future electricity demand from the selected value chains are presented.

### SELECTION OF VALUE CHAINS

The value chains selected for this study help illustrate the nature of electricity demand from the rural agriculture and agribusiness sectors, along with the power-demand profile. These value chains represent both high growth potential and the ability to create electricity demand for irrigation and/or processing in rural areas (table 3.1). The potential for agricultural electricity demand extends well beyond the value chains discussed here and is often driven by site- and country-specific factors that create

**TABLE 3.1:** ANALYSIS OF COMMODITY VALUE CHAINS, BY SCALE AND REGION/COUNTRY

| Commodity | Scale (if applicable)[a] | Region/Country |
|---|---|---|
| Maize | Small and large | East and Southern Africa |
| Rice | Small and large | Tanzania (primarily) |
| Cassava | Small | West, Central, East, and Southern Africa |
| Wheat | Large | Southern Africa |
| Oilseed | Small (primarily) | East and Southern Africa |
| Horticulture (pineapple) | Small and large | West, Central, and Southern Africa |
| Sugarcane | Small and large | East and Southern Africa |
| Oil palm | Small and large | West and Central Africa |
| Dairy | Small and large | Kenya |
| Poultry | Large | East and Southern Africa |
| Tea | Large | East and Southern Africa |
| Floriculture (roses) | Large | East Africa |
| Cotton | Small | West, East, and Southern Africa |

*Source:* FAOSTAT (http://faostat3.fao.org).
a. Farming systems are defined in terms of labor type and not merely scale. Large-scale commercial farming is defined by family labor that is predominantly managerial, with full-time labor hired for specific tasks and production catering to market supply.

opportunities along other crop and processing activities. The case studies presented in chapter 4 analyze examples of such opportunities.

The commodity value chains shown in table 3.1 were selected according to the following criteria. Starting with the top 20 commodities by production value for 2012 (from FAOSTAT), the list was modified to assure the inclusion of (i) key export commodities (e.g., tea, cotton, and horticulture); (ii) value chains based on assessed electricity use; (iii) commodities with large production volume and importance for local food markets with potential for future growth in processing requirements (e.g., cassava and maize); (iv) commodities that figure in the top ones by value for many countries in the region (e.g., tea and soybean), which may not appear on a region-wide list; (v) commodities with large irrigation schemes (e.g., irrigated wheat); and (vi) value chains with the potential to supply fuel for electricity generation (e.g., oil palm and sugarcane).

Table 3.2 shows the estimated production volume for the selected commodities in 2030, along with their estimated average annual growth rates between 2013 and 2030. Future projections are calculated using the historical growth rate (between 2009 and 2013) for each commodity (FAOSTAT) and applying a concavity parameter to project a declining growth rate over time. The assumed growth rates are qualitatively more conservative than those assumed by Alexandratos and Bruinsma (2012), who predict mostly convex growth rates, owing to large existing potential on the extensive (area expansion) and intensive (yield growth) margins.

According to future production estimates, cassava and maize—primary staple food crops in the region—will remain dominant over the period until 2030. Sugarcane, a well-established industry with conducive growth conditions, is also expected to remain dominant across the region for the foreseeable future. In addition, recent high growth rates of cotton, pineapple, and rice suggest that these commodities will likely gain greater regional importance in the coming decades.

**Cassava.** In terms of production quantity, cassava is Sub-Saharan Africa's most important crop, accounting for more than half of global production. Nigeria is the leading global producer, followed by the Democratic Republic of the Congo (DRC), Angola, Ghana, and Malawi.[2] Cassava is experiencing growing demand as a staple food crop and an intermediate input into various other commercial value chains (e.g., starch and livestock feed). The crop is still mainly grown under small-scale farming conditions with limited use of irrigation. Owing to its drought tolerance and ability to grow in relatively poor soils, production is fairly widespread in rural areas across the region. Further development to make the crop's value chain more market oriented can have large effects on the livelihoods of small farmers. Growth in cassava production depends critically on improved processing and drying of roots to reduce bulk and prevent deterioration.

**TABLE 3.2:** COMPARISON OF HISTORICAL AND PROJECTED COMMODITY GROWTH RATES AND ESTIMATED PRODUCTION

| Commodity | Growth Rate, 2009–13 (%) | Assumed Average Annual Growth, 2013–30 (%) | Estimated Production in 2013 (million MT) | Projected Production in 2030 (million MT) |
|---|---|---|---|---|
| Cassava | 6.4 | 2.8 | 157.7 | 252.7 |
| Maize | 5.8 | 2.5 | 65 | 101.2 |
| Sugarcane | 1.7 | 0.8 | 73.9 | 84.6 |
| Rice (paddy) | 5.9 | 2.6 | 22.6 | 35.5 |
| Wheat | 5.1 | 2.3 | 7.1 | 10.6 |
| Pineapple | 9.5 | 4.2 | 4.4 | 9 |
| Dairy | 1.6 | 0.7 | 3.2 | 3.6 |
| Poultry | 1.5 | 0.6 | 2.7 | 3 |
| Cotton (lint) | 8.1 | 3.5 | 1.3 | 2.5 |
| Oil palm | −0.7 | −0.3[a] | 2.4 | 2.2 |
| Tea | 5.4 | 2.4 | 0.7 | 1 |
| Oilseed (soybean) | 2.6 | 1.2 | 0.5 | 0.6 |

*Sources:* FAOSTAT and World Bank estimates.
a. The oil palm industry is now considered less attractive; some developments are proving unsustainable and are being converted to other uses.

**Maize.** Due to its tolerance of diverse climates, maize is one of the world's most widely grown crops. In 2013, total global production was estimated at more than 1 billion metric tons (MT). In Sub-Saharan Africa, maize is one of the most prevalent cereals, with more than 65 million MT produced in 2013 (table 3.2). However, the region's average yield of 1.4 MT per ha is low compared to the global average of 5 MT per ha, and 11.6 MT per ha in the United States (Iowa) (2009 figures, FAO). A few countries are dominant in maize production, but their market share is less pronounced. Maize's utilization is wide ranging; it serves as a leading food staple and important feed crop, as well as an input in the processing of food, chemicals, and fuels (ethanol).[3] In East and Southern Africa, maize is principally a food staple, accounting for 30–50 percent of low-income household expenditure.[4] As such, growth in production is expected to increase, propelled by growing regional demand.

**Sugarcane.** According to the FAO, sugarcane is the world's largest crop in terms of production quantity, with 1.83 billion MT produced in 2012. Brazil is its largest producer, followed by India. Sub-Saharan Africa accounts for roughly 4–5 percent of global production, with about 74 million MT produced in 2013. The region's largest producers are South Africa, followed by Sudan and Kenya; South Africa and Mozambique lead in terms of area under cultivation (table 3.3). Eighty percent of the world's sugar is produced from sugarcane, while the other 20 percent is from sugar beet (FAO 2009). The most common production model is contracting commercial and small-scale outgrowers to supply the sugar refineries.

**Rice (paddy).** Sub-Saharan Africa has witnessed rapid growth in rice production, driven mainly by urbanization. The compound annual growth rate (CAGR) of domestic production has averaged about 6 percent, with more than 22 million MT reached in 2013. According to the Africa Rice Center's analysis, the region's rice yields have increased in real terms by an average of 108 kg per ha annually, comparable to the Green Revolution's growth rates in Asia (Seck et al. 2013). Despite such rapid growth, rice imports have also increased significantly; in 2012, 12 million MT were imported. The region has considerable potential for production growth through increasing the area under cultivation and increasing yields.

**Wheat.** Among all cereals, wheat is the most highly traded. As of 2013, it was the world's third most widely produced cereal (behind maize and rice), at a total of 713 million MT.[5] In Sub-Saharan Africa, Ethiopia and South Africa are the main wheat producers. Generally, production has not kept pace with the region's growing demand for wheat;

**TABLE 3.3:** COUNTRIES IN SUB-SAHARAN AFRICA WITH SIMILAR COMMODITY PRODUCTION AND PROCESSING SYSTEMS

| Commodity | Countries |
|---|---|
| Maize | Kenya, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe; also Burkina Faso, Ghana, Mali, and Nigeria (but not at such large commercial volumes) |
| Rice | Madagascar and Tanzania |
| Small-scale cassava | Angola, DRC, Mozambique, Nigeria, Tanzania, and Zambia |
| Irrigated wheat | Zambia and Zimbabwe |
| Rainfed wheat | Ethiopia and Kenya |
| Commercial soya | Zambia and Zimbabwe |
| Sugarcane | Ethiopia, Kenya, Malawi, Mozambique, South Africa, Swaziland, Tanzania, and Zimbabwe |
| Oil palm | Cameroon, Côte d'Ivoire, and Ghana |
| Dairy | Kenya, Ethiopia, Rwanda, South Sudan, and Uganda |
| Poultry | Kenya, Malawi, Zambia, and Zimbabwe |
| Tea | Kenya, Malawi, Rwanda, and Uganda |
| Floriculture (roses) | Ethiopia, Kenya, Tanzania, Uganda, Zambia, and Zimbabwe |
| Cotton | Benin, Burkina Faso, Côte d'Ivoire, Mali, Mozambique, Tanzania, Uganda, Zambia, and Zimbabwe |

*Source:* ECA and Prorustica (2015).

thus, wheat imports have been on the rise. Among the region's handful of countries that are fully self-sufficient in wheat production, Zambia is noteworthy; that country's annual production, mainly commercial in scale, totals 300,000 MT (table 3.3).[6] Many parts of East, Southern, and Central Africa are suitable for wheat production.

**Pineapple.** In Africa, horticulture, in the form of tropical fruit production, caters mainly to own consumption and domestic markets; in some countries, it also caters to Europe and other export markets (e.g., canned fruits and pulp). After banana, pineapple is Sub-Saharan Africa's most important tropical fruit. Nigeria is the region's largest pineapple producer. Kenya, the second largest, ranks among the world's top five exporters of pineapple; canned pineapple, exported mainly to Europe, is its largest manufactured export.

**Dairy.** The robust growth in dairy production reported in many parts of Sub-Saharan Africa today is being driven by economic growth and urbanization. Traditionally, milk has been produced for own consumption or local consumption by farmers; however, growing urban demand is increasing the need for cold supply chains to maintain product quality. According to the FAO, the region's dairy production totaled 3.2 million MT in 2013. Along with this demand growth is the demand created for processing milk-derivative products (e.g., cheese, butter, and evaporated milk). Transport of raw milk, which is prone to spoilage, is generally uneconomical; thus, it is kept to a minimum, suggesting that dairy storage and processing centers are located in the vicinity of dairy farms.

**Poultry.** Population growth, changing diets resulting from urbanization, and income growth are the major drivers of Sub-Saharan Africa's ongoing demand for poultry. During 2000–11, poultry (meat) production across the African continent grew by 5 percent per year, reaching 4.62 million MT in 2011. Major producers are in Northern Africa: Egypt, Algeria, Morocco, Libya, and Tunisia. In Sub-Saharan Africa, 2013 production totaled 2.75 million MT, with South Africa and Nigeria as lead producers. These two countries are also the region's major egg producers; and hatcheries are usually large-scale commercial operations. Modern poultry complexes are usually integrated with chicken farms to reduce the costs associated with the transport of live animals. Contract farmers receive chicks from the hatchery, ideally housing them in climate-controlled chicken houses. Broiler processing operations are typically located on-site at poultry farms.

**Cotton (lint).** Cotton is one of Africa's main cash crops among small-scale farmers. In 2013, Sub-Saharan Africa produced 1.3 MT of cotton (lint) (table 3.2). The region's major producers are Burkina Faso, Mali, Côte d'Ivoire, Benin, and Zimbabwe. In West Africa, Burkina Faso and Mali each produce about 400,000 MT per year. In East and Southern Africa, Zimbabwe is the lead producer, with an annual output of 200,000–300,000 MT in seed cotton (table 3.3).

**Oil palm.** The source of palm oil, one of the world's leading edible vegetable oils, oil palm constitutes 60 percent of the global trade in vegetable oils (World Bank 2011a). Oil palm fruit yields two distinct types of oils: (i) palm oil, which is edible, used mainly in the form of vegetable oil and (ii) palm kernel oil, which is extracted from the seed kernel, used as an input to process other foods (e.g., biscuits and margarine), manufacture household products (e.g., soap, shampoo, and cosmetics), and produce biodiesel fuel. Southeast Asia (mainly Malaysia and Indonesia) produces 85 percent of the world's palm oil. In Sub-Saharan Africa, West Africa is the main producer. Nigeria is the largest producer; however, Côte d'Ivoire, DRC, Ghana, Guinea, and Uganda are also establishing major operations. While commercial-scale farmers account for most production, small-scale farmers also find oil palm an attractive crop since it is relatively high yielding and requires limited labor inputs.

**Tea.** Tea is one of Sub-Saharan Africa's most important export commodities, especially for East Africa. Kenya is the world's largest exporter of black tea. In 2011, it produced 378,000 MT, about two-thirds of Sub-Saharan Africa's output. Uganda and Malawi are the region's next two largest producers, while Tanzania and Rwanda are experiencing steady growth in production (table 3.3).[7] Tea-growing usually occurs on large plantations, with processing located either on-site or nearby.

**Oilseed (soybean).** Although Sub-Saharan Africa's soybean production is fairly small by global standards, contributing only 1 percent of global production, the region's production is growing faster than the world average (ACET 2013). South Africa has the highest growth in percentage terms, while Nigeria has the largest absolute growth.[8] Soybean is grown mainly on small farms, while commercial soybean farming is prevalent in South Africa, Zambia, and Zimbabwe. Soybean is sold for both human consumption and as an animal feedstock.

**Floriculture (roses).** The introduction of rose cultivation in Sub-Saharan Africa began in Kenya about three decades ago. To this day, Kenya remains the region's main producer and exporter of roses; that country also has the highest area under rose cultivation, followed by Ethiopia and Uganda. Rose production in Ethiopia has been growing rapidly, and the country is fast establishing itself as a major exporter, to some extent capturing market share from Kenya. Most production is for export markets, especially Europe, which generates more than US$1 billion in export revenues for the region (International Trade Center 2014). On a per hectare basis, rose production is one of the most high-value agricultural activities, generating revenues of $100,000–200,000 per ha.[9]

## ELECTRICITY DEMAND AND FARMING SCALE

Electricity demand along the value chain is likely to vary by scale or type of farming operations (e.g., commercial versus small-scale) due to differences in farming processes (e.g., irrigation) and the extent and nature of post-harvest processing (box 3.1). While farming in Sub-Saharan Africa is predominantly in the form of smallholder agriculture, a significant portion of the future potential rests on increasing yields on such farms by employing more modern inputs and connecting them to higher value markets and value chains (i.e., employing large-scale operations).

It is useful to compare electricity needs across these types of agricultural arrangements. The implication for overall magnitude depends on the evolving proportions of commercial and small-scale farming techniques in the

### BOX 3.1: FARM TYPE DEFINITIONS

Defining farming systems in terms of labor can be useful, given that the definitions do not depend on production scale or crop type. Accordingly, three types of farm systems are distinguished here:

**Family farms.** These small-scale farms are characterized by the predominant use of family labor, lack of permanent workers, and presence of seasonal labor hired during peak production times.

**Small investor farms.** The owners/family members are involved primarily in management and supervisory roles, while the bulk of labor input is provided by hired farm workers; this group is less well-defined in Africa, but most, if not all, of their crops are produced for market.

**Large-scale commercial farms.** Family labor for these farms is exclusively or predominantly managerial. A permanent hired staff of full-time workers, specialized to a certain degree (e.g., drivers), produces primarily for market.

*Source:* Poulton et al. (2008).

region. For example, greater proportional growth in the adoption of commercial-scale farming, which depends more heavily on power input, will induce higher overall electricity demand by the agriculture sector.

Examining typical electricity use for irrigation and processing shows that, for most of the value chains analyzed, irrigation constitutes a large proportion of the potential electricity demand. As small-scale farming largely relies on rainfed or gravity irrigation, electricity demand from commercial-scale irrigated agriculture is an order of magnitude greater than from smallholder agriculture. Figure 3.1 compares typical rates of power usage for large-scale irrigated and small-scale rainfed (or gravity fed) irrigation for selected value chains. For the most widely grown crops in Sub-Saharan Africa, including maize, rice, and cassava, irrigation accounts for the highest potential electricity load.[10]

As shown, potential peak power loads for small-scale informal production are quite small relative to loads from commercially irrigated production on a per unit basis (figure 3.1b), although this is partly offset by the predominance of smallholder agriculture across the region, representing over 80 percent of the cultivated area (Livingston, Schonberger, and Delaney 2011).

Though irrigation accounts for a major part of the potential on a per unit basis, post-harvest processing can play a significant role in supporting rural electrification, especially in the case of some commodity value chains. Adding electricity demand for processing to that for irrigation, commercially oriented value chains such as sugarcane, tea, floriculture, and dairy have the overall highest potential electricity demand (figure 3.1a). Tea is easily the most power-intensive commodity, with demand emanating primarily from processing (figure 3.1c).[11] Activities with potentially large loads from processing (sugarcane, tea, and floriculture) are developed and operated mainly by large single entities or organized groups of small-scale farmers (see case study 6, chapter 4).[12] In such cases, the power load and potential power supply are usually part of the planning process; examining options and incentives for rural electrification can be integrated into the planning stage itself.

However, in Sub-Saharan Africa most agricultural production occurs in small-scale, informal value chains. The potential power demand from small-scale agriculture is much less than from commercial agriculture. Lower yields mean that a larger area is required to produce sufficient production volume for processing facilities. Figures 3.1b and 3.1d exclude small-scale sugarcane, oil palm, and tea since these typically occur only with small-scale farmers operating as outgrowers for commercial estates; thus, the scale of power demand cannot be viewed independent of larger commercial estates.[13] The figures include dairy with zero values to highlight that informal dairy value chains do not utilize power in Sub-Saharan Africa.

Given the economies of scale in generation capacity, commercial agricultural activities are likely to be more financially viable anchor loads to support affordable rural electricity supply to rural Sub-Saharan Africa. However, due to recent technological improvements, accompanied by the creation of enabling regulatory conditions, electricity provision in the form of mini-, micro-, and even pico-grids has dampened the scale economies in electricity generation and distribution investments. Increasingly, advances in renewable energy technologies, such as solar photovoltaics (PV), are allowing viable electricity infrastructure investments catering to smallholder agriculture and rural households. Even for more conventional technologies, ubiquitous small-scale, informal agriculture can enhance the viability of rural electrification on the margin. As discussed earlier, given the diversity of conditions across agricultural areas, site-specific opportunities still exist if cost-effective technologies (e.g., biomass, solar, or small hydro), which may not exhibit strong economies of scale in installed capacity, can be utilized.

## ELECTRICITY DEMAND IN THE SELECTED VALUE CHAINS

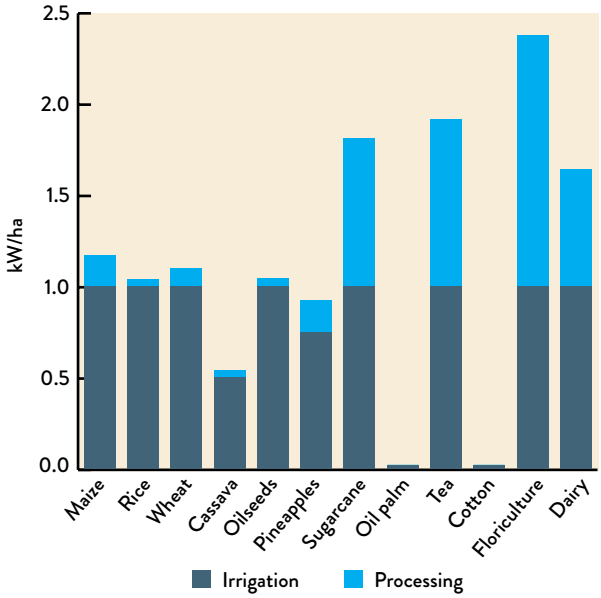
The development of power profiles for each commodity, region, and farm type utilized a range of information sources. Value chains were analyzed in terms of their nature and magnitude of power use for irrigation and processing, growth potential, and ability to serve as an anchor load.

To enable comparison, the power profiles presented below are for (arbitrary) standardized farm sizes of 300 ha, based on the unit electricity demand presented in table 3.4. The 300 ha benchmark was chosen to represent the cultivated area that might constitute a typical project site.[14]

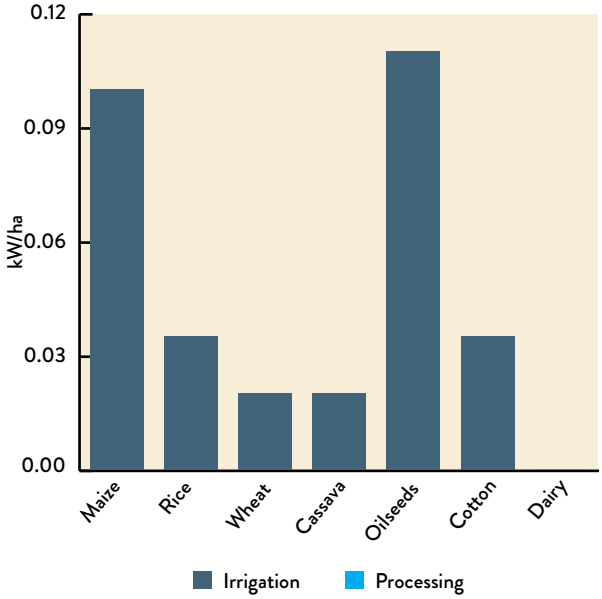
**Maize.** For the maize value chain, the input of rural electricity is primarily for irrigation (largely restricted to large-scale farming) and milling (figure 3.2a). The gain in value from electricity use comes from the higher yields resulting from irrigation and the saving of labor and higher productivity resulting from electricity powered (versus manual) milling. The estimated electricity demand from these two activities is about 1.17 kW per ha for large-scale

**FIGURE 3.1:** POTENTIAL PEAK CAPACITY AND ENERGY DEMAND FOR LARGE- AND SMALL-SCALE SYSTEMS

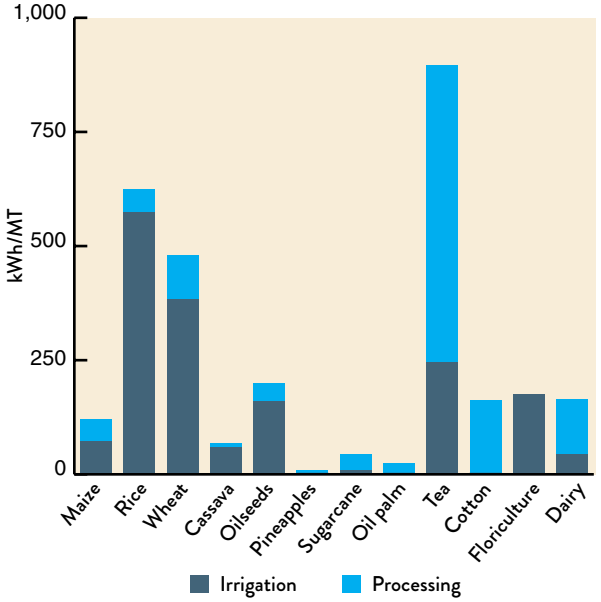
a. Peak capacity: Large-scale irrigated production



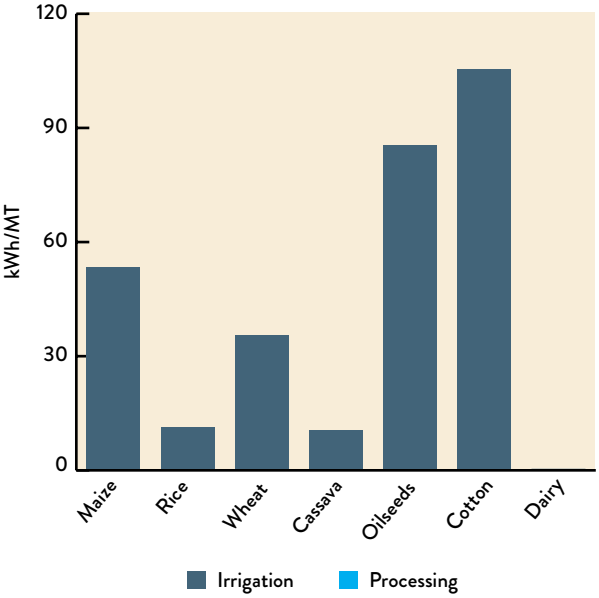

b. Peak capacity: Small-scale rainfed production




c. Energy demand: Large-scale irrigated production

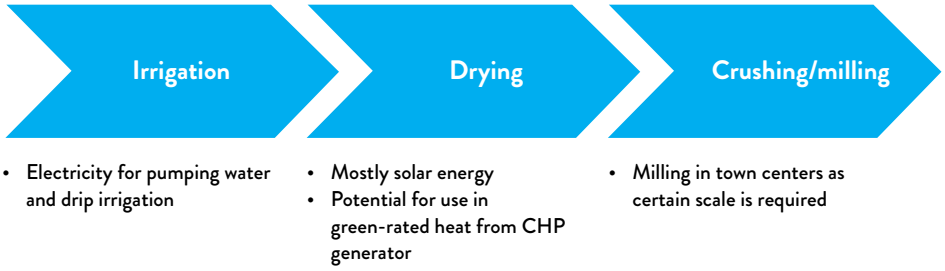



d. Energy demand: Small-scale rainfed production




*Note:* Unit electricity demands are constructed from various sources and field observations by ECA and Prorustica. Figure 3.1a does not plot poultry as it is a significant outlier and not feasible to depict on the same scale. Figure 3.1c omits floriculture due to the incomparability of yield data. Figures 3.1b and 3.1d are restricted to those commodities with significant production on smallholder farms (thus omitting such cash crops as tea, sugarcane, floriculture, and horticulture).

**FIGURE 3.2a:** ELECTRICITY INPUT IN THE MAIZE VALUE CHAIN




production and about 0.77 kW per ha for small-scale irrigated production, suggesting that 300 ha of cultivated maize will require about 250–350 kW of installed power generation capacity.

**Rice.** For rice, irrigation and milling are the primary sources of rural electricity demand (figure 3.2b). Because rice can be grown under a variety of irrigated or rainfed water regimes, electricity demand for irrigation varies by type of cultivation. The value gain from electricity use is from the higher yields resulting from irrigation (an increase of up to 4 MT per ha) and the value added from milling. The estimated electricity demand from irrigation and milling is 1.04 kW per ha for large-scale, irrigated production and 0.03 kW per ha for small-scale (paddy) production with no irrigation. Thus, for a cultivated area of 300 ha, the power demand is in a range of 9–315 kW, depending on farming type. Additionally, rice husk biomass provides a readily available and cost-effective fuel source to generate electricity to supply mills and potentially the neighboring community.[15]

**Cassava.** For cassava, the electricity demand ranges from 0.02 kW per ha to 0.56 kW per ha, depending on whether the land is under irrigation (figure 3.2c). For a 300 ha cultivated area, the power demand would be about 160 kW.

**FIGURE 3.2b:** ELECTRICITY INPUT IN THE RICE VALUE CHAIN

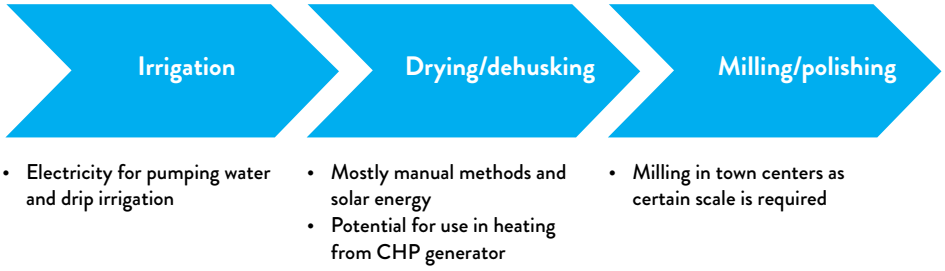
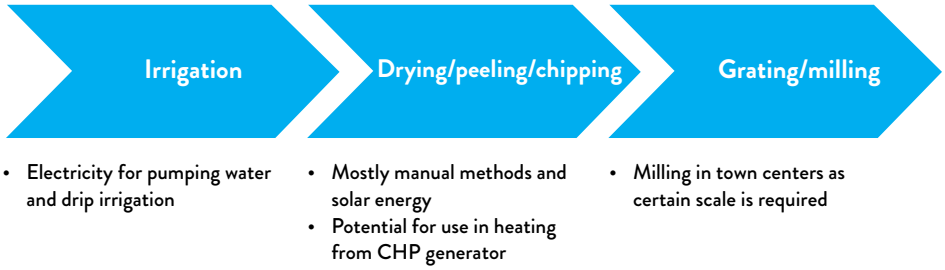



**FIGURE 3.2c:** ELECTRICITY INPUT IN THE CASSAVA VALUE CHAIN




**Processing chain: High-quality cassava flour**

**Wheat.** For winter wheat production, powered activities include irrigation; on-farm drying, cleaning, and conveying in and out of silos; and milling (figure 3.2d). The value added from electricity use is through the higher yields from irrigation (an increase of about 4 MT per ha) and electric milling and processing. The total power demand from irrigation and post-harvest processing is estimated at 1.1 kW per ha for large-scale production and 0.52 kW per ha for small-scale production. For a 300 ha cultivated area, power demand would be in a range of 150–230 kW, depending on the farming type.

**Oilseed (soybean).** For soybean, the value added from electricity use occurs through the higher yields made possible by irrigation and increase in value from processing (figure 3.2e). The total electricity demand resulting from irrigation and milling is estimated at 1.04 kW per ha for large-scale production and 0.64 kW per ha for small-scale production. These figures suggest power demand in a range of 200–300 kW for a 300 ha cultivated area.

**Horticulture (pineapple).** Along the pineapple value chain, juicing and canning activities comprise the main demand for electricity. Irrigation for other horticultural crops (e.g., beans, peas, and potatoes) is fairly limited and usually small in scale. Owing to perishability, electricity is needed for cooling and to power a cold chain from farm to market, although this is usually provided in the form of mobile refrigeration units (reefers). The value added from electricity use in the pineapple value chain includes higher yields resulting from irrigation, increased product value resulting from juicing and canning, and reduced wastage due to cold storage (figure 3.2f).[16] The electricity demand from irrigation is estimated at 0.75 kW per ha for commercial production, implying that 225 kW of power would be needed for 300 ha cultivated area. In addition, the by-products of post-harvest processing can potentially provide biomass for electricity and heat generation, which can significantly reduce power costs.[17]

**Sugarcane.** Sugarcane yields are highly responsive to irrigation; thus, water pumping for irrigation is an important source of electricity demand in the sugarcane value chain. In addition, sugar mills constitute considerable processing demand for electricity (figure 3.2g). The value

**FIGURE 3.2d:** ELECTRICITY INPUT IN THE WHEAT VALUE CHAIN

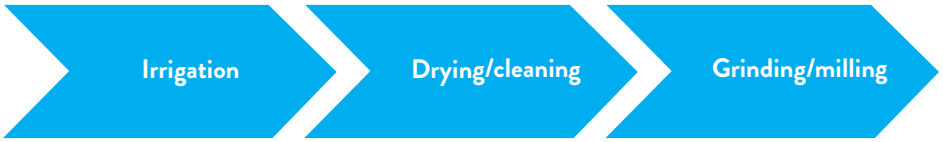



**FIGURE 3.2e:** ELECTRICITY INPUT IN THE SOYBEAN VALUE CHAIN

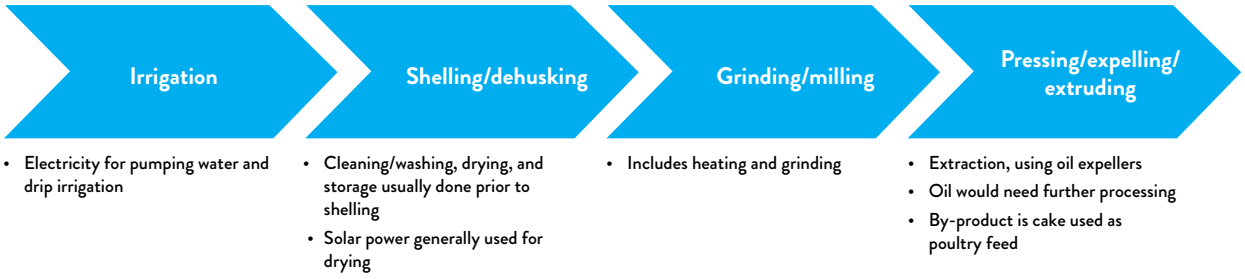



**FIGURE 3.2f:** ELECTRICITY INPUT IN THE PINEAPPLE VALUE CHAIN

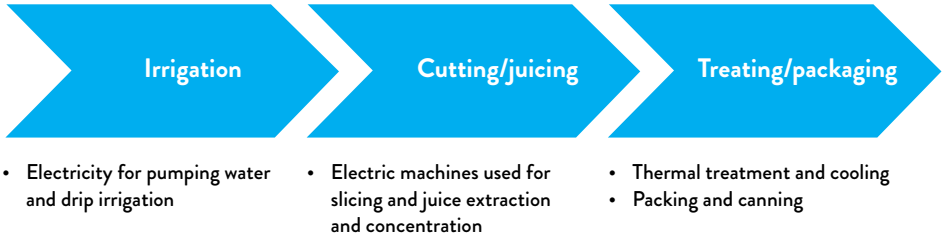


**FIGURE 3.2g:** ELECTRICITY INPUT IN THE SUGARCANE VALUE CHAIN


- Electricity for pumping water and drip irrigation

- Milling: washing, chopping, shredding, and crushing to extract cane juice
- Subsequent clarification, concentration, and crystallization to produce mill-white
- Biomass by-product used for electricity and heat generation

- Further refining of raw sugar produced from milling
- Usually located near urban markets

gains from electricity use are derived from the higher yields from electricity powered irrigation and the price differential between raw cane and partially processed sugar. The increased yields from irrigation could reach 50 MT per ha and even up to 150–200 MT per ha if the latest drip irrigation methods are utilized. On top of the value added, maintaining processing activities close to the farm helps to reduce transport costs. The combined power demand of irrigation and refining is estimated at 1.81 kW per ha for large-scale production and 1 kW per ha for small-scale production. These figures imply that a 300 ha cultivated area will demand 300–550 kW of power, depending on the scale of production and related farming practices.

The biomass residue (bagasse) from sugarcane processing has a high potential to generate electricity. Refineries often produce their own electricity and sell the excess to the grid. Bagasse generated electricity could become important for the rural populations of sugarcane producing nations. For example, in Ethiopia, the Wonchi, Metehera, and Finchaa sugar factories produce approximately 300,000 tons of sugar each year, powering an installed electricity capacity of 62 MW. The electricity is used to power factories, with the surplus power exported to the national grid. For both the South Africa sugar industry and Uganda's Kinyara sugar manufacturer, the power output is approximately 30 kWh per MT of crushed sugarcane.

**Oil palm.** The processing of oil palm usually occurs on or nearby the farm due to its bulky nature and ability to produce biomass used to generate the heat and electricity required for oil extraction and processing. Oil palm irrigation is largely rainfed. The main sources of electricity demand are oil processing and extraction from the fresh fruit bunches (FFBs) (figure 3.2h). Though uncommon, drip irrigation can raise yields by 6 MT of FFB per ha. The value gained from using electricity is through processing and reduced transport costs. For milling, the estimated electricity demand is 0.02 kW per ha, suggesting a 6 kW power requirement for a 300 ha cultivated area. Substantial amounts of solid palm oil waste are available from the palm oil mills, which are energy self-sufficient; that is, they produce their own energy to operate and use the surplus generated to supply estates, sell to the grid, and possibly sell to villages and towns in the area (box 3.2).[18]

**FIGURE 3.2h:** ELECTRICITY INPUT IN THE OIL PALM VALUE CHAIN


- Electricity for pumping water and drip irrigation
- Electricity-powered irrigation uncommon in Sub-Saharan Africa

- Sterilization, stripping, digesting, and pressing used to extract oil extracted from the FFBs

- Refining of extracted crude oil
- Not necessarily nearby oil palm plantations

### BOX 3.2: PALM OIL AND POWER INTEGRATION IN UGANDA

One example of an integrated palm oil/power setup is Uganda's Bugala Power Station, a 1.5 MW biodiesel-fired thermal power plant located on Bugala Island on Lake Victoria. The power station is integrated with the palm oil processing plant owned by Bidco Oil Refineries Ltd., which also owns a 6,500 ha palm oil plantation on Bugala Island. The oil-processing factory generates heat through biomass incineration, used to supply superheated steam to help extract oil and also turn turbines and create electricity in the process. The electricity is used inside the factory, with any excess sold to neighboring towns.

**Dairy.** Dairy production systems can potentially create significant electricity demand in rural areas where there are commercial milk producers or cooperatives. The main source of rural electricity demand from dairy production is cold storage, and machines for electricity powered milking are also becoming more prevalent (figure 3.2i). Another potential source is machinery for processing milk-based products (e.g., butter, cheese, and evaporated milk). The value gain from electricity use results from reduced spoilage due to cold storage,[19] the ability to access urban markets, and the value added from processing milk products. For large-scale operations, the estimated power demand is about 0.61 kW per ha. Animal manure from dairy farms may also be used to generate electricity.

**Poultry.** Hatcheries are usually relatively large-scale commercial operations that require electricity input for a host of processes, including egg incubation and cleaning. For poultry (meat) production, processing plants use electricity to power conveyor belts, cooling and heating, and cutting (figure 3.2j). The value added from electricity use results from reduced spoilage, increased egg-laying productivity, higher labor productivity, value addition from processing, and ability to supply higher value urban markets. The estimated energy demand for commercial-scale broilers (meat) and layers (eggs) is 75 kW per ha each. A typical 1–2 ha operation would generate a demand of about 150 kW (300 kW if the two operations are co-located).

**Tea.** For the tea value chain, electricity demand is from irrigation and processing activities. Irrigation is mainly rainfed since most tea is grown in areas with abundant rainfall. Even so, there is a considerable potential

**FIGURE 3.2i:** ELECTRICITY INPUT IN THE DAIRY VALUE CHAIN

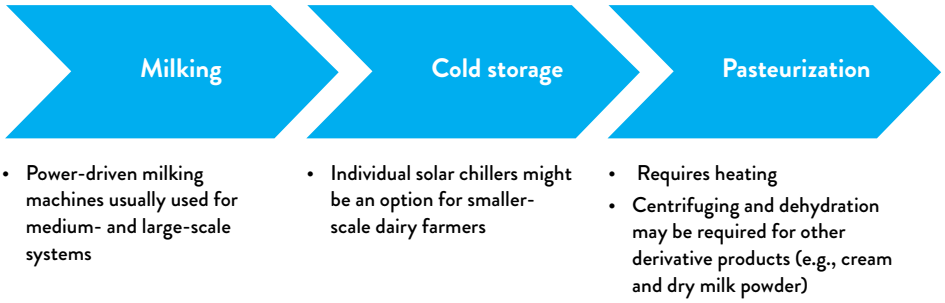



**FIGURE 3.2j:** ELECTRICITY INPUT IN THE POULTRY VALUE CHAIN

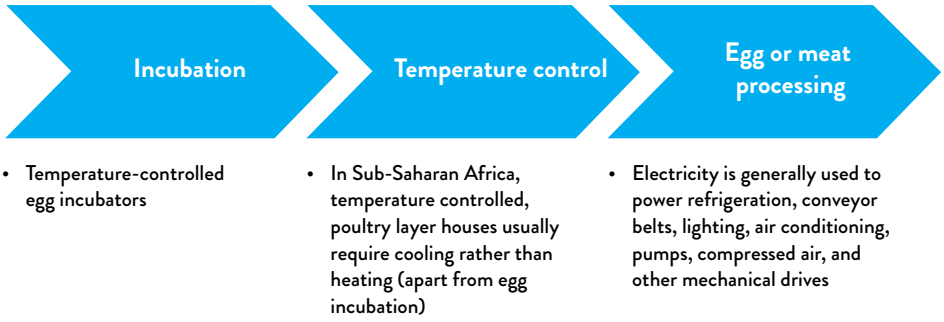


**FIGURE 3.2k:** ELECTRICITY INPUT IN THE TEA VALUE CHAIN

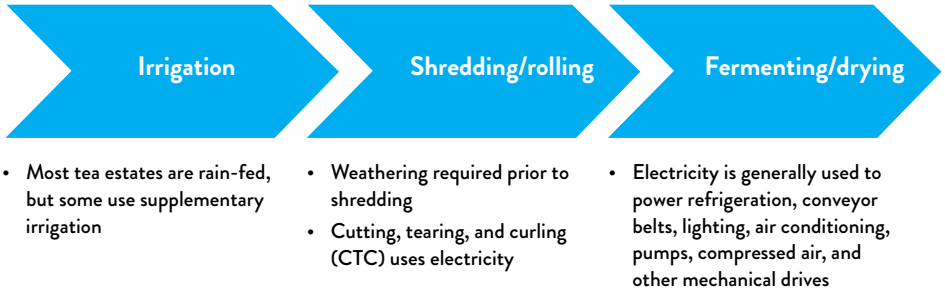
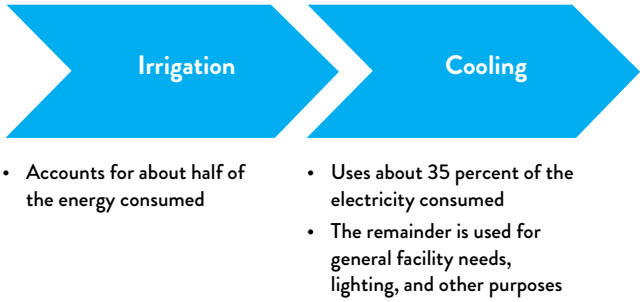



**FIGURE 3.2l:** ELECTRICITY INPUT IN THE FLORICULTURE (ROSES) VALUE CHAIN




value gain from irrigation (i.e., increased yields of up to 8 times from sprinkler irrigation and up to 16 times from drip irrigation) (figure 3.2k). Thus, the value gain from electricity use results from both increased yields in response to irrigation and the value addition from processing (including reduced transport and spoilage costs). In Sub-Saharan Africa, there is considerable potential for tea producers to gain from increasing yields and moving further up the processing value chain. In Kenya, 88 percent of tea production is exported raw in bulk; but in Rwanda and Uganda, processing is rising. Electricity demand from tea cultivation and processing is estimated at 1.91 kW per ha for large-scale plantations and 0.51 kW per ha for small-scale, rainfed facilities. For a 300 ha cultivated area, power demand is in a range of 150–575 kW, depending on the scale of cultivation and associated farming and post-harvest practices.

**Floriculture (roses).** In Sub-Saharan Africa, roses are cultivated mainly in large-scale greenhouses, and most power demand is from irrigation and cold storage (figure 3.2l). Electricity is usually sourced through diesel generation sets. All farms have on-site cold storage, and growing is done in temperature controlled environments. For large-scale production, power demand is estimated at 2.37 kW per ha, with irrigation accounting for nearly half of energy consumption; thus, a 300 ha cultivated area can be expected to have about 700 kW of power demand.

**Cotton (lint).** For cotton (lint) production, electricity powered irrigation is not prevalent. Rather, electric power is used mainly for seed crushing and ginning (figure 3.2m). Due to perishability, cotton ginning must be done soon after harvest. Gins are usually located near reliable power sources in rural and peri-urban towns. Moving ginning closer to farms would save on transport costs and possible

**FIGURE 3.2m:** ELECTRICITY INPUT IN THE COTTON (LINT) VALUE CHAIN

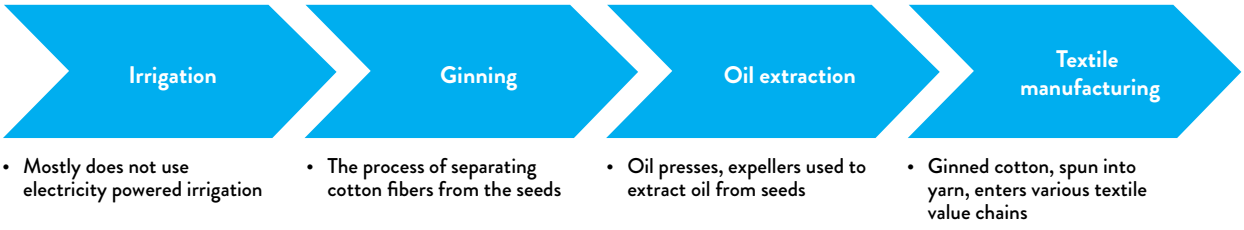


**TABLE 3.4:** POWER DEMAND FOR STANDARD 300 HA CULTIVATED AREA

| Agricultural Commodity | Per Unit Total Electricity Capacity (kW/ha) for Irrigation and Processing | | Electricity Capacity Required for 300 ha Cultivated Area (kW) | |
|---|---|---|---|---|
| | Small-scale | Large-scale | Small-scale | Large-scale |
| Maize | 0.77 | 1.17 | 230 | 350 |
| Rice | 0.03 | 1.04 | 9 | 312 |
| Wheat | 0.52 | 1.10 | 156 | 330 |
| Cassava[a] | 0.56 | | 168 | |
| Oilseed (soybean) | 0.64 | 1.04 | 192 | 312 |
| Horticulture (pineapple)[b] | | 0.75 | | 225 |
| Sugarcane | 1.00 | 1.81 | 300 | 543 |
| Oil palm[b] | | 0.02 | | 6 |
| Tea[c] | 0.51 | 1.91 | 153 | 573 |
| Cotton (lint)[b] | 0.03 | 0.03 | 9 | 9 |
| Floriculture (roses)[b] | | 2.37 | | 711 |
| Poultry[b] | | 75.00 | | 22,500 |
| Dairy[b] | | 0.61 | | 183 |

*Note:* Choice of the 300 ha benchmark reflects the amount of cultivated area that may constitute a typical project site. For example, this would amount to 300 households, each having 1 ha of landholdings. While this benchmark is somewhat arbitrary (i.e., project sites are likely to have a variety of crops under cultivation), it can be used to construct back-of-the-envelope estimates on electricity demand from the value chains presented.
a. Cassava is small-scale only.
b. Horticulture (pineapple), oil palm, cotton (lint), floriculture (roses), poultry, and dairy do not use electricity for small-scale operations or are only large-scale operations.
c. Small-scale tea cultivation uses rainfed irrigation.

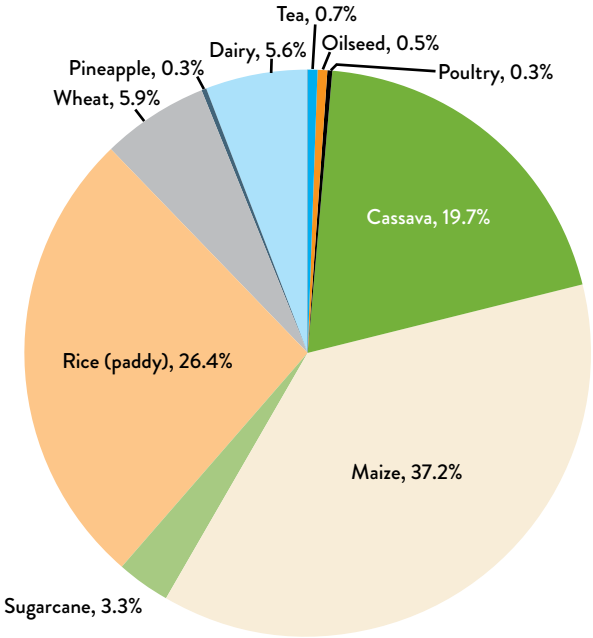
spoilage. Cottonseed crushing is done to produce cottonseed oil (used in some instances as a biofuel for vehicles) and livestock feed. The power demand from cotton cultivation and processing is estimated at 0.03 kW per ha for both large- and small-scale farming production. This implies that a 300 ha cultivated area will have about 9 kW in power demand.

For each of the 13 selected value chains, table 3.4 summarizes the estimated electricity demand for a 300 ha cultivated area and the per-hectare electricity demand estimates from irrigation and processing. The unit estimates show that per-hectare electricity demand is largest for poultry by far, followed by floriculture, tea, and sugarcane. The potential per-hectare demand for poultry (meat) is considerably higher because the process is much more intensive, using less land for a much larger yield. The higher per-hectare demand estimates for large-scale production mainly reflects the use of commercial-scale irrigation and the power input required to process large yields. The range of values for the 300 ha cultivated area is considerable. For small-scale production, potential electricity demand ranges from 9 kW for rice or cotton (lint) to 300 kW for sugarcane. For large-scale production, it ranges from 6 kW for oil palm to 711 kW for floriculture (roses); poultry is an outlier, at 22.5 MW. These estimates are useful for considering whether the economics of these values chains make them viable anchor loads for rural electrification.

Using the forecasted production for the 13 value chains presented in table 3.2, along with the constructed unit electricity demand for each commodity, a bottom-up estimate of the total increase in demand for electricity stemming from the selected value chains can be constructed. The calculations show that electricity demand could increase by 2 GW (from 3.9 GW in 2013 to 6 GW in 2030). This figure represents nearly half of the total potential increase in electricity demand from agriculture calculated for Sub-Saharan Africa in chapter 2 (4.2 GW).

To the extent that the value chains selected represent the best potential of the agriculture and agribusiness

**FIGURE 3.3:** POTENTIAL POWER DEMAND IN 2030 FROM PROCESSING FOR SMALL-SCALE AGRICULTURE, BY SELECTED VALUE CHAINS




*Note:* The underlying calculations assume concave production growth until 2030, based on historical average growth rates (2009–13), and 15 percent of the crop being irrigated and processed—no estimate available for floriculture

sectors in Sub-Saharan Africa, the estimated electricity demand provides a good indication of the possible electricity-agriculture synergies (figure 3.3). The required underlying assumption is the percentage of irrigated and processed production. Clearly, even by 2030, not all production is likely to be cultivated on irrigated land or processed using electricity driven machinery. With little detailed data available on irrigation and processing proportions by value chain, this study makes conservative assumptions for each of the value chains considered: only 15 percent of the land is assumed to be irrigated and 15 percent of crops are assumed to be processed.[20]

## ENDNOTES

1. Of course, all of these factors are correlated. A value chain catering to export markets would likely add more value to the primary product through many production and processing steps and use of greater modern inputs.
2. FAOSTAT 2013 (http://faostat3.fao.org).
3. FAOSTAT 2014 (http://faostat3.fao.org).
4. International Institute of Tropical Agriculture (IITA) (http://www.iia.org/maize).
5. FAOSTAT 2013 (http://faostat3.fao.org).
6. In Zambia, an abundance of water and access to cheap grid electricity have played a significant role in the adoption of large-scale irrigated farming systems.
7. Tea and coffee are Rwanda's most important exports (e.g., tea exports in 2013 totalled US$55 million); see FAOSTAT 2014 (http://faostat3.fao.org).
8. Production growth in Nigeria is driven by poultry-sector demand.
9. Estimates of ECA and Prorustica (2015).
10. For further analysis of commercial irrigated agriculture's potential, see case studies 1 and 3 (chapter 4).
11. The load from processing rainfed tea is just 0.6 kW per ha.
12. Floriculture may not demand a large load in absolute terms as estates are seldom larger than 50 ha (requiring less than 120 kW for production). Exceptions may be additional power requirements for staff housing (see case study 5, chapter 4).

13. Data for horticulture (pineapple) is missing and therefore not included.

14. A complementary analysis is the ongoing work in Latin America and the Caribbean on energizing agriculture; the study estimates energy demand for processing for selected value chains, and proposes energy efficiency options and associated costs (World Bank 2016b).

15. In India, this model has had some success through husk power systems.

16. Data on the electricity requirements of post-harvest activities (juicing, cooling, and canning) were unavailable.

17. An example is Del Monte's biogas plant in Kenya, which is based on pineapple residue.

18. The produced biomass consists of empty fruit bunches (EFBs), palm kernel shells, fibers, and possibly solids from decanters; in most cases, this biomass is used to boil water and generate (super-heated) steam.

19. According to the FAO, economic losses for the dairy sector in Kenya, Tanzania, and Uganda total up to US$56 million per year.

20. The assumption for the irrigated proportion of a crop is in the ballpark of the CAADP target of doubling the land under irrigation by 2030; considering that about 6 percent of cultivated area is currently irrigated (FAO 2005), irrigated production has disproportionately greater yield, and the selected value chains are the best performing crops in the region.

# Lessons from Ongoing Power-Agriculture Integration Projects

## CHAPTER 4

This chapter presents a suite of case studies on power-agriculture integration in several countries of Sub-Saharan Africa. All three countries covered—Tanzania, Zambia, and Kenya—show a high potential for on-farm and agro-processing activities to contribute toward regional and, in some cases, national power-sector development. These cases offer indicative analysis of specific project areas in terms of their potential and viability for furthering rural electrification.[1] The objective is to provide a point of reference for the potential of power-agriculture integration and to highlight some of the important issues to consider in trying to promote such an integration. Each case study project asks (i) whether the investment in expanding rural electrification is economically viable and (ii) under what conditions private-sector participation in electricity supply is feasible.

A standard cost-benefit analysis reveals that most of the projects analyzed are economically viable and are thus worth undertaking by governments.[2] The social and economic benefits generated as a result of rural electrification often outweigh the costs incurred and may justify well-designed subsidies to improve the financial viability of the project. Indeed, if the economic value of the grid extension exceeds the economic costs (due to positive externalities), an otherwise financially unviable project can be undertaken with subsidy financing to cover the shortfall.

In many cases, private-sector participation is desirable for developing and operating electricity supply as it can improve supply efficiency and reduce the financial and capacity burden on public-sector providers. Thus, when analyzing various supply options, it is instructive to consider their commercial viability in order to understand whether private-sector participation is viable and the amount of subsidy that may be required to attract private-sector operators and developers.

Another important consideration is the trade-off between affordability and cost recovery in setting electricity tariffs. While different regulatory environments afford different levels of flexibility in tariff setting for individual schemes, it is instructive to assess the tariff level that can optimally balance the cost recovery objective and affordability, in particular with respect to the anchor customer. The case studies aim to answer two key questions: (i) Up to what price is power affordable for agriculture activities? and (ii) Below what price is power uneconomic to supply?

Each case study is organized into four sections: (i) power demand (agriculture and residential/commercial), (ii) power supply options and commercial arrangements, (iii) financial viability, and (iv) economic viability. Annex D presents the maps corresponding to the case study project areas.

### CASE STUDY 1. TANZANIA: SUMBAWANGA AGRICULTURE CLUSTER

The Sumbawanga agriculture cluster is located in the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), on the country's western border (map D.1). SAGCOT focuses on the coordinated development of small and commercial agriculture, physical and market infrastructure along the transport corridor that runs from Dar es Salaam through to (and immediately across) the Zambian border at Tunduma.[3] Small-scale farmers are integrated into commercial value chains as outgrowers and benefit from the agglomeration economies that lower costs of access to shared infrastructure and inputs (e.g., electricity, roads, markets, labor, and extension services) (table 4.1).

**TABLE 4.1:** SUMBAWANGA AGRICULTURE CLUSTER AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Expansion of electricity supply to support the development of an agriculture cluster and surrounding households through main power grid extension. |
| **COMMODITIES** | Maize, sunflower, finger millet, paddy, and sorghum. |
| **DESCRIPTION** | Powered irrigation and residential demand are the main drivers of increased power demand.<br>Grid extension is a viable option given that the grid extension passes through the Sumbawanga cluster to connect other load centers beyond it. Forecasted size of the load and limited local generation potential make grid extension the most feasible option.<br>Powered irrigation is an important concentrated source of electricity demand. In its absence, greater dispersion of electricity demand over a wider area may reduce viability; thus, a greater cultivated area will be required to have large enough demand from processing. |
| **FINANCIAL VIABILITY** | As a stand-alone project, it is marginally financially unviable. A relatively small increase in electricity demand from agriculture or residential consumers would increase the financial viability of the grid extension. |
| **ECONOMIC VIABILITY** | Economic benefits would be significant (US$134 million) and justify the project. The benefits come mainly from household cost savings, small-scale irrigation, and increased commercial sale of produce. |

Still at a concept stage at the time of this writing, the Sumbawanga agriculture cluster aims to integrate small-scale and commercial farming, along with processing and storage facilities, transport, and logistics hubs, and improved 'last mile' infrastructure to farms and local communities over an area of 27,000 km$^2$. The cluster has strong natural characteristics for agricultural development, including proximity to Lake Tanganyika, good quality soils, and high rainfall. However, owing mainly to its geographical isolation, the area lacks both physical infrastructure (e.g., good roads, rail access, and power) and market infrastructure (e.g., integrated production and processing, traders, finance, and input suppliers).

Access to reliable and affordable electricity is critical to realize the cluster's potential. Currently, the Sumbawanga area benefits from a power capacity of 10.6 MW serving a population of just over 1 million people (table 4.2).[4] Where it is available, farmers and agribusinesses purchase power from TANESCO (including from its mini-grids). There is very little powered irrigation, but a few farmers use petrol and diesel-powered pumps which are inefficient in water use and costly to run. To date, there has been little penetration by solar pumps.

**TABLE 4.2:** SUMBAWANGA GEOGRAPHIC AND DEMOGRAPHIC FEATURES

| Feature | Value |
|---|---|
| Estimated population (2012) | 1,000,000 |
| Population growth rate (%) | 4.0 |
| Electricity connection rate (% of households) | 7.0 |

*Sources:* SAGCOT; ECA and Prorustica (2015).

With demographic and agricultural growth, forecasted demand for electricity is expected to far exceed the currently available capacity. To meet this future demand, the Government of Tanzania, through the Tanzania Electric Supply Company Limited (TANESCO), intends to extend a 220 kV line from Tunduma (on the Zambian border) to Sumbawanga (and beyond through Mpanda to Kigoma on Lake Tanganyika).

### *POWER DEMAND*

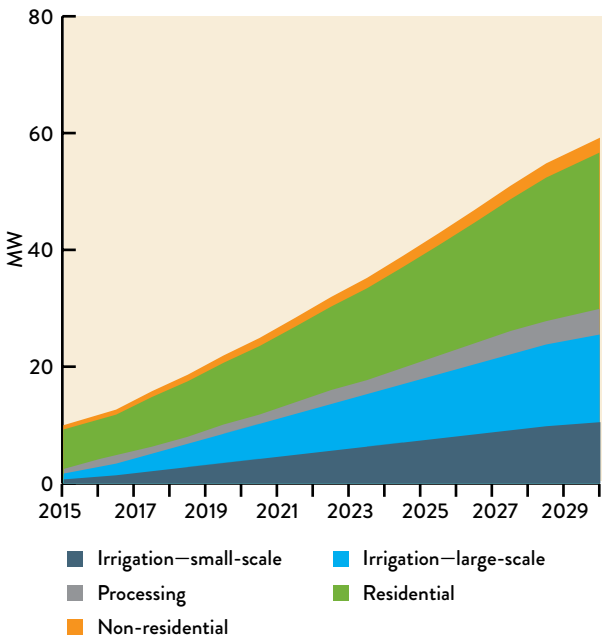
The annual power demand in the Sumbawanga region has the potential to increase to an estimated 60–70 MW by 2030. Irrigation and residential demand are the expected main drivers of load growth, with commercial and processing loads playing a relatively less significant role (figure 4.1).

**Agricultural demand**. The majority of growth in electricity demand from agriculture will come from developing the region's irrigation potential, roughly estimated at 50,000 ha.[5] Assuming 35,000 ha of this amount is dedicated to small-scale agriculture implies a total energy demand of roughly 25.5 MW by 2030 from both bulk water pumping and in-field irrigation. Newly irrigated land, higher quality inputs, crops switching, and knowledge sharing are expected to increase yields from 461,000 MT to 1.09 million MT by 2030 (table 4.3).

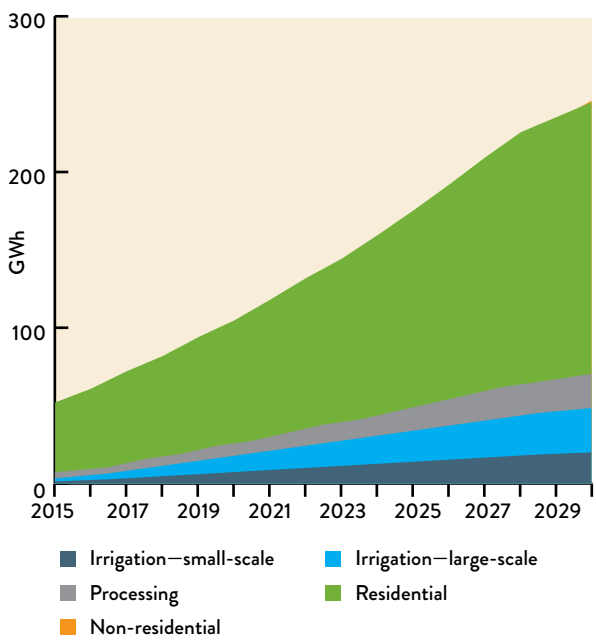
**FIGURE 4.1:** ESTIMATED PEAK LOAD AND ENERGY DEMAND, BY SECTOR

| Source of Demand | Power Capacity Demand (MW) | | Energy Demand (MWh/year) | |
|---|---|---|---|---|
| | 2012 | 2030 | 2012 | 2030 |
| Irrigation | 0.0 | 25.5 | 0 | 48,450 |
| Processing | 0.4 | 4.4 | 2,000 | 22,000 |
| Residential | 3.9 | 26.7 | 26,232 | 174,327 |
| Commercial | 0.2 | 2.6 | 85 | 1,056 |
| **Total** | **4.5** | **59.2** | **28,317** | **245,833** |

a. Peak load




b. Energy demand



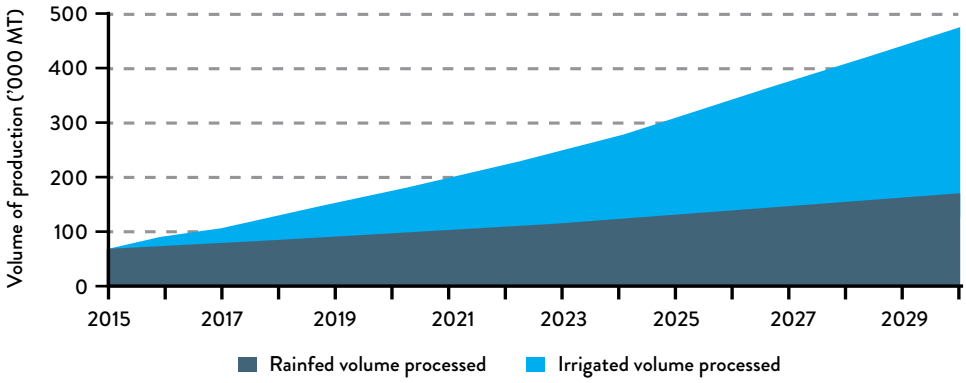

*Source:* ECA and Prorustica (2015).

**TABLE 4.3:** TOTAL POWER DEMAND FROM AGRICULTURE BY 2030

| Agriculture Activity | Power Capacity Demand (MW) | Hours of Operation/Year | Energy Demand (MWh/year) |
|---|---|---|---|
| Irrigation | 25.5[a] | 1,900 | 48,450 |
| Processing | 4.4[b] | 5,000 | 22,000 |
| **Total** | **29.9** | **6,900** | **70,450** |

*Sources:* SAGCOT; JICA; Rukwa District Council; WREM International; ECA and Prorustica (2015).
a. Based on a potential area of 50,000 ha under irrigation and an estimated power demand for irrigation of 0.65kW/ha (0.3kW/ha for small-scale farms and 1kW/ha for commercial farms).
b. Based on a processed production of 472,500 MT and an estimated 11 mills required (400 kW).

**FIGURE 4.2:** ESTIMATED VOLUME OF CROPS THAT MAY UTILIZE ELECTRICITY FOR PROCESSING




*Source:* ECA and Prorustica (2015).

The power demand for post-harvest processing will depend on the crops produced and the volume of production. Electricity demand is expected for post-harvest processing of crops (e.g., milling and oil extrusion) such as maize, paddy rice, beans, millet, sorghum and sunflower.[6] Greater electricity supply and better access to markets for farmers would boost the electrification rate of agro-processing activities. An estimated 40 percent of the current crop yield and an assumed 75 percent of the increased yield due to irrigation expansion will be processed by 2030. Together, this implies an estimated power demand of about 4.4 MW by 2030 (figure 4.2).

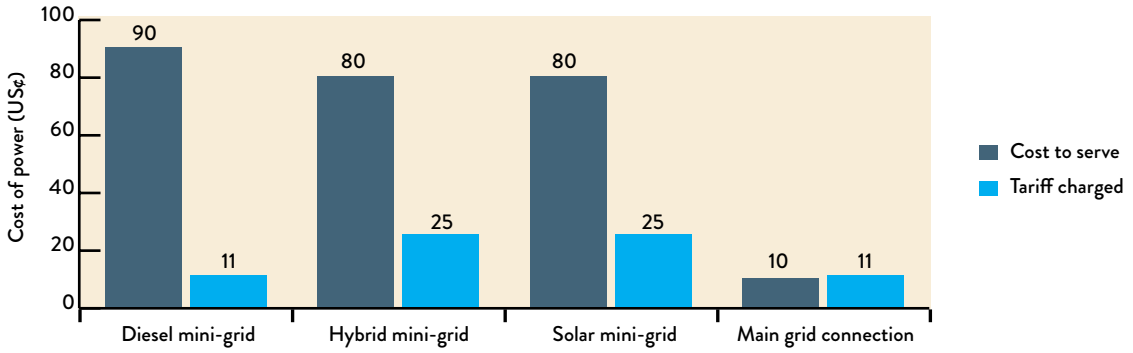
**Residential/commercial demand**. Based on the regional population growth rate of 4 percent, Rukwa's population is expected to reach 2 million by 2030, representing 400,000 households.[7] Considering the households' annual consumption and anticipating that their demand and consumption will likely evolve over time with the adoption of additional electric appliances, residential consumers will be the main driver of energy demand (table 4.4).

**TABLE 4.4:** RESIDENTIAL AND COMMERCIAL DATA TO CALCULATE POWER DEMAND

| Residential | 2012 | 2030 |
|---|---|---|
| Population | 1,000,000 | 2,025,817 |
| Population growth | | 0.04 |
| People per household | 5 | 5 |
| No. of households | 200,000 | 405,163 |
| Household connection rate | 7% | 20% |
| Households connected | 14,000 | 81,033 |
| Per household peak consumption (kW) | 0.28 | 0.33 |
| Per household energy consumption (kWh/month/HH)[a] | 156 | 179 |
| Total peak (MW) | 3.9 | 26.7 |
| **Total energy consumption (MWh)** | **26,232** | **174,327** |
| **Commercial** | | |
| No. of customers | 6 | 75 |
| Consumption peak (kW) | 34 | 34 |
| Consumption energy (kWh) | 14,085 | 14,085 |
| Total peak (MW) | 0.2 | 2.6 |
| **Total energy consumption (MWh)** | **85** | **1,056** |

*Sources:* SAGCOT; ECA and Prorustica (2015).
a. Assumes a daily demand of 5.13 kWh per household.

**FIGURE 4.3:** COMPARATIVE COST OF POWER SUPPLY OPTIONS IN SUMBAWANGA




*Source:* ECA and Prorustica (2015).

Commercial demand from current loads averages 85 kWh per month across six TANESCO customers, with a peak load of 0.21 MW. Should per-customer demand levels remain as observed when electricity was supplied in other areas of comparable size (e.g., Morogoro, Iringa, and Mwanza), the number of customers would increase to 75; thus, annual power consumption would rise to 1,056 MWh by 2030, and power-capacity demand would reach 2.6 MW (table 4.4).

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

The analysis considered various options for additional power capacity to meet projected demand. Localized generation potential from diesel, solar, hybrid, hydro, and bagasse/biomass was considered, along with the option to extend the national grid. Preliminary analysis showed insufficient potential for hydro- and biomass-based generation, so these options were ruled out.

The option to expand mini-grid capacity, based on diesel, solar or a hybrid of the two, was also found unviable for the region. The cost of a diesel-based mini-grid is estimated at US¢90 per kWh, which is much higher than the cost of extending the national grid.[8] Even if hybrid solutions enable the lowering of generation costs (i.e., at US¢80 per kWh), they are still much more costly than grid extension. Finally, solar mini-grids are not adapted to the load profiles of agro-processing and irrigation activities, which would imply expensive investments in storage and backups (figure 4.3).

The least-cost method is thus estimated to be an extension of the national grid. This would allow for more efficient generation capacity sizing for demand on the system at more competitive costs. In deciding how much transmission capacity to invest in, it is more feasible to install adequate capacity to meet future projected demand rather than upgrade capacity in response to increase in demand. The subsection below describes a scenario where sufficient capacity is directly incorporated into a project's initial design.

### *FINANCIAL VIABILITY: EXTENSION OF MAIN GRID FROM MBEYA TO SUMBAWANGA AND RUKWA*

The financial viability of grid extension is estimated from the perspective of TANESCO. To supply activities in Sumbawanga, both grid extension and generation capacity expansion are required. However, generation capacity expansion is on a national least-cost basis; the focus here is on the viability of the transmission and distribution network development (table 4.5).

The costs associated with provision of grid electricity to Sumbawanga consist of the cost of electricity generation and transmission and distribution costs (expansion and operation). The corresponding revenues would be those of electricity sales at the national tariff level (table 4.6).

**TABLE 4.5:** ESTIMATED CAPITAL AND OPERATING COSTS FOR TRANSMISSION AND DISTRIBUTION EXPANSION

| Grid Extension Assumptions | Distance (km) | Cost (thousand US$/km) | Total Cost (million US$) | Operating Expense Assumption (%) | AC Losses (%) |
|---|---|---|---|---|---|
| 11 kV | 200 | 15 | 3.3 | 3 | 4.6 |
| 33 kV | 200 | 35 | 7.7 | 3 | 4.6 |
| 220 kV | 350 | 138 | 53.1 | 3 | 4.6 |
| **Subtotal (million $)** | | | **64.1** | | |
| Present value (million $) | | | 61.2 | 18.3 | 3.8 |
| **Total (million $)** | | | | | **83.4** |

*Sources:* Ministry of Energy and Minerals (MEM), Power System Master Plan; ECA and Prorustica (2015).

**TABLE 4.6:** ESTIMATED POWER CONSUMPTION AND TRANSMISSION AND DISTRIBUTION TARIFF REQUIREMENT

| Variable | Value |
|---|---|
| Cost (million US$) | 83.36 |
| Estimated consumption (MWh) | 1.2 million |
| **Transmission and distribution, tariff requirement (US¢/kWh)** | **6.9** |

*Source:* ECA and Prorustica (2015).

**TABLE 4.7:** FINANCIAL PRESENT VALUE OF GRID EXTENSION

| Variable | Value (million US$) |
|---|---|
| Revenue, based on TANESCO tariff | 167.34 |
| Transmission costs | (83.36) |
| Generation costs | (89.83) |
| **Effective project shortfall** | **(5.85)** |
| **Internal rate of return (%)** | **12** |

*Sources:* ECA and Prorustica (2015); World Bank.
*Note:* Assumes a consumption of 1.2 million MWh over 20 years. The generation cost is based on cost for the upcoming Kiwira coal plant, at US¢ 7.5 per kWh (TANESCO 2012 Power System Master Plan Update, May 2013). The coal plant near Mbeya is expected to be completed by 2020. The average retail tariff is about US¢ 14 per kWh.

At the assumed 10 percent average cost of capital, the project is marginally financially unviable as a stand-alone project (table 4.7). However, TANESCO's ability to attract financing on more favorable terms or greater revenues from electricity demand, would improve the project's financial viability. On the other hand, a larger proportion of consumers paying lower lifeline tariffs, lower electricity demand, and/or higher costs would further reduce the financial viability of the investment in grid extension.

### *ECONOMIC VIABILITY*

Analysis of the project's economic viability adds social net benefits to the financial net benefits accruing to the developer (TANESCO). Thus, the economic analysis includes benefits accruing to newly connected households, benefits from improvement in agricultural yields, market access, and jobs creation (table 4.8).

The economic analysis shows that the economic benefits significantly outweigh the associated costs. In fact, the benefits accruing to the households alone are sufficient to justify the investment in grid extension.

**TABLE 4.8:** ECONOMIC COSTS AND BENEFITS OF SUMBAWANGA GRID EXTENSION

| Economic Cost/Benefit | Beneficiaries (number) | Present Value of Cost/Benefit (million US$) |
|---|---|---|
| Net financial costs | | (5.85) |
| Household cost savings[a] | 52,671 households by 2030 | 42.00 |
| Small-scale irrigation | 35,000 farmers (1 ha each) | 34.50 |
| Margin uplift from market access | All small-scale farmers | 26.80 |
| Import substitution | Tanzania broadly | 8.52 |
| No. of jobs created by electrifying the agriculture field | 3,750 | 24.00 |
| No. of jobs created by electrifying the town | 550 | 4.20 |
| **Economic net present value** | | **134.14** |

*Source:* ECA and Prorustica (2015).
a. These are the additional households that are assumed to be connected from the grid extension project—over and above the baseline (w/o project). Additional household benefits may include better health outcomes from reduced fuel use, better educational outcomes for school going children, women's time savings, and better nutrition.

## CASE STUDY 2. TANZANIA: MWENGA MINI-HYDRO MINI-GRID

The 4 MW Mwenga mini-hydro mini-grid project is located in Tanzania's Southern Highlands, close to the Mufindi Tea and Coffee Company (MTC) (map D.2). The project is operated by the Rift Valley Energy (RVE), a 100 percent subsidiary of the Rift Valley Corporation, which also owns MTC. The project came about as a result of MTC's need to supplement electricity from the main grid to ensure access to a reliable source of uninterrupted power. Cofinanced by the European Union (EU) and the Rural Energy Agency (REA), the project was developed as an independent power producer (IPP) to supply power to the main grid, local tea industry, and surrounding rural communities. The project was the first green-field development under the Small Power Purchase Agreement (SPPA) scheme. The SPPA was signed with TANESCO in 2009, and the plant was commissioned in 2012 (table 4.9). RVE owns and operates the distribution network connecting roughly 20 villages and relies on a mobile phone based pre-paid vending system for electricity billing.

Notwithstanding its long and complex development process, Mwenga is considered Tanzania's most successful private mini-grid development project. For the tea factory, the mini-grid is an opportunity to switch from grid-based power to a more reliable supply produced by renewables. Although the project was initially designed to supply only the MTC, having power lines extending from

**TABLE 4.9:** MWENGA MINI-HYDRO MINI-GRID AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | A 4 MW hydro mini-grid connected to the main grid. Main local anchor load is the Mufindi Tea Estates and Coffee Limited; 2,600 households connected in the surrounding communities. |
| **COMMODITIES** | Coffee, tea. |
| **LESSONS LEARNED** | The tea estate is the main anchor load of the grid connected mini-grid. Given the seasonality in tea processing operations, the peak load demand more than doubles during the summer season. This impacts the choice of power supply arrangement.<br>Excess supply was sold to the grid, which helps mitigate the impact of seasonality. While residential consumers are numerous, their power demand is not high enough, at least initially, to mitigate the impact of a seasonal anchor load. |
| **FINANCIAL VIABILITY** | The project's financial viability depends critically on the ability to sell excess power to the main grid. Despite financial viability, capital subsidies were provided for the project to keep local electricity tariffs low. |
| **ECONOMIC VIABILITY** | Economic benefits are positive (US$9 million) and come from households' energy cost savings, reduced reliance on diesel backup for the tea estate, and job creation from new electrified businesses. |

the hydro plant through nearby villages facilitated the connection of 2,600 households, as well as other community facilities. Beyond enhancing electricity access, the project has replaced the use of diesel and kerosene with sustainable hydropower among neighboring communities.

### *POWER DEMAND*

Demand for power from the Mwenga mini-grid comes from the main grid (TANESCO), commercial and community users, agriculture, and residential customers. As local demand is expected to grow, the sales to the grid are expected to decline. Local demand growth is expected to be led by the informal and semi-formal agriculture and forestry sectors, highlighting the significant economic development potential of the project.

**Agricultural demand**. In terms of power for agriculture, MTC mainly requires electricity for processing. Specifically, electricity is used to power large motors, fans, and vibrating sieves (used to cut to length the leaves, and wither, dry, sort, and grade the tea). The tea factory's peak load averages about 700 kW (with a summer peak of 900 kW and a winter peak of 400 kW), with an annual power consumption of 2,880 MWh.[9]

**Community and commercial demand**. In addition to supplying agro-processing activities, the Mwenga mini-grid project specifically targets facilities such as schools and clinics, as well as small commercial businesses, thereby improving electricity access for productive uses. According to RVE, annual power consumption for community and commercial users is estimated at 2,988 MWh.

**Residential demand**. Residential customers comprise the majority of the customer base; however, most residential customers have very low demand and pay lifeline tariffs. Annual demand from the 2,600 customers is estimated at just 936 MWh (table 4.10).

All excess power from the mini-grid (about 80 percent of generated power) is sold to TANESCO, in accordance with its SPPA and feed-in tariff (FiT) arrangement; these have been instrumental in guaranteeing offtake and have helped justify development of a scheme of its size, thus benefiting from economies of scale. Selling power only to local consumers would not have justified the project in terms of its scale or commercial viability.

### *POWER SUPPLY OPTIONS, COMMERCIAL ARRANGEMENTS, AND FINANCIAL ANALYSIS*

Proximity to the Mwenga River enabled the tea plant to access a renewable source of power, with sufficient volume and head to develop a 4 MW run-of-the-river, mini-hydro plant. The project is owned and operated by MTC's sister company and both are held by the RVC parent company.

The project was developed as a private-public partnership and partly funded through public funds, including elements of grant and concessional loans from the EU and REA.[10] The use of concessional funds was necessary to reduce the tariff burden on local electricity customers. While the electricity regulator allowed RVE to set cost-reflective tariffs, as per Tanzania's SPP framework, fairness and affordability concerns led to the tariff being set in line with the tariff on the main grid. The regulator has allowed recent adjustments in the tariff, which is currently TZS 100 per kWh up to 75 per kWh (equivalent to US¢6.25 per kWh under the pre-devaluation exchange rate). However, since 80 percent of the generated power is sold to TANESCO under the SPPA and FiT, the viability of Mwenga's hydro plant is not relying on the profitability of selling electricity to local communities.

**TABLE 4.10:** ESTIMATED POWER DEMAND FROM MWENGA MINI-HYDRO PLANT

| Customer Group | Connections (current) | Forecast Connections (2030) | Approved Tariff (TZS/kWh) | Total Monthly Usage (all customers) (MWh) |
|---|---|---|---|---|
| Households | 2,600 | 5,600 | 100 | 78 |
| Commercial | 374 | 557 | 205 | 114 |
| Public/community services | 468 | 668 | 205 | 135 |
| Tea estate | 1 | 1 | Uncertain | 240 |
| TANESCO | 1 | 1 | 189 | 1,922 |
| **Total monthly usage (MWh)** | | | | **2,489** |

*Source:* RVE.

**TABLE 4.11:** ECONOMIC COSTS AND BENEFITS OF MWENGA MINI-HYDRO PLANT

| Economic Cost/Benefit | Benefits | Present Value of Cost/Benefit (million US$) |
|---|---|---|
| Net financial costs | | 0.0 |
| Development subsidies received by project | | (7.1) |
| Household cost savings (no. of households)[a] | 5,600 | 6.4 |
| Tea company savings from reduced diesel backup requirement (hours/year)[b] | 288 | 1.4 |
| Jobs created by electrifying villages (no.)[c] | 1,120 | 8.6 |
| **Economic NPV** | | **9.3** |

*Source:* ECA and Prorustica (2015).
a. Households are assumed to save $14 per month from access to electricity; b. diesel backup requirement is assumed to be 10% of the total power consumption; c. it is assumed that 65 percent of the businesses will each create 1.5 jobs. Each job created is valued at the average expected salary: $1500/year.

### *FINANCIAL ANALYSIS*

The financial analysis considers the Mwenga mini-hydro project from the perspective of the revenues and costs incurred by the owner, RVE. However, information on revenue, operating cost, and capital expenditures was confidential and thus not available. Despite this limitation, discussions with the operator allow us to make certain salient points:

- Tanzania's SPP framework allows RVE to charge a tariff that should ensure full cost-recovery, including a return on capital, even if all capital is at commercial rates, and adjusted for any subsidies received.
- In practice, social concerns implied that the tariff was set equal to the main grid. Thus, in order to accommodate this lower tariff, subsidies for capital expenditure were sought to reduce the effective cost recovery, such that it aligned with the tariff.

Given that RVE, a private-sector company, continues to operate the facility, one can assume that the project at least breaks even financially.

### *ECONOMIC ANALYSIS*

Economic net present value (NPV) is estimated at about US$9 million, based on a 10 percent discount rate over the assumed project life till 2030 (table 4.11). Benefits accrue from household energy cost saving, reduced reliance on diesel backup for the tea estate, and job creation from newly electrified businesses.

## **CASE STUDY 3.** ZAMBIA: MKUSHI FARMING BLOCK

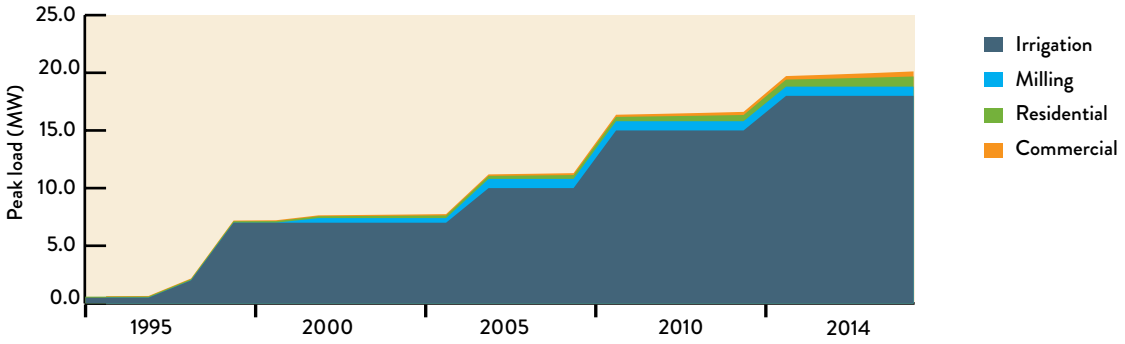
The Mkushi farming block project is located in Zambia's Central Province (300 km northeast of Lusaka) and stretches over 176,000 ha of land (map D.3). The Mkushi farming block is one of Sub-Saharan Africa's largest multi-farmer commercial farming areas outside South Africa. Mkushi produces the largest share of Zambia's wheat (40 percent) and soybean (21 percent), and is its sixth largest maize producer. Other export crops grown in the area include tobacco, soya, vegetables, and coffee (Chu 2013). Mkushi experiences distinct dry winter seasons (May to October) and wet summer seasons (November to April). Irrigation is thus critical for growing winter crops, especially wheat (table 4.12).

Electrification of the Mkushi farming block occurred over time, given the evolving demand and difficulty of raising the necessary capital. Mkushi was first connected to the grid in 1996 through a 33 kV line. This effort was financed by the government and a group of 20 farmers who contributed US$10,000 per km (50 percent of the total cost), which was the policy of the Zambia Electricity Supply Corporation (ZESCO) at the time. However, unreliable power supply due to inadequate feeder capacity meant that farmers had to continue to use backup diesel generators for irrigation. A subsequent grid expansion was undertaken in 2000, followed by a third in 2005 to connect all farmers and many households in the area. Expansion of the national grid into the area has enabled the area under irrigation to expand to about 18,000 ha

**TABLE 4.12:** MKUSHI FARMING BLOCK AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Extending a transmission line into a farming area with significant agricultural potential. |
| **COMMODITIES** | Wheat, soybean, tobacco, soya, vegetables, coffee. |
| **DESCRIPTION** | Irrigation counts for more than 90 percent of total power demand. Given their interest in the project, farmers accepted to contribute to capital costs. The grid extension enables a significant increase in household connection rates (from 2 percent in 1995 to 7 percent in 2014). However, more than 30,000 households remain unconnected to the main grid. |
| **FINANCIAL VIABILITY** | From a purely financial perspective and as a stand-alone project, grid extension to Mkushi was not profitable for the utility. However, in order to expand access to new farmers coming into the area, sharing of capital costs was an appropriate and successful approach to project financing. |
| **ECONOMIC VIABILITY** | Thanks to household energy cost savings, increased yields from irrigation on small-scale farms, and job creation, the project's economic NPV was positive (US$46 million). |

**FIGURE 4.4:** TOTAL PEAK LOAD IN MKUSHI, 1995–2014




*Source:* ECA and Prorustica (2015).

and led to the subsequent development of milling activities.

Out of 150 commercial farms hosted on the farming block in 2014, 80 farms have developed irrigation schemes to enable wheat production in winter and to supplement summer crops. The availability of water and the connection to the national grid, supported by ZESCO and the Zambia National Farmers Union, were central to development of these irrigation schemes and processing facilities.

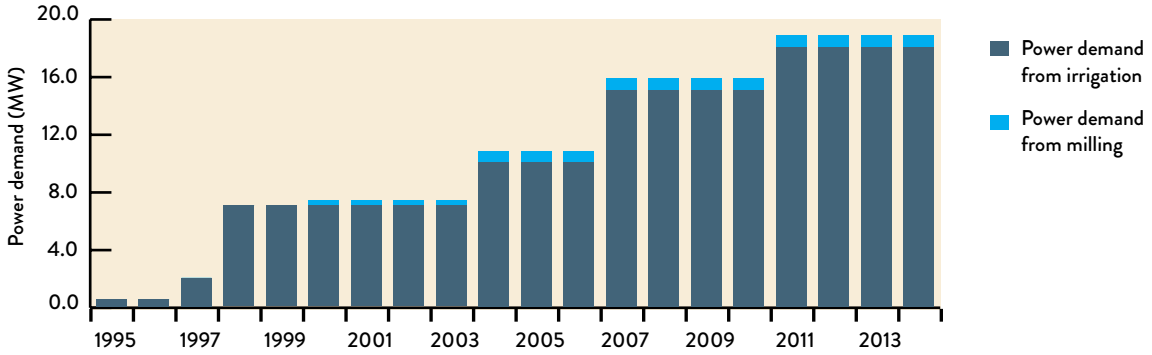
### *POWER DEMAND*

Between 1995 and 2014, overall peak load in Mkushi (from agriculture, residential, and commercial consumption) increased from 0.6 MW to 20.1 MW. Over that period, irrigation accounted for more than 89 percent of total power demand (figure 4.4).

**Agricultural demand**. Among agriculture activities, irrigation has been the main driver of power demand, with milling accounting for only a small share of total agricultural power demand. Power demand for irrigation grew from 0.5 MW to 18 MW between 1995 and 2014, with a yearly consumption of 34,200 MWh in 2014 (figure 4.5).[11] In addition to development of irrigation schemes, two mills were installed in the area following arrival of the grid. Power demand for milling was estimated at 800 kW,[12] for a consumption of 4,000 MWh (table 4.13).

**Residential/commercial demand**. Between 1995 and 2014, household connection rates grew from 2 percent to 7 percent, with the corresponding number of connected households increasing from 362 to 2,516 (table 4.14). Over the same period, power demand from residential and commercial customers increased from 0.13 MW to 1.32 MW, with households representing 67 percent.

**FIGURE 4.5:** POWER DEMAND FROM IRRIGATION AND MILLING IN MKUSHI, 1995–2014




*Source:* ECA and Prorustica (2015).

**TABLE 4.13:** POWER REQUIREMENTS FOR IRRIGATION AND MILLING IN THE MKUSHI FARM BLOCK

| Agricultural Activity | Requirement | 1995 | 2000 | 2005 | 2014 |
|---|---|---|---|---|---|
| Irrigation | Irrigated land area (ha) | 500 | 7,000 | 10,000 | 18,000 |
| | Power demand (MW) | 0.5 | 7 | 10 | 18 |
| | Power consumption (MWh) | 950 | 13,300 | 19,000 | 34,200 |
| Milling | Power demand (MW) | 0 | 0.4 | 0.8 | 0.8 |
| | Power consumption (MWh) | 0 | 2,000 | 4,000 | 4,000 |

*Sources:* Ministry of Agriculture; ECA and Prorustica (2015).

**TABLE 4.14:** ELECTRIFICATION RATES AND POWER LOAD OF HOUSEHOLDS IN MKUSHI

| Consumer Type | 1995 | 2000 | 2005 | 2014 |
|---|---|---|---|---|
| **Residential** | | | | |
| Households (no.) | 18,092 | 21,488 | 25,521 | 34,782 |
| Household connection rate (%) | 2 | 3 | 4 | 7 |
| Households connected (no.) | 362 | 603 | 1,004 | 2,516 |
| Power demand per household (kW) | 0.24 | 0.26 | 0.29 | 0.35 |
| Peak demand (MW) | 0.09 | 0.16 | 0.29 | 0.88 |
| Total consumption (MWh)[a] | 222 | 408 | 751 | 2,247 |
| **Commercial** | | | | |
| Total demand (MW) | 0.04 | 0.08 | 0.15 | 0.44 |
| Total consumption (MWh)[b] | 190 | 349 | 642 | 1,921 |

*Sources:* Ministry of Agriculture; Zambia Census 2010; ECA and Prorustica (2015).
a. Assuming household energy consumption of 75 kWh/month. b. Assuming that commercial consumers operate 14 hour per day 6 days a week.

Total power demand in 2014 was 20.1 MW, with corresponding annual energy demand of 42,368 MWh. Of this amount, 18 MW came from irrigation, 0.8 MW from processing, 0.88 MW from households, and 0.44 MW from commercial customers.

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

Zambia has one of the lowest electricity tariffs in Sub-Saharan Africa owing to fully depreciated hydropower dominating the generation mix. This implies considerable benefits from reliable electricity supply to farmers who previously relied on backup diesel generation. This, along with the relative proximity of the main grid, ruled out a mini-grid option.

As described above, to extend the grid to Mkushi, farmers were initially required to apply to ZESCO, specifying their peak demand load. They were required to cofinance up to 50 percent of the cost of the line extension and pay for the transformers.

### *FINANCIAL ANALYSIS*

Given the cofinancing arrangement, the financial analysis of extending the grid to the Mkushi farming block was analyzed from the perspective of both ZESCO and a representative farmer newly settled in the area. From the utility's standpoint, even after capital costs were partially paid for by customers, the revenue generated from the grid extension remained below the costs incurred. The financial NPV was estimated at US$8.9 million, mainly because of the very low electricity tariffs (table 4.15).

The farmer was required to invest in half of the line extension for 20 km (US$10,000 per km), a transformer ($50,000), and irrigation capital ($2,500 per ha).

**TABLE 4.15:** FINANCIAL ANALYSIS OF MKUSHI FARMING BLOCK FROM THE PERSPECTIVE OF THE UTILITY AND A REPRESENTATIVE FARMER

| Factor | Thousands of US$ | | | |
|---|---|---|---|---|
| | 1995 | 2000 | 2005 | 2014 |
| **UTILITY** | | | | |
| Tariff revenue | 14 | 161 | 244 | 424 |
| Capital costs | 1,300 | 10,000 | 5,045 | 0 |
| Operating costs | 39 | 339 | 342 | 342 |
| Net benefits | −1,325 | −10,178 | −5,142 | 82 |
| **Financial NPV**[a] | **−8,89** | | | |
| **REPRESENTATIVE FARMER (500 ha of irrigated land)**[b] | | | | |
| **Wheat** | | | | |
| Extra profit | 60 | | | |
| **Maize** | | | | |
| Extra production because of irrigation (MT) | 1,250 | | | |
| Extra profit | 199 | | | |
| Total extra revenue from irrigation | 259 | | | |
| Capital costs | 1,500[c] | | | |
| Electricity consumption from irrigation (MWh) | 950 | | | |
| Cost of electricity | 33 | | | |
| Net benefits | −1,275 | 226 | 226 | 226 |
| **Financial NPV** | **523** | | | |
| **IRR (%)** | **17** | | | |

*Note:* The financial NPV is calculated over a 20-year project life starting from the initial investment (1995–2014).
a. The estimated negative NPV is over 20 years. Given the magnitude of the stream of revenues relative to the costs, considering 30-year project life will not make the project financially viable from the utility's perspective.
b. Irrigated production of 500 ha of wheat in winter and 500 ha of maize in summer.
c. For a 20km connection expansion.

However, after deducting the cost of electricity and capital costs from the extra profit generated by irrigation, the financial NPV for a representative farmer was positive ($522,653), showing that the representative farmer benefited from increased yields, owing to supplementary summer irrigation, as well as irrigated winter cropping (table 4.15).

### *ECONOMIC ANALYSIS*

From an economy-wide perspective, between 1995 and 2014, the largest benefits from access to grid electricity accrued from savings on electricity expenditure, displacement of imports due to increased wheat and maize yields and job creation (table 4.16). The economic NPV is estimated at about US$46 million, which justifies the 130-km grid extension (table 4.17).

The project faced various implementation barriers. Since it was not financially profitable for the utility, the shortfall had to be covered by subsidies. Other issues that had to be overcome included lack of access to capital for project financing, lack of coordination between farmers, and insufficient grid capacity to provide reliable power supply. Moreover, ZESCO and farmers competed over water availability and use; the utility wanted water for its hydropower plant, while the farmers wanted it to irrigate their lands.

**TABLE 4.16:** NET SOCIAL BENEFITS OF GRID EXTENSION, MKUSHI

| Factor | 1995 | 2000 | 2005 | 2014 |
|---|---|---|---|---|
| **Savings on Energy Consumption** | | | | |
| Electrification rate (%) | 2 | 3 | 4 | 7 |
| Households electrified (no.) | 362 | 603 | 1,004 | 2,516 |
| Savings from grid electrification per household ($/month) | 10 | | | |
| Total savings on energy consumption (million $) | 0.04 | 0.07 | 0.12 | 0.30 |
| **Import Savings** | | | | |
| **Wheat** | | | | |
| Irrigation area (ha) | 500 | 7,000 | 10,000 | 18,000 |
| Production (MT) | 3,000 | 42,000 | 60,000 | 108,000 |
| Import substitution value of wheat (million $)[a] | 0.21 | 2.94 | 4.20 | 7.56 |
| **Maize** | | | | |
| Production without irrigation (MT) | 2,750 | 38,500 | 55,000 | 99,000 |
| Production with large-scale irrigation (MT) | 4,000 | 56,000 | 80,000 | 144,000 |
| Benefit of locally grown production over imports (million $)[a] | 0.11 | 1.51 | 2.15 | 3.87 |
| **Revenue from Job Creation** | | | | |
| Job creation from area under irrigation | 143 | 2,008 | 2,868 | 5,163 |
| Extra income from irrigation (million $) | 0.22 | 3.01 | 4.30 | 7.74 |
| **Present Value of Social Benefits over the Period 1995–2014 (million $)** | | | | **65.47** |

*Note:* Assumes a 10 percent discount rate over a 20-year project life.
a. Import substitution is valued at the difference between farm gate price in Zambia and import price.

**TABLE 4.17:** ECONOMIC COSTS AND BENEFITS OF GRID EXTENSION, MKUSHI

| Factor | Value (million US$) |
|---|---|
| Financial NPV of utility | −8.90 |
| Present value of capital cost contributions from farmers | –10.83 |
| Present value of social benefits | 65.47 |
| **Economic NPV** | **45.74** |

*Source:* ECA and Prorustica (2015).

## CASE STUDY 4. ZAMBIA: MWOMBOSHI IRRIGATION DEVELOPMENT AND SUPPORT PROJECT

The Mwomboshi Irrigation Development and Support Project (IDSP) is situated along the banks of the Mwomboshi river in Zambia's Central Province (World Bank 2011b) (map D.4). The IDSP aims to support irrigation development in order to increase agricultural yields and incomes in the area. The project also includes support for complementary infrastructure, including roads and electricity. Irrigation will be developed from water storage (via construction of small- and medium-sized dams) and transport to individual farms (table 4.18). An extension of the grid to and within the site will be funded under the project and handed over to the utility to operate (ZESCO).

Direct beneficiaries of the IDSP are the area's 3,700 inhabitants, along with small-scale and commercial farmers. Commercial farms are located along the southern bank of the river, while small-scale farming is mainly on the north side. The connection to electricity is critical to enable irrigation development, which creates greater opportunities to increase incomes.

Covering 100,000 ha, on-farm irrigation development can be categorized into four tiers: (1) small parcels of less than 1 ha each, which utilize flood irrigation systems; (2) individual farms with parcels in a range of 1–5 ha, which utilize spraying irrigation schemes; (3) plots larger than 60 ha each, cultivated by a community or commercial farm that uses modern irrigation systems (e.g., center pivots); and (4) large parcels cultivated by large-scale commercial farmers that are supplied water through a bulk-water storage facility (figure 4.6).

### *POWER DEMAND*

Currently, Mwomboshi's access to grid electricity is low. The northern bank of the river has no electricity supply. Among small-scale farmers who are not connected to electric power, only a small portion uses petrol or diesel pumps for irrigation purposes. Along the southern bank, electricity from the national grid is used to power staff housing, crop irrigation, processing, and other small-load activities (e.g., offices, water pumping, and tea drying).

Planning for sufficient capacity to consider future loads from expanded farming activities includes upgrading the current 11 kV line to a 33 kV line with a 30 km grid extension to the north side of the river, which would provide all farmers with electricity. By 2031, it is estimated that the aggregated peak load from agriculture, households, and commercial activities will reach 6.4 MW, representing an 18.5 percent average annual increase from the 2016 peak load (figure 4.7a). Driven by irrigation, power consumption is forecasted to reach up to 15,000 MWh by 2031 (figure 4.7b).

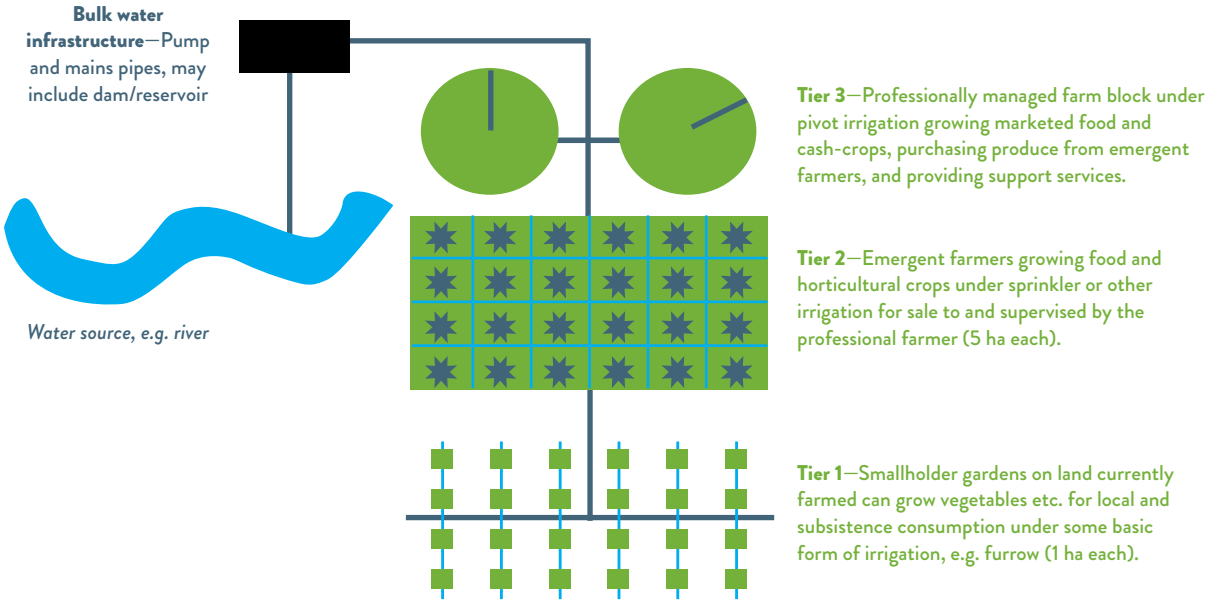
**Agriculture demand (irrigation)**. In addition to the 439 ha currently underirrigated in Mwomboshi, the IDSP plans to add an extra 3,200 ha, distributed between small-scale and commercial-scale farms. This will allow for the release of bulk water supplied from a water storage dam through pump stations for irrigation schemes. The project will become the area's major power load, requiring 2 MW to supply the southern bank of the dam and 3.1 MW for the north side. Once the first pumps are installed, the power consumption of pumping stations is forecasted to rise from 872 MWh in 2016 to about 10,000 MWh by 2031 (table 4.19).

**Agriculture demand (milling)**. Development of the region's wheat milling capacity will evolve along with the increasing yields expected from irrigation. Total energy

**TABLE 4.18:** MWOMBOSHI IRRIGATION DEVELOPMENT AND SUPPORT PROJECT AT A GLANCE

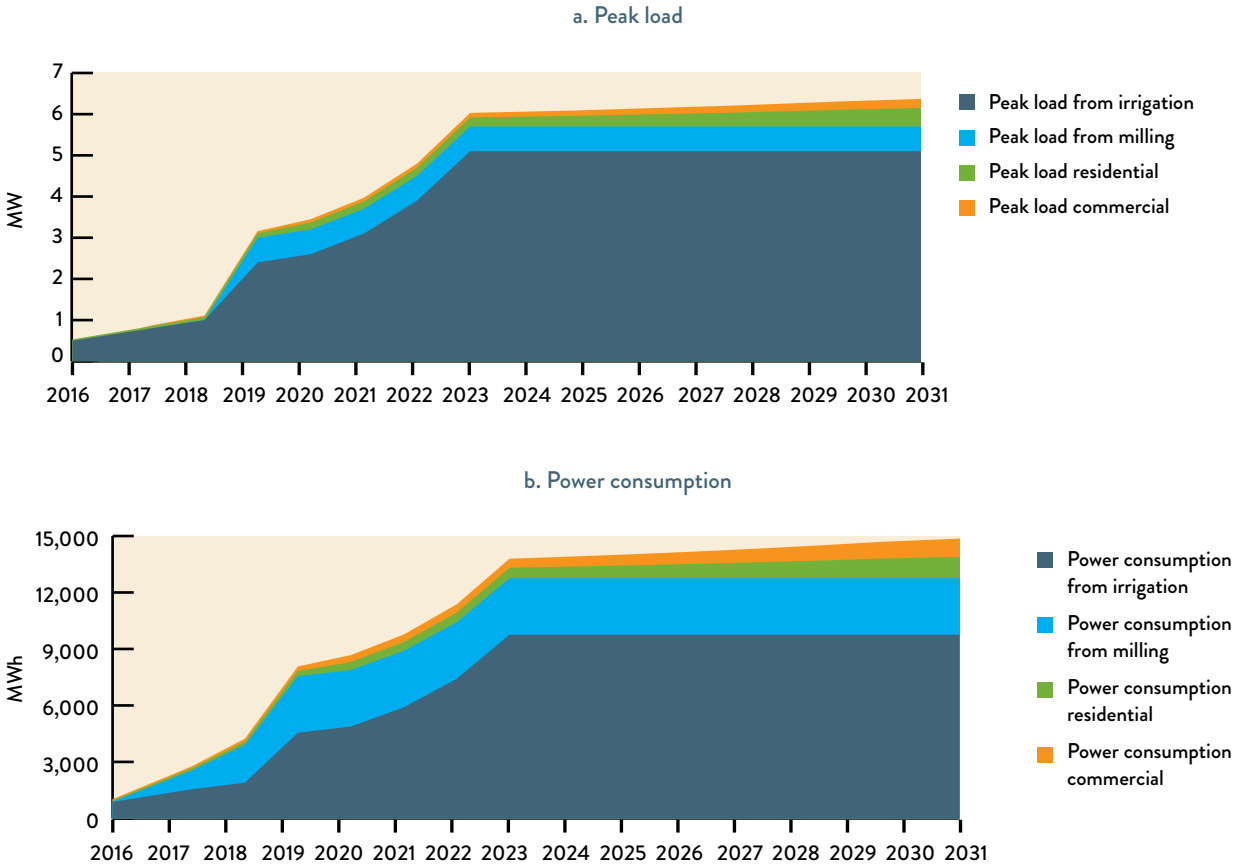
| | |
|---|---|
| **PROJECT OVERVIEW** | Grid upgrade and extension to support irrigation development and household electrification. |
| **COMMODITIES** | Tobacco, wheat, poultry, maize, sunflower, horticulture (tomatoes, onions, bananas). |
| **DESCRIPTION** | Electrification is mainly driven by irrigation of small-scale and commercial farming, leading to crop diversification and increased yields. The project also targets near universal residential access in the area by 2031.<br>Proximity of the existing grid and power needs meant grid extension was the only option considered viable. |
| **FINANCIAL VIABILITY** | Positive financial NPV estimated at US$1.1 million. |
| **ECONOMIC VIABILITY** | Positive economic NPV estimated at US$2.0 million for the power line extension, mainly from greater irrigated tomato and maize production. |

**FIGURE 4.6:** MWOMBOSHI IDSP PLOT SITES DEVELOPED FOR SMALL-SCALE FARMERS




*Source:* World Bank 2011b.

**FIGURE 4.7:** MWOMBOSHI PEAK LOAD AND POWER CONSUMPTION FORECAST




*Source:* ECA and Prorustica (2015).

**TABLE 4.19:** IRRIGATION POWER REQUIREMENTS IN MWOMBOSHI, ZAMBIA

| Irrigation Requirement | 2016 | 2031 |
|---|---|---|
| Power demand (MW) | 0.5 | 5.1 |
| Power consumption (MWh) | 872 | 9,757 |

*Source:* ECA and Prorustica (2015).

**TABLE 4.20:** MILLING POWER REQUIREMENTS IN MWOMBOSHI, ZAMBIA

| Milling Requirement | 2016 | 2031 |
|---|---|---|
| Power demand (MW) | 0 | 0.6 |
| Power consumption (MWh) | 0 | 3,000 |

*Source:* ECA and Prorustica (2015).
*Note:* Assumes a mill operates 5,000 hours per year (16 hours a day, 6 days per week)/mill size: 200 kW.

demand from milling is expected to be significantly lower than that from irrigation (table 4.20). The first mill is expected to be installed when total production from commercial farmers and the marketed portion (80 percent) of small-scale production reaches 20,000 MT. The plan is to add an additional mill for every 20,000 MT of extra production.

**Residential/commercial demand**. The IDSP plans to increase household connections from 15 percent (2014) to 97 percent (2031). Based on a per-household power demand estimate, peak load would increase by 2 percent a year as the household load evolves over time. Total residential peak load should therefore increase from 0.03 MW in 2016 to 0.45 MW by 2031, while electricity consumption over this period should rise from 78 MWh to 1,137 MWh. Nonresidential demand, led by commercial activities, is assumed at half of residential power consumption. Its peak consumption is thus expected to increase from 0.015 MW in 2016 to 0.22 MW by 2031 (figure 4.8).

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

Since the southern part of the area is already connected to the national grid, no other supply option has been considered for improving power availability. To do so, the Ministry of Agriculture and Cooperatives and ZESCO will sign a Memorandum of Understanding (MOU) framing responsibilities for the construction and maintenance of the new power line. ZESCO will own the assets and be responsible for line maintenance after construction and will recover its operating costs through tariff revenues.

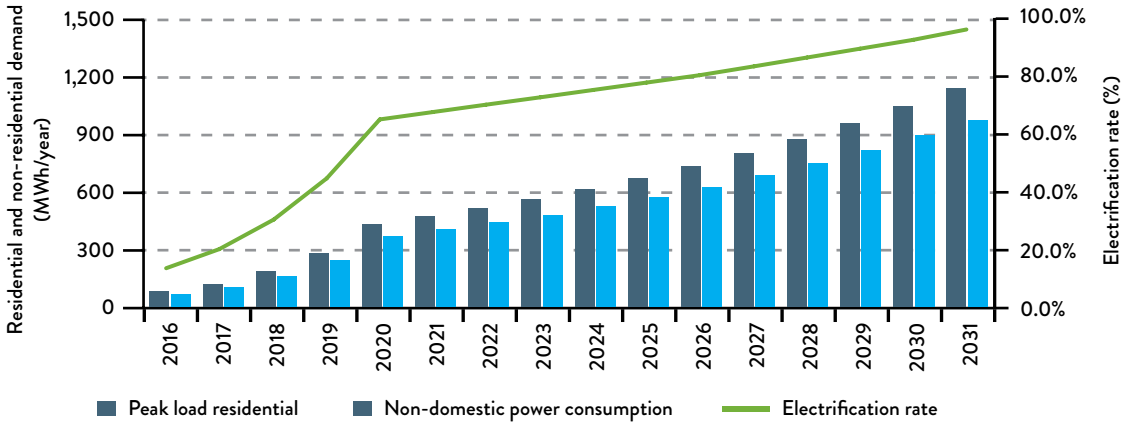
### *FINANCIAL ANALYSIS*

From ZESCO's perspective, the grid upgrade project in Mwomboshi is financially viable, with a positive NPV of US$1.1 million. Given the current average electricity tariff of US¢3.5 per kWh and the estimated level of demand, the utility's revenues are calculated as the additional revenues received by the utility due to the project (table 4.21).

### *ECONOMIC ANALYSIS*

The IDSP is estimated to generate positive net benefits with a NPV of US$2.0 million. The economic benefits are driven largely by the increase in yields of irrigated tomato,

**FIGURE 4.8:** RESIDENTIAL AND COMMERCIAL DEMAND, ELECTRIFICATION RATE 2016–2031




*Source:* ECA and Prorustica (2015).

**TABLE 4.21:** FINANCIAL ANALYSIS, MWOMBOSHI

| Factor | Assumption |
|---|---|
| Electricity tariff (US¢/kWh) | 3.5 |
| Transmission tariff (US¢/kWh) | 1.0 |
| Transmission OpEx (% of CapEx) | 3 |
| Cost of capital (%) | 10 |
| Line expansion (km) | 30 |
| Cost of grid expansion ($/km) | 30,000 |
| Total cost of transformers ($) | 175,000 |
| **Net Present Value (NPV) Calculations 2016–2031** | |
| Present value of revenues (million $) | 2.4 |
| Capital costs (million $) | 1.1 |
| Present value of operating costs (million $) | 0.3 |
| **Financial NPV (million $)** | **1.1** |
| **IRR (%)** | **20** |

*Source:* ECA and Prorustica (2015).

wheat, and maize production (table 4.22). Irrigation will allow farmers to increase production through better yields and crop diversification. The electrification savings to farmers from using diesel pumps and switching to electrified irrigation schemes will be minor since only a small number of farmers are currently using these irrigation solutions. As a result, the total present value of social benefits for the entire project is estimated at US$34 million. However, as these benefits are the result of the whole irrigation project in Mwomboshi (not only the electrification component), the share of the cost of power line extension is used as a benchmark to allocate the share of benefits accruing to the electrification investments in the project area.

## CASE STUDY 5. KENYA: OSERIAN FLOWERS AND GEOTHERMAL POWER

The Oserian Development Company Limited (ODCL) operates a 216 ha flower farm—including roses, carnations, and statice—situated in Kenya's Nakuru County (map D.5). The farm produces and exports 380 million stems annually, and employs 4,600 people (table 4.23).

ODCL is a pioneer business in its use of heat from geothermal wells for internal power generation and consumption; its 50 ha Geothermal Rose Project is the largest of its kind. In addition to geothermal heat, a 3.2 MW generator is dedicated to powering the farm's operations and distribution within its estate. Although the company is connected to the main grid and purchases electricity from the utility, it can generate power at a lower cost. To increase output by 0.4 MW, a planned upgrade of the generation plant aims to provide power to both industrial activities and some 2,000 households.

### *POWER DEMAND*

Currently, ODCL's power demand is 3.2 MW, with 13 MWh in annual consumption. Seventy percent of the company's total energy consumption is for industrial use—mainly heating, ventilation, air conditioning (HVAC), refrigeration, irrigation (pumping, drip irrigation, and spraying), and lighting. Except for heating directly supplied by steam, many other industrial processes (e.g., ventilation, refrigeration, and irrigation) require electricity.

Part of the power generated by ODCL is distributed within the company's estate to the community (e.g., staff housing, schools, and clinics) and sister companies (e.g., tourism lodge). Currently, 2,000 households are connected to electricity through a mix of power from ODCL's own power generation (95 percent) and utility power (5 percent). However, 2,000 other households within the estate remain without an electricity connection. ODCL is planning an increase in power generation by improving generation efficiency (via installation of a partial condenser). The improvement in efficiency is expected to increase generating capacity by 0.4 MW. The expansion project seeks to supply these additional households for basic electricity uses (e.g., lighting and mobile phone charging) and to power such facilities as schools

**TABLE 4.22:** ECONOMIC COSTS AND BENEFITS OF THE IDSP PROJECT, MWOMBOSHI

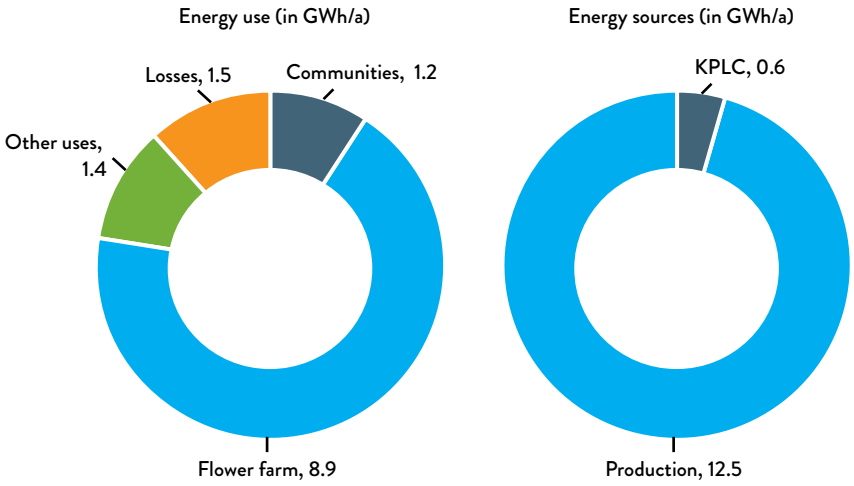
| Benefit | 2016 | 2019 | 2031 |
|---|---|---|---|
| **Revenue from job creation**[a] | | | |
| Jobs resulting from the project | – | 313 | 313 |
| **Present value of increase in employees' income ($ million)** | **3.4** | | |
| **Increase in profit revenue** | | | |
| *Small-scale (MT)* | | | |
| Tomato production with project | 5,000 | 57,833 | 57,833 |
| Maize production with project | 1,000 | 6,403 | 6,403 |
| Wheat production with project | – | 3,602 | 3,602 |
| **Present value of profit of extra production ($ million)** | **20.5** | | |
| *Commercial (MT)* | | | |
| Wheat production with project | 2,634 | 12,240 | 12,240 |
| Maize production with project | 3,512 | 16,320 | 16,320 |
| **Present value of profit of extra production ($ million)** | **3.5** | | |
| **Savings from import substitution** | | | |
| **Present value of wheat and maize import substitution savings ($ million)** | **6.7** | | |
| **Savings from household electrification** | | | |
| Electrification rate (%) | 15 | 46 | 97 |
| Electrified households without project | 93 | 101 | 144 |
| Electrified households with project | 93 | 283 | 598 |
| **Present value of household electrification savings ($ million)** | **0.2** | | |
| **Total present value of economic benefits ($ million)** | **34.0** | | |
| Financial NPV of utility ($ million) | 1.1 | | |
| Share of line upgrade project cost to total IDSP project cost (%)[a] | 2.6 | | |
| Net social benefits ($ million) | 0.9 | | |
| **Economic NPV ($ million)** | **2.0** | | |

*Source:* ECA and Prorustica (2015).
*Note:* Assumes that present values are over the 15-year period (2016–31).
a. Because the project has multiple complementary investments, it is hard to disentangle the benefits accruing to the power line extension without a simplifying assumption; it is thus assumed that the accrual of benefits to electricity versus other investments is in the same proportion as the accrual of costs.

**TABLE 4.23:** OSERIAN FLOWERS AND GEOTHERMAL POWER PROJECT AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Expansion of the estate geothermal generating capacity and its distribution network to power the farm's operations and distribution within the estate (staff housing, community facilities, and sister companies). |
| **COMMODITIES** | Floriculture. |
| **DESCRIPTION** | ODCL's captive power generates 95 percent of its requirements internally. Industrial use (heating, ventilation, irrigation, and lighting) represents 70 percent of the company's total energy consumption. Since no power is exported to the grid or sold beyond the estate, ODCL has a license from the Energy Regulatory Commission for captive power generation and distribution. |
| **FINANCIAL VIABILITY** | With a positive financial NPV, the planned expansion project of 0.4 MW and electrification of 2,000 households is financially viable. |
| **ECONOMIC VIABILITY** | Positive economic benefits estimated at US$2.5 million. The main economic benefit is based on increased household electrification and, as a result, the savings are due to lower energy consumption costs (e.g., less use of kerosene and no more payment for cell-phone charging services and disposable batteries). |

**FIGURE 4.9:** POWER USES AND SOURCES AT ODCL




*Source:* ODCL.

and a clinic. The limited increase in capacity implies that monthly household consumption may be constrained; however, households willing to upgrade may get individual connections through the state-owned utility, Kenya Power and Lighting Company (KPLC) (figure 4.9).

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

ODCL's captive power generates 95 percent of its requirements. Power is generated from a farm-operated plant, and steam is bought from the Kenya Electricity Generating Company (KenGen) under a 15-year purchase agreement. Since no power is exported to the grid or sold beyond the estate, ODCL has a license from the Energy Regulatory Commission for captive power generation and distribution. ODCL supplies power to staff workers within the estate using a mix of geothermal generation and the main grid supply. Households consume low levels of energy and are not metered individually, and KPLC bills ODCL rather than individual households. Over the years, ODCL has developed a skilled, in-house engineering team dedicated to geothermal power generation.

To meet unmet power demand and offset electricity purchased from the utility, an investment of US$1 million is planned for expanding geothermal plant capacity up to 3.6 MW (figure 4.10). An additional $0.2 million will be required to finance the distribution network extension. ODCL is considering charging electricity customers a cost-reflective tariff, but this would require an additional $0.2 million investment in individual meters.

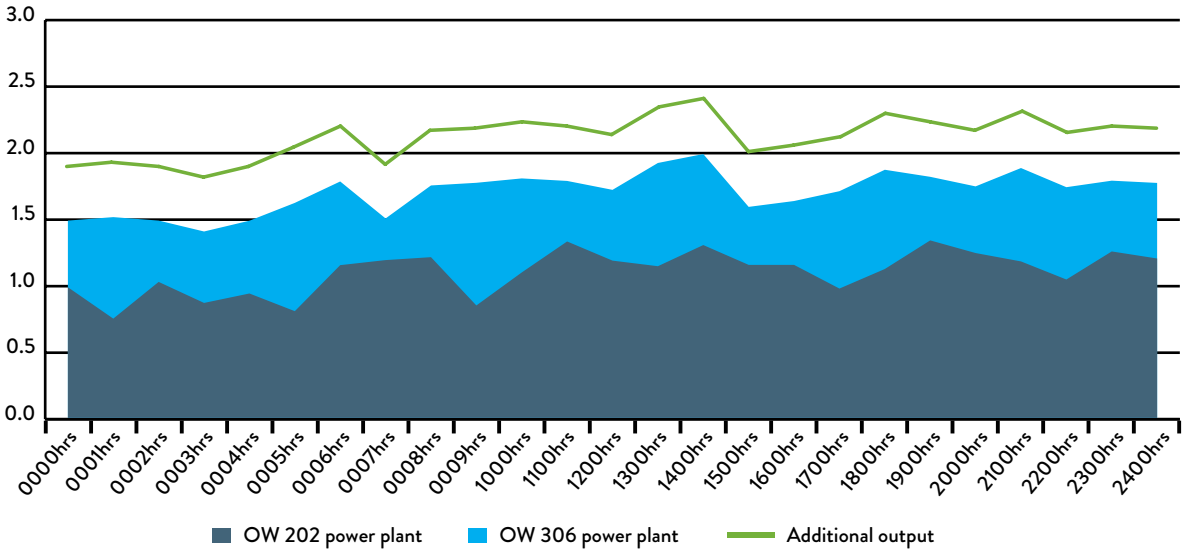
After this generation expansion, it is expected that the plant will generate an additional 2,500 MWh per year. This will include 600 MWh to offset electricity bought from KPLC, another 600 MWh to supply the local population that does not yet have access to power, and the remaining 1,300 MWh to cover ODCL industrial processes (figure 4.11).

### *FINANCIAL VIABILITY*

The planned expansion project of 0.4 MW and electrification of 2,000 households is marginally financially viable, with a positive financial NPV of US$3,742. The costs incurred for generation and distribution expansion and operation are slightly more than offset by the revenue from cost reduction in electricity purchased from KPLC. An investment of US$1.2 million is required for expansion of generation (partial condenser) and the distribution network (conductors, transformer, and switchgear). Also, operating cost is not expected to increase as the expansion will not consume additional resources (e.g., the same volume of purchased steam). In fact, the increased output will lower the per-unit cost from US¢6 per kWh to US¢5 per kWh. The operating cost will therefore amount to $125,000 (table 4.24).

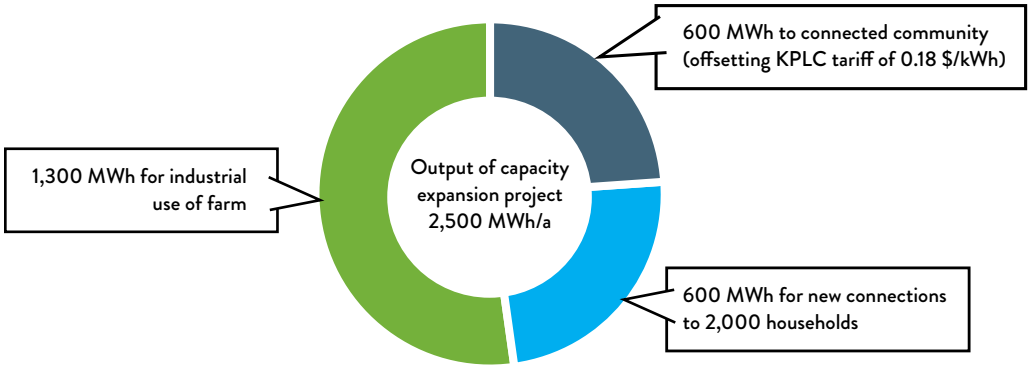
In comparison, the savings from the reduced purchases from KPLC amount to $342,000. Staff households are to be supplied electricity free of charge. Charging households cost-reflective tariffs would incur additional costs due to metering and billing. Considering these costs in the analysis shows that, in order to break even, a cost-recovery tariff of US¢8 per kWh would be required.

**FIGURE 4.10:** OUTPUT OF ODCL'S POWER PLANTS AND EXPECTED INCREASED OUTPUT




*Source:* ODCL.

**FIGURE 4.11:** ELECTRICITY OUTPUT OF CAPACITY EXPANSION PROJECT AND INTENDED USES




*Source:* ECA and Prorustica (2015).

**TABLE 4.24:** FINANCIAL ANALYSIS, ODCL

| Item | US$ Amount |
|---|---|
| Revenues | 342,000 |
| Power generation Opex costs | 125,000[a] |
| Capex costs | 1,200,000[b] |
| Margin | –983,000 |
| Discount rate (%) | 10 |
| **Financial NPV ($ amount)** | **3,742** |

*Source:* ECA and Prorustica (2015).
a. Assumes a cost per kWh of $0.05.
b. Assumes $1 million for distribution and $200,000 for metering.

### *ECONOMIC ANALYSIS*

The expansion project constitutes a relatively small portion of the estate's electricity use; most electricity is used for irrigation and refrigeration. The main economic benefit from the expansion project is thus from increased household electrification and, as a result, the savings due to lower energy consumption costs (e.g., less kerosene use and no more payment for cell-phone charging services and disposable batteries). An electricity connection is estimated to save households US$11 per month, implying

$2.5 million in total net economic benefit (NPV) over the life of the project. No significant impact is expected in terms of job creation or commercial development.

## CASE STUDY 6. KENYA TEA DEVELOPMENT AGENCY HOLDINGS: MINI-HYDRO MINI-GRIDS

This case study analyses the mini-hydro based tea factory electrification project of the Kenya Tea Development Agency (KTDA). The agency is planning the implementation of several small-scale (≤ 15 MW) run-of-the river hydropower projects at various locations in Kenya to serve a number of tea factories under its management (map D.6).

KTDA is the single largest producer and exporter of tea in Kenya. The company was created in 2000, subsequent to privatization of the Kenya Tea Development Authority. KTDA is the holding company of a number of subsidiaries owned by small-scale tea companies. The agency currently manages 63 factories in Kenya's small-scale tea subsector. Currently, its network covers about half a million small-scale farmers, with each tea factory owned by 5,000–10,000 tea farmers (table 4.25).

KTDA Power Company Limited, a subsidiary of KTDA, is charged with consolidation, investment, and management of energy initiatives undertaken by tea factories managed by KTDA. Notably, KTDA Power Company supports the development of hydropower projects in the small-scale tea subsector aimed at reducing factory operating costs, improving power supply reliability, and diversifying tea farmers' revenue sources. The power generated from these schemes will be used primarily in the tea factories, with the surplus sold to KPLC under a power purchase agreement (PPA). KTDA is in the process of setting up several small hydropower projects for its tea factories. One hydropower plant has been operational in the Imenti tea factory since 2010; an additional 17 projects are in the pipeline, ranging from 0.5 MW to 9 MW, eight of which are at an advanced stage of development, with feasibility studies completed.

### *POWER DEMAND*

Considering the near-term pipeline, along with the operational Imenti plant, the total installed capacity is 24.4 MW. About 40 percent of power generated will be used primarily for the tea factories' self-consumption, supplying mainly tea industrial processes. The remaining 58 percent of output will be sold to KPLC under a PPA and feed-in-tariff (FiT) scheme. Farmers will benefit from the electricity supplied to the factories that they partially own, but residential electricity connections will only be provided through KPLC, and not directly though KTDA. Approximately 187,500 small-scale farmers, representing 25 tea factories, will benefit from these power projects to run their farming activities. Currently, 70 percent of neighboring households (i.e., more than 130,000 farmers) lack access to electricity.

**TABLE 4.25:** KENYA TEA DEVELOPMENT AGENCY HOLDINGS: MINI-HYDRO MINI-GRIDS AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Development of hydropower plants powering tea factories and staff housing, and selling surplus power to the grid. |
| **COMMODITIES** | Tea. |
| **DESCRIPTION** | The operational power plant and eight projects have a total installed capacity of 24.4 MW. About 187,500 small-scale farmers, representing 25 tea factories, will benefit from these power projects to run their farming activities.<br>Mini-hydro plants provide a more reliable power supply to tea factories at lower cost and avoid the need for backup generators. |
| **FINANCIAL VIABILITY** | Evaluation of a sample project (North Mathioya) shows that the project is financially viable, with a NPV of US$3.3 million. Revenues accrue from the sale of power to the grid and cost savings by tea factories. |
| **ECONOMIC VIABILITY** | The same sample project is evaluated as economically viable, with a NPV of US$10 million. Direct and indirect impacts on rural electrification include the following: electrification of staff housing, reduced connection costs for surrounding households, development of stand-alone home systems. About 30,000 households will benefit from electricity connections. |

### *POWER SUPPLY OPTIONS*

The KTDA tea factories have two feasible supply options for meeting their power requirements: (i) purchase from the main utility at the retail tariff or (ii) self-generate electricity through the planned hydropower projects. Grid-supplied electricity is often unreliable, with frequent outages and voltage fluctuations. The need for a reliable power supply for tea operations requires investment in backup diesel generation, which adds to the overall cost of electricity. Where feasible, a captive mini-hydro generation plant, with the ability to sell excess power to the main grid, is an attractive option both financially and in terms of increased reliability.

In terms of commercial arrangements, KTDA Power Company leads the project development cycle (e.g., permitting acquisition, securing land, and raising capital) and forms special purpose vehicles (SPVs) in the form of regional power companies for each project (e.g., North Mathioya Power). The factory farmers served by the mini-hydro plant are shareholders, and raise 35 percent of the investment cost as equity from deductions of farmers' tea revenues. Electricity to residential consumers in the area will be provided through KPLC and not directly through the project.

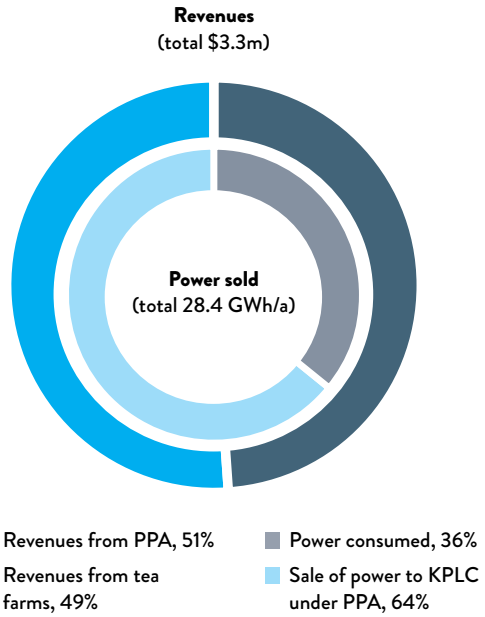
### *FINANCIAL ANALYSIS*

The financial analysis focuses on the North Mathioya (5.6 MW) hydropower project from the perspective of the SPV owners. Project revenues derive from the sale of electricity to the grid at the FiT.[13] The remaining electricity sold to tea factories is valued at the avoided cost of grid plus diesel backup electricity at US¢16 per kWh (figure 4.12).[14]

The costs include the capital and annual operating expenditures of the generation plant incurred by the SPV, at US$22.5 million and $165,800, respectively. Comparing the present value of the stream of revenues and costs, the project is estimated to be financially viable, with a NPV of $3.3 million (at 10 percent cost of capital) and an IRR of 13 percent.

Although the project does not include household or community electrification, except for factory staff housing, a simplified financial analysis shows that such activity would be financially unviable without subsidies. Despite the relatively high margin between household retail rates (US¢20 per kWh) and the PPA rate (US¢9 per kWh), distribution and retail would require an additional capital expenditure of US$15 million and administrative expenses of about $1 million per year, as well as pressure to reduce tariffs along with KPLC's national rates. Given these assumptions, subsidies for both capital expenditure and operating expenses would be required.

**FIGURE 4.12:** KTDA'S NORTH MATHIOYA HYDROPOWER PROJECT: FINANCIAL BENEFITS AND POWER SOLD




*Source:* ECA and Prorustica (2015).

### *ECONOMIC ANALYSIS*

Although KTDA power projects are not involved in the retail sale of electricity to neighboring communities, they have several direct and indirect impacts on rural electrification. First, they provide electricity to staff housing, which represents an average of 60 households per factory. Second, they may facilitate grid access for the surrounding households by reducing connection costs. Third, these areas will be targeted by a pilot project—led by the KTDA subsidiary, Greenland Fedha (microfinance institution), and the KTDA Foundation—which aims to finance solar home systems (SHSs) for farmers and support their grid connections.

The estimate of economic benefits is based on facilitating households' access to electricity connections. Tea factory activities remain unchanged, although they gain access to a more reliable, cheaper source of power supply. Approximately 30,000 households will benefit from electricity connections, which will offset their expenditure on traditional or more expensive forms of energy.

The project will facilitate grid connection by connecting the generation facility. Costs are estimated at US$500 per grid connection, with a monthly electricity bill of $3 per household. Also, the above-mentioned SHS scheme in place for farmers will further increase connections,[15] with an average household savings of $11 per month.[16] Thus, development of the North Mathioya hydropower project will provide households net economic benefits; the project's NPV is $6.7 million, implying $10 million in total economic NPV.[17]

## KEY CONCLUSIONS FROM THE CASE STUDIES

The six case studies discussed in this chapter offer varied contexts for power-agriculture integration. Each is unique in terms of the type of anchor load and country setting; thus, one must be cautious about generalizing from the lessons learned from any particular case. Keeping this in mind, this section discusses key findings from the six case studies in terms of large power loads, supply options, financial and economic viability, and financing of development.

### *LARGE POWER LOADS*

The viability of providing electricity depends critically on the existence of a large and stable demand for electricity (or supply, especially if the grid is supply constrained). In rural areas, it is likely that the largest single source of power demand is either agriculture or an agriculture-related commercial activity. Residential electricity could also be a significant source of demand (e.g., in the case of Tanzania's Sumbawanga agriculture cluster); however, this demand is often relatively dispersed, which reduces its viability.

In rural agricultural areas, irrigation is often the single largest potential source of electricity demand, as exemplified in Tanzania's Sumbawanga agriculture cluster, Zambia's Mkushi farming block and Mwomboshi's IDSP. These projects also show that the loads for agro-processing activities (e.g., milling and extrusion) are comparative smaller, suggesting that the latter activities, taken alone, may not be sufficient to justify rural electrification investments. These several projects also highlight how irrigation and processing are often linked. The Zambia cases show how increased yields from irrigation are an important prerequisite for the development of large-scale processing activities; the agriculture cluster concept in Tanzania also shows this cause-and-effect relationship between irrigation and processing. Increase in the scale of processing activity can lead to a significant increase in power demand.

The seasonality of power demand from the agriculture sector can significantly constrain a project's viability. Large seasonal differences in electricity-dependent agricultural activity will impact the cost recovery of investments in electricity supply. In such cases, it is important to consider ways to mitigate the impact of a variable load. One option, especially for mini-grid or captive generation, is the ability to sell excess power to the grid, as in the cases of mini-hydro development in Tanzania (Mwenga) and Kenya (KTDA).[18] Increased processing activities in the post-harvest season may complement electricity demand from irrigation, and irrigation itself may reduce seasonality in agricultural production and thus electricity demand by allowing multi-cropping (e.g., in the case of Zambia's Mkushi farming block).

Finally, when considering agricultural anchor loads, it is more risky for the investment to depend on a single large customer since any negative shock to the customer would negatively affect operating revenues for the electricity supplier. For this reason, agricultural clusters (e.g., Sumbawanga in Tanzania) can be used to increase the viability of rural electrification. Clusters development, by design, has load diversity and thus involves less risk than reliance on a single anchor load. While not included in the case studies discussed in this chapter, the presence of a private electricity supplier and private off-takers will price any such risk into the supply contract, thus increasing the price of electricity for all customers. In such cases, diversified cluster development can also help reduce the price of electricity. The public sector may also help mitigate this risk through a grid connection and FiT, subsidies to increase the customer base, or various guarantee/insurance instruments.

### *SUPPLY OPTIONS*

Most of the grid extension projects are justified by irrigation development, with agro-processing as a supporting activity. These developments require cultivating suitable commodities (e.g., maize, wheat, rice, and sugar), typically grown on large-scale commercial farms, enabling large production volumes. Small-scale farmers can then be incorporated alongside; however, they also need other forms of support, including access to a reliable water supply, good physical and market infrastructure, and clear land with good quality soils.

The case studies discussed indicate that the national grid usually plays an important role in the viability of rural electrification investments—either in the form of the main supply option for agricultural and rural electricity demand (e.g., the Sumbawanga cluster in Tanzania) or as the main off-taker of the locally generated electricity from a small power producer (e.g., the Mwenga mini-hydro mini-grid in Tanzania). Whether the grid is the most viable supply option depends on various factors, including distance to the grid, size and stability of electricity demand, grid reliability, and local resource potential for generation.

Supplying rural electricity demand though small power producers (SPPs) depends critically on local generation potential (e.g., for mini-hydro, geothermal, and biomass). Viable generation potential can be a cost-effective option in cases where the grid is far away, unreliable, or expensive. In the latter case, especially, SPPs may benefit primarily from selling to the grid and supplying local agricultural activities and residential customers in the process (e.g., Tanzania's Mwenga mini-hydro mini-grid).

Companies specializing in the agriculture or agribusiness sectors may be unwilling to enter into electricity generation and, especially, the distribution business. This would be a departure from their core activities and may not be financially attractive enough to change their business model. In this respect, a variety of arrangements are possible, depending on the context and capacity of the entities involved. For Kenya's Oserian geothermal project and KTDA's mini-hydro project, the companies chose to develop and operate the generation plant and supply their operations, preferring to sell power to the grid and leave retail power supply to the utility. For Tanzania's Mwenga mini-hydro project, by contrast, RVE manages the mini-grid generation and distribution, including retail power sales.[19]

### *FINANCIAL AND ECONOMIC VIABILITY*

The case studies discussed show that a rural electrification project can be financially viable where there is a creditable large off-taker and access to concessional loans/grants for capital investments. All six projects were estimated to generate economic benefits well in excess of associated costs, thus implying that all were economically viable.

Tautologically, financial viability rests on the ability to charge cost-reflective tariffs. In the case of mini-grid development, charging consumers a tariff that is much higher than the grid tariff might be difficult to do, even if the regulation allows it. Given this difficulty, financial viability, in most cases, depends on the ability to sell bulk power and lower costs. The Oserian geothermal and KTDA projects show that estate-type developments (floriculture and tea in these respective cases) can undertake financially viable electricity investments, benefiting from reduced electricity costs and selling excess electricity to the grid. Another example is the case of the IDSP in Zambia, where a grid extension was financially viable from the utility's perspective, owing to proximity to the grid (i.e., lower costs) and complementary investments in a large irrigation scheme that increased electricity demand. In contrast, grid extension to the Mkushi farming block, also in Zambia, was not financially viable for the utility, despite a capital cost-sharing arrangement with beneficiary farmers.

The choice of optimal tariffs—such that costs are recovered and electricity consumption is affordable to farmers, businesses, and other customers—depends on the size of the financial surplus generated from electricity consumption and the constraints on how to allocate it across various suppliers and customers. Additional considerations, such as parity with the main grid tariff, are the main determinants (e.g., Mwenga mini-hydro mini-grid in Tanzania).

If there is flexibility in setting tariffs, then the range of feasible tariffs would be determined by the difference between the customer's willingness to pay (WTP) and the supplier's willingness to accept (WTA).[20] A customer's WTP will be determined by the monetary benefit from consuming a unit of electricity. For households, this may be a reduction in spending on their current energy supply options, which are usually more expensive and less reliable (e.g., kerosene lamps or batteries). For agricultural consumers, it may be driven by a reduction in backup energy supply and/or increased revenues from higher productivity. A supplier's WTA will be determined by development and operating costs, often represented by the levelized cost of electricity (LCOE) (table 4.26). Assuming the WTP is more than the WTA, an optimal tariff may be negotiated based on some surplus allocation rule. Otherwise, if the WTP is lower than the WTA, the government must step in to provide subsidies to bridge the gap as long as the project remains economically viable.

For all six of the cases analyzed in this chapter, the economic viability was high. For projects that are not financially viable, economic viability is an important criterion to determine whether subsidies should be provided and at what level. Even with financial viability, subsidies

**TABLE 4.26:** TYPICAL LCOE VALUES FOR SMALL-SCALE GENERATION AND DISTRIBUTION SYSTEMS

| Generation System | | | | |
|---|---|---|---|---|
| Technology | Size Range (kW) | Power Plant Capital Expenditure (US$/kW) | LCOE (US$/kWh) | Operating Time (hours/year) |
| Diesel genset | 5–300 | 500–1,500 | 0.3–0.6 | Any |
| Hydro | 10–1,000 | 2,000–5,000 | 0.1–0.3 | 3,000–8,000 |
| Biomass gasifier | 50–150 | 2,000–3,000 | 0.1–0.3 | 3,000–6,000 |
| Wind hybrid | 1–100 | 2,000–6,000 | 0.2–0.4 | 2,000–2,500 |
| Solar hybrid | 1–150 | 5,000–10,000 | 0.4–0.6 | 1,000–2,000 |
| **Distribution System** | | | | |
| Distribution Type | | Voltage Level | LCOE (US$/km) | Required Length |
| Low-voltage | | 400 V | 5,000–8,000/km | 30 customers/km |
| Average connection cost: $350/customer; average distribution cost: $200/customer. | | | | |
| Medium-voltage | | 33 kV | 13,000–15,000/km | |
| **Total ($/kWh)** | | | **0.25–1** | |

*Source:* IED Reference Costs for Green Mini-Grids.

may be incorporated into the project to achieve other goals, such as grid parity in terms of tariffs or greater adoption of electric irrigation.

### *FINANCING OF DEVELOPMENT*

All six projects analyzed shared two common issues: (i) making projects financially viable and (ii) providing funding for viable projects. Several ways have been identified to make projects financially viable. To benefit from economies of scale, capacity for local generation can be increased beyond the level of local demand, and surplus power can be sold to the grid. This option is particularly relevant in countries that have introduced FiT programs set above the utility's avoided costs. Selling excess power makes it possible to lower the per-megawatt cost, but relies on the ability to sell excess generated power. For example, the capacity of Tanzania's Mwenga mini-hydro mini-grid is greater than what the tea estate requires; therefore, the surplus is sold to the utility and nearby rural customers.

Another option, as done for the main grid extension projects in Zambia (Mkushi and Mwomboshi), is to require the beneficiaries to partially finance projects and share the development costs with major customers. In this way, farmers partially contribute to the capital costs in exchange for receiving power. A further option is load balancing across beneficiary categories, which enables the spread of fixed costs, especially capital costs, across a larger pool of customers with diverse peak-load profiles. For example, since productive users need electricity during the day and households' peak load is in the evening, the system peak load should be lower than the sum of individual peak loads. However, load balancing requires an analysis of load profiles to optimize supply, and the level of additional benefit depends on the proportion of capital costs in total costs and the load matching between customers. The utilities—owing to their larger-capacity cross-subsidization and ability to spread costs over a wider customer base—are usually in a better position to do so.

As detailed for the Mwenga and KTDA projects, selling power to more reliable customers, such as the utilities, increases a project's viability since anchor customers are assumed to be better payers. This is especially true in countries where clear schemes for renewable energy FiTs have been introduced with dedicated funding. Although relying on the utility still depends on its ability to afford payments, the anchor-customer approach has reduced the risk of the utility's non-payment by giving certainty on tariffs.

Finally, the role of subsidies to cover certain costs should be highlighted. All of the distributed schemes analyzed in this chapter have received subsidy payments to decrease the level of cost recovery through retail tariffs. This approach contributes to ensuring maximum capacity development, increasing the project's NPV, improving

tariff affordability for customers, and attracting private-sector participation. Subsidies are particularly necessary for most privately developed, small-scale projects under 5 MW. By subsidizing household connections, which tend to be financially unviable, developers can be encouraged to expand their customer base to capture additional subsidies, prioritizing smaller customers close to each other rather than larger ones.

## ENDNOTES

1. The analysis presented in these case studies is indicative only and not a comprehensive feasibility study.

2. The only exceptions are projects based on quite expensive sources of power generation for small demand loads.

3. SAGCOT aims to facilitate the development of seven agribusiness clusters along the southern corridor of Tanzania's Southern Highlands.

4. This comprises 3 MW from a 66 kV line into Zambia, 5 MW from a mini-grid in Sumbawanga, and a 2.6 MW mini-grid in Mpanda; both are isolated, diesel based mini-grids operated by TANESCO.

5. ECA and Prorustica estimates, consistent with the SAGCOT investment blueprint, constructed from own analysis and various official sources.

6. Other products such as cassava and livestock are also likely to demand electricity for processing, but for the sake of simplicity, are not included in the calculations here.

7. According to Tanzania's national census, Rukwa had 1 million inhabitants in 2012.

8. The cost calculations consider all capital and operating expenditures; the calculations are based on ECA analyses conducted for small-scale systems in Kenya, Tanzania, and elsewhere in Sub-Saharan Africa.

9. Assumes that the factory operates 16 hours per day, 6 days a week for 10 months out of the year.

10. EU funds were through the African, Caribbean, and Pacific Group of States facility; and REA funding was supported by the World Bank's Tanzania Energy Development and Access Project (TEDAP).

11. Assumes that the area's power demand from irrigation is 1 kW per ha and average irrigating hours per year are about 1,900 (with a 15 percent load factor), representing in part the seasonality in demand for irrigation.

12. Assumes that the average mill has a power demand capacity of 400 kW and operates 5,000 hours per year.

13. US¢9.29 per kWh under a FiT.

14. Assumes a diesel generation cost of US¢60 per kWh (KTDA) and an overall tariff decrease of 5 percent annually.

15. Since this analysis focuses on the impact of an anchor load on household electrification, we restrict it to grid-connected households.

16. Observed for mini-grid development in Kenya.

17. If we assume that 50 percent of the 30,000 households connected are from SHS, then the household net benefits increase to US$14 million and the overall NPV to $17.2 million.

18. Apart from the mitigating impact of seasonal variation, the ability to sell excess power to the grid also helps invest in large generation capacity and reduces costs due to economies of scale in generation.

19. Enabling small-scale, private power generation and distribution requires clear regulations and purchasing processes (e.g., PPAs and FiTs); regulations in Tanzania are relatively transparent in this regard.

20. The difference between WTP and WTA is a measure of the total surplus generated by the electricity sale/consumption.

# Opportunities to Harness Agriculture Load for Rural Electrification

## CHAPTER 5

What is Sub-Saharan Africa's potential for harnessing power-agriculture synergies for rural electrification? This chapter considers this question, using a simulation model and case studies from Ethiopia and Mali—two countries that exhibit a range of innovative options moving forward to 2030. Before turning to the case studies, the chapter presents a hypothetical case illustrating the conditions under which power demand from agriculture could be economically viable.

### SIMULATION OF POWER DEMAND IN A STYLIZED AGRICULTURAL SETTING

A simplified simulation model was developed to analyze the relationship between agricultural activity, power demand, and the geographic area that a power supply would serve (table 5.1). The model assumed a theoretical circular area around the generation source, with electricity consumers distributed uniformly throughout. Further simplifying assumptions were made about what percentage of this area was under cultivation and the proportions split between small-scale and commercial farmers. The electricity demand from each of the two farmer groups were estimated separately, with differing proportions of area under irrigation and yields (on rainfed and irrigated summer and winter crops). The model assumed that there were two crops: summer maize and winter wheat. Across Sub-Saharan Africa, maize is a common summer crop on both mixed-used commercial and small-scale farms. In the winter months, irrigated wheat is commonly grown. Based on the areas under irrigation, assumptions about the power load of bulk water pumping and infield irrigation systems were made.[1]

For each farming type, the production volume was used to calculate the milling load for the area, based on assumptions about the proportions of milled production. With total milling volumes, the total load requirement for milling was estimated, based on the load characteristics of an assumed average mill. Household and business connections for the given area were also estimated, based on assumptions about a consistent population density and members per household, connection rate, household power consumption, and proportion of this load for business consumption.

The stylized analysis from the simulation model helps to determine the general features of power demand from agricultural areas. Based on the average power demand from agricultural sources, the results show that a fairly large area of coverage would be required to aggregate sufficient electricity demand from customers; based on the model assumptions, a 50 km radius area would, on average, aggregate 60 MW of demand.

In the simulation, as in the case studies, irrigation accounts for a substantial proportion of power demand from agriculture (figure 5.1).[2] The irrigation power load is dependent on choice of crops and availability of bulk water. Some systems with a large body of available water nearby the infield irrigation system may require little bulk water pumping; however, in cases where water must be pumped into storage before utilization, additional electricity is required. As such, total observed power loads for irrigation are in a range of 0.5 kW–2.0 kW per ha.

**TABLE 5.1:** ASSUMPTIONS FOR TYPICAL AREA/AGRICULTURAL ACTIVITY/POWER DEMAND MODEL

| Assumption | Basis | Small-scale Value | Commercial Value | Overall Value |
|---|---|---|---|---|
| Proportion of total land area under cultivation (%) | Observations of other large-scale production areas | | | 25 |
| Proportion of farming type within cultivated area (%) | Observations of other large-scale production areas | 70 | 30 | |
| Proportion of irrigated land (%) | Observations of other large-scale production areas | 20 | 50 | |
| Summer crop yield (rainfed) (MT/ha) | Maize yields observed | 1.5 | 6 | |
| Summer crop yield (irrigated) (MT/ha) | Maize yields observed | 4 | 8 | |
| Winter crop yield (irrigated) (MT/ha) | Wheat yields observed (not grown without irrigation) | 2 | 5 | |
| Proportion of crop milled (%) | Observations of other production areas | 25 | 80 | |
| Irrigation load requirement (kW/ha) | Average, based on schemes observed | 0.3 | 1.0 | |
| Milled load (kW) | Average mill, consultant calculations | | | 200 |
| Hours of operation (hrs/day) | Average mill | | | 16 |
| Days of operation (hrs/year) | Average mill | | | 313 |
| Population density (per km$^2$) | Comparison with other countries | | | 50 |
| People per household (no.) | Comparison with other countries | | | 5 |
| Household connection rate (%) | Comparison with other countries | | | 50 |
| Peak household consumption (kW) | Various household power-consumption studies | | | 0.3 |
| Business load as proportion of household load (%) | Various rural business power-consumption studies | | | 50 |

*Source:* ECA and Prorustica (2015).

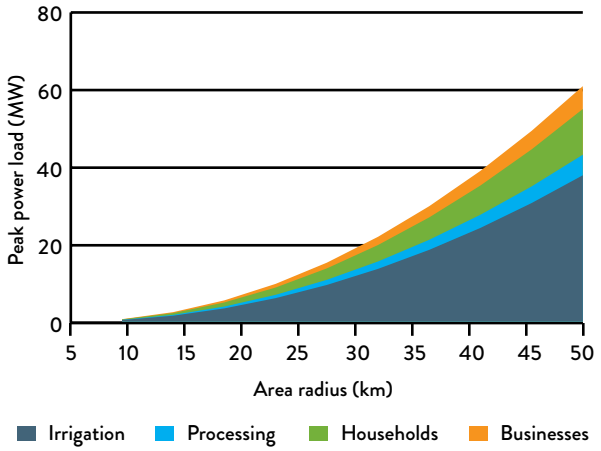
The relatively low load for processing suggests that the machinery used for typical post-harvest processing operations (e.g., mills) does not require large amounts of electricity, in part, because of the small size; also, it may be in operation for fewer hours in a year. Thus, most crop-processing loads are fairly small for the volume processed, with the exception of such activities as sugar processing, which provides much or all of its own power.

The total power load for a given area is highly sensitive to the assumed area under commercial irrigation, reiterating the importance of irrigation to power loads (figure 5.2). By contrast, the impact of the proportion of crop processed is relatively low, especially as this load is already minimal.

## SIMULATION STUDY 1. ETHIOPIA: POWER GENERATION FROM SUGAR ESTATES

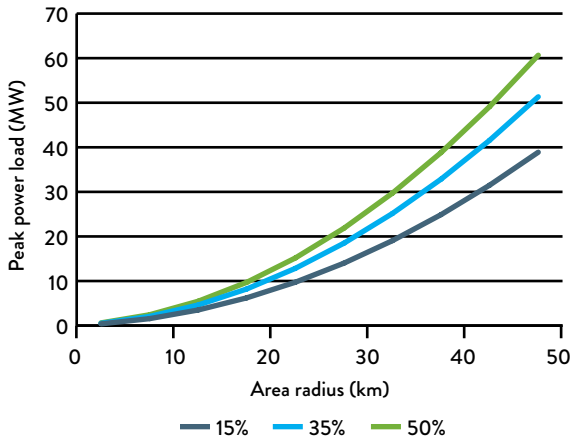
Sugarcane is an important crop in Ethiopia (map D.7). Indeed, the Ethiopian Sugar Corporation (ESC) aims to increase national annual production nearly eightfold

**FIGURE 5.1:** POWER DEMAND AND BREAKDOWN FOR A GIVEN AREA RADIUS




*Source:* ECA and Prorustica (2015).

**FIGURE 5.2:** SENSITIVITY OF POWER LOAD TO CHANGES IN PERCENT OF COMMERCIAL IRRIGATION




*Source:* ECA and Prorustica (2015).

**TABLE 5.2:** ETHIOPIA: POWER GENERATION FROM SUGAR ESTATES

| | |
|---|---|
| **PROJECT OVERVIEW** | Self-generation of power from bagasse and sale of power surplus to the main grid. |
| **COMMODITIES** | Sugar. |
| **DESCRIPTION** | Sugar processing and irrigation are the largest sources of electricity demand.<br>Irrigation makes it possible to extend the sugarcane production season and therefore smooth the annual profile of both production and processing. Processing and refining are the most power consuming activities in the sugar estate.<br>Typically, a sugar processing plant can produce enough electricity from bagasse to meet its own electricity demand, and sell excess power to the grid.<br>The viability of connecting such processing plants to the grid depends on the amount of excess power produced, the cost of producing it relative to other sources, and additional customers that can be connected. |
| **FINANCIAL VIABILITY** | From the utility's perspective, extending the grid to the sugar estate is not financially viable—the net present value (NPV) is negative because the utility does not benefit from sales to the estate, which self-supplies; from the sugar estate's standpoint, the project is highly profitable (US$139 million). |
| **ECONOMIC VIABILITY** | The economic NPV for the whole period is positive ($367 million), thus justifying development of the project. |

within five years. To do so, the government has launched the Sugar Development Programme, with the objective of upgrading existing estates and commissioning new ones (table 5.2).

This simulation analyzes a representative example of power-agriculture integration on sugar estates in Ethiopia. Sugar estates have the potential to generate power from bagasse, a natural by-product of sugar refining. Hypothetically, the potential electricity generation is enough to cover the electricity needs of the refinery and associated facilities and sell the surplus to the main grid or other supply schemes.

### *POWER DEMAND*

**Agriculture (Irrigation).** Traditional sugarcane production is heavily water dependent. Irrigation ensures year-round production of the crop and therefore a smoothing of the annual profile of processing activity. This means that sugar facilities operate throughout the year with a consistent electricity demand.

Irrigation is also a major source of power demand in the sugarcane production process. In Ethiopia, irrigated land is expected to increase from 1,500 ha to 9,000 ha over 20 years. The associated power demand from

irrigation over the same period is expected to rise from 0.8 MW to 4.7 MW,[3] with power consumption increasing from 2,340 MWh to 14,040 MWh (table 5.3).[4]

**Agriculture (Processing and refining).** Processing and refining are the most power-consuming activities in the sugar estate, depending highly on production volume. Considering forecasts in terms of yield rates and production increases, the power requirements for processing irrigated sugarcane will amount to 6,300 MWh in year 1 of the hypothetical model, rising to 37,800 MWh five years later. For processing rainfed production, power consumption will increase from 3,150 MWh to 18,900 MWh over the same 20-year period (figure 5.3).

Beyond processing, refining activities also consume power for centrifuging raw sugar and crystallization. Over the 20-year period, electricity consumption from refining is estimated to rise from 300 MWh to 1,800 MWh, while power load will increase from 0.09 MW to 0.54 MW.[5]

**Staff housing.** In addition to agricultural needs, sugar estates also require power for staff housing and other supporting activities. Given that the average household electricity consumption in rural Ethiopia is about 0.10 kW (increasing to 0.15 kW by year 20),[6] total electricity demand from staff housing is estimated at 0.02 MW in year 1, increasing to 0.21 MW by year 20.

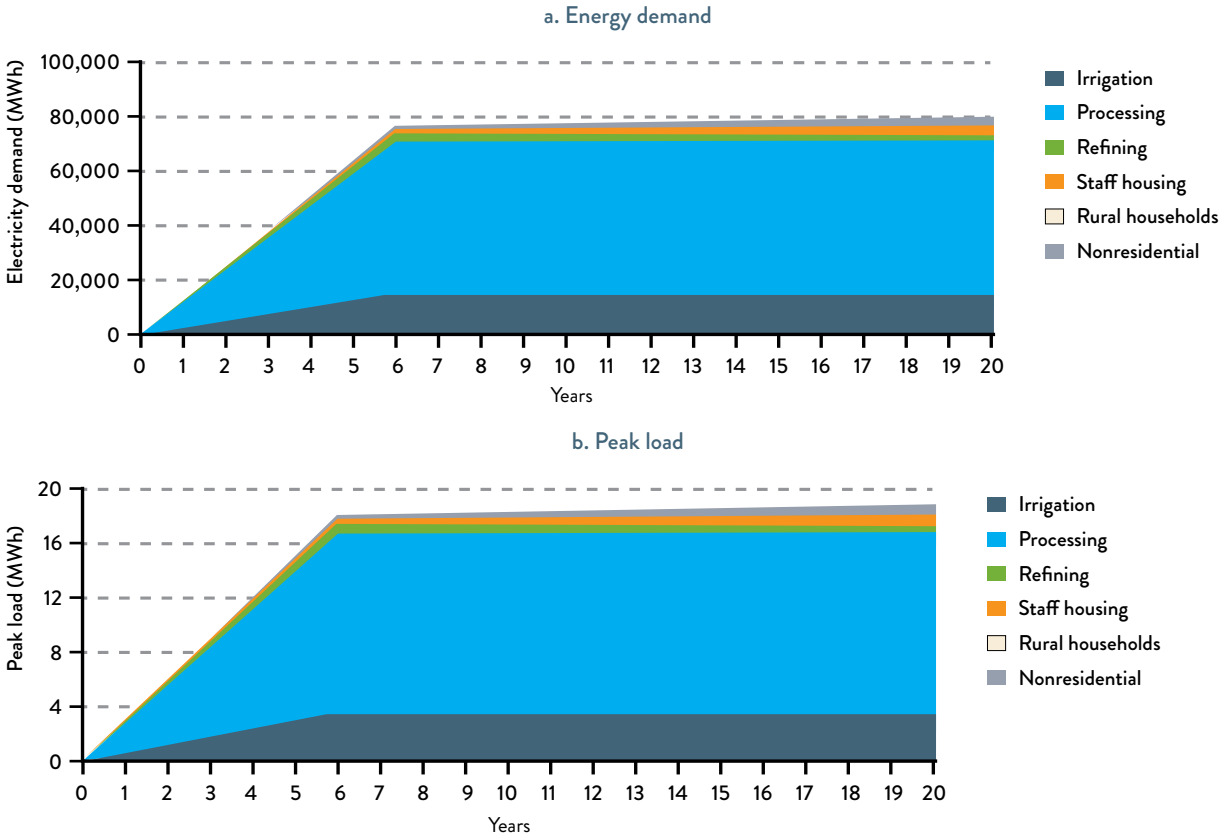
**Residential/Commercial demand.** In this model, the area is not yet connected to the grid, but a 30-km

**TABLE 5.3:** TOTAL POWER DEMAND FROM AGRICULTURE AND RESIDENTIAL/ COMMERCIAL LOADS

| Demand Source | Power Capacity Demand (MW) | | Energy Demand (MWh/year) | |
|---|---|---|---|---|
| | Year 1 | Year 20 | Year 1 | Year 20 |
| Irrigation | 0.8 | 4.7 | 2,340 | 14,040 |
| Processing | 2.9 | 17.5 | 9,450 | 56,700 |
| Refining | 0.1 | 0.5 | 300 | 1,800 |
| Residential (including staff housing) | 0.1 | 1.5 | 384 | 3,783 |
| Commercial | 0.1 | 0.6 | 278 | 2,780 |

*Source:* ECA and Prorustica (2015).

**FIGURE 5.3:** ESTIMATED ENERGY DEMAND AND PEAK LOAD, BY SECTOR




*Source:* ECA and Prorustica (2015).

grid extension is finalized once the sugar factory is built. Thanks to the proximity of houses and the factory, the electrification rate rises sharply to 85 percent by year 4. As the population grows from 28,500 to 50,386 by year 20,[7] with household growth following the same trend,[8] the total electricity load from rural households will reach 1.3 MW by year 20. For commercial activities surrounding the sugar estates, consumption is expected to increase from 278 MWh in year 1 to 2,780 MWh by year 20 (table 5.3).[9]

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

Bagasse is commonly used to generate electricity in sugar factories. It is mainly used as a boiler fuel to generate steam to meet the sugar factory's heating and power needs. The level of net electricity generation assumes (i) a bagasse generation potential of 29 MT for every 100 MT of sugarcane produced and (ii) a 70 kWh generation capacity for every MT of sugarcane. Since irrigated and rainfed processing of sugarcane do not occur simultaneously, the power capacity of generation equals the maximum capacity of the two, that is 47 MW by year 20 (table 5.4).

**TABLE 5.4:** SUGAR FACTORY POWER GENERATION IN YEARS 1 AND 20

| Sugarcane Processing Type | Electricity Generation Capacity (MW) | | Electricity Demand (MWh/year) | |
|---|---|---|---|---|
| | Year 1 | Year 20 | Year 1 | Year 20 |
| Irrigated | 3.8 | 22.5 | 12,600 | 75,600 |
| Rainfed | 5.8 | 35.0 | 6,300 | 37,800 |
| **Total** | **5.8** | **35.0** | **18,900** | **113,400** |

*Source:* ECA and Prorustica (2015).

Beyond meeting its own power needs, the sugar factory can generate surplus power.[10] This supports the development of estate activities, especially irrigation, before enough on-site bagasse has been produced. It also covers shortfalls in power generation during planned annual maintenance when the mills are not operating (May–September) (table 5.5).

The capital cost of extending the grid line 30 km to the sugar estate and surrounding villages is US$2.4 million (table 5.6).

**TABLE 5.5:** NET POWER GENERATION FROM SUGAR FACTORY BY YEAR 20

| Agricultural Activity | Power Capacity Demand (MW) | Hours of Operation/Year | Energy Demand (MWh/year) |
|---|---|---|---|
| Irrigation (A) | 4.7 | 3,000 | 14,040 |
| Processing (B) | 17.5 | 3,360 | 56,700 |
| Refining (C) | 0.5 | 3,360 | 1,800 |
| **Total demand** | **22.7** | | **72,500** |
| Power generated during processing (D) | 35 | | 113,400 |
| **Net power surplus D − (A + B + C)** | **12.3** | | **40,900** |

*Source:* ECA and Prorustica (2015).

**TABLE 5.6:** CAPITAL COST ASSUMPTIONS FOR GRID CONNECTION

| Cost Component | No./Distance (km) | Unit Cost | Cost (million US$) |
|---|---|---|---|
| 230 kV shunt/line/transformer (thousand $/unit) | 15 | 25 | 0.4 |
| Associated switchgear (thousand $/unit) | 1 | 120 | 0.1 |
| 33 kV line (thousand $/km) | 50 | 14 | 0.7 |
| 11 kV line (thousand $/km) | 120 | 10 | 1.2 |
| **Total** | | | **2.4** |

*Source:* ECA and Prorustica (2015).
*Note:* Costs estimates are based on those for similar projects in Ethiopia's 2014 Electrification Master Plan; cost assumptions include connecting villages along the power line (i.e., 33 kV and 11 kV lines and transformers). In reality, the estate may feed back power to the villages from the substation.

Currently in Ethiopia, however, no sugar factory exports its power to the grid because of the country's (i) low electricity tariffs and (ii) unclear regulations on conditions of exporting power to the main grid. A feed-in-tariff (FiT) proposal, which aims to provide incentives to private investors, is expected to become law in 2016 and should clarify those conditions; thus, under future development plans, power sold to the grid will be at the FiT. It is unlikely that sugar estates will sell directly to residential customers; this will be left up to the electricity utility.

### *FINANCIAL ANALYSIS*

The project's financial viability can be analyzed separately from the respective standpoints of the utility and the sugar estate. From the utility's perspective, extending the grid to the sugar estate is not financially viable; the estimated NPV is negative, at US$ –1.5 million (table 5.7). The viability is driven by the amount of power purchased by the utility, the margin between retail tariff and the price at which electricity is purchased from the sugar factory (possibly the FiT), and the cost of extending the grid.

The price at which the utility purchases power from the independent power producer (IPP) is confidential. In the absence of actual data, it is assumed that the utility tariff margin is US¢1 per kWh, which amounts to 40 percent of the domestic tariff.[11]

The project is not viable for the utility, in large part because it does not benefit from sales to the estate, which self-supplies. Subsidies would thus be required for project development. Given the significant financial benefits that will accrue to the sugar estate from the project, one option could be to have the sugar estate contribute to capital costs.

**TABLE 5.7:** FINANCIAL ANALYSIS FROM THE UTILITY'S PERSPECTIVE

| Component | Present Value (million US$) |
|---|---|
| Net revenue from sales | 2.7 |
| Expenses (Opex, losses, depreciation) | 1.8 |
| Capital cost | 2.4 |
| **NPV** | **–1.5** |
| **IRR (%)** | **7.6** |

*Source:* ECA and Prorustica (2015).
*Note:* The discount rate is 10 percent over the 20-year period; of total capital costs, operating costs account for 3 percent, while losses and depreciation each account for 5 percent.

From the sugar estate's perspective, the combination of heating and power from bagasse combustion is a fundamental asset for sugar processing and refining. The project's financial viability depends on the following factors (table 5.8):

- Capital costs, linked to development of the whole estate, including land improvement, buildings and equipment, and staff housing.
- Production costs, including employee wages, seeds, harvesting, loading, transport, maintenance, and electricity costs.
- Expected revenues from sugar sales and power sales.

The project is highly profitable for the sugar estate, with a NPV of US$139 million. As mentioned above, the large financial benefits for the sugar estate create ample scope for a negotiated arrangement of capital cost sharing to improve the utility's financial viability.

**TABLE 5.8:** SUGAR ESTATE CAPITAL COSTS, ASSUMPTIONS FOR PRODUCTION COSTS, AND REVENUES

| Component | Value |
|---|---|
| **Capital costs (million US$)** | |
| Land improvement ($3,500/ha) | 41.9 |
| Buildings and equipment | 80.5 |
| Staff housing ($5,000/house) | 7.0 |
| **Present value of total capital costs** | **129.4** |
| **Production costs** | |
| Average wage ($/month) | 100 |
| Permanent employees (months/year) | 12 |
| Temporary employees (months/year) | 7 |
| Seeds costs ($/ha) | 515 |
| Harvest cost ($/MT) | 6 |
| Loading cost ($/MT) | 2 |
| Transport to sugar mill ($/MT) | 3 |
| Maintenance (% of capital expenditure) | 3 |
| **Present value of total production costs (million US$)** | **311** |
| **Revenue (million US$)** | |
| Present value of sugar sales | 573 |
| Present value of exported power to the grid | 6 |
| **Present value of total revenues** | **579** |

*Sources:* Agritrade; ECA and Prorustica (2015); ESC; IEA; National statistics.

### *ECONOMIC ANALYSIS*

The project's total economic benefits, estimated at about US$410 million, comprise household energy cost savings, sugar estate profits, job creation, and import substitution (table 5.9).

The economic NPV over the period, about US$367 million, equals the sum of the net social benefits linked to the electrification project (figure 5.4), the financial NPV, and the present value of the sugar estate investment cost (table 5.10).

Various factors could hinder the development of such agriculture-power schemes in Ethiopia. The first one is funding availability for grid extension; however, given the project's associated economic benefits, funding from the government, development partners, or even cost sharing with the sugar estates could be sought. Second, for greenfield development, investors face issues about uncertainty over land ownership; despite the government's ability to make quick investment decisions regarding state-owned property, identifying large tracts of high quality agricultural land is difficult in Ethiopia. Third, regulations on exporting power to the grid must be clarified by defining tariff rates that guarantee investors a price for selling generated power from bagasse to the utility. Finally, selling power to the utility carries off-taker risk; delayed payments for power sold or even payment defaults would greatly impact the sugar factory investor.

## SIMULATION STUDY 2. MALI: MINI-GRID EXPANSION FOR PRODUCTIVE USERS

Mali is a regional success in rolling out private mini-grid concessions for rural electrification (map D.8).

**TABLE 5.9:** NET ECONOMIC BENEFITS OF GRID EXTENSION TO THE SUGAR ESTATE

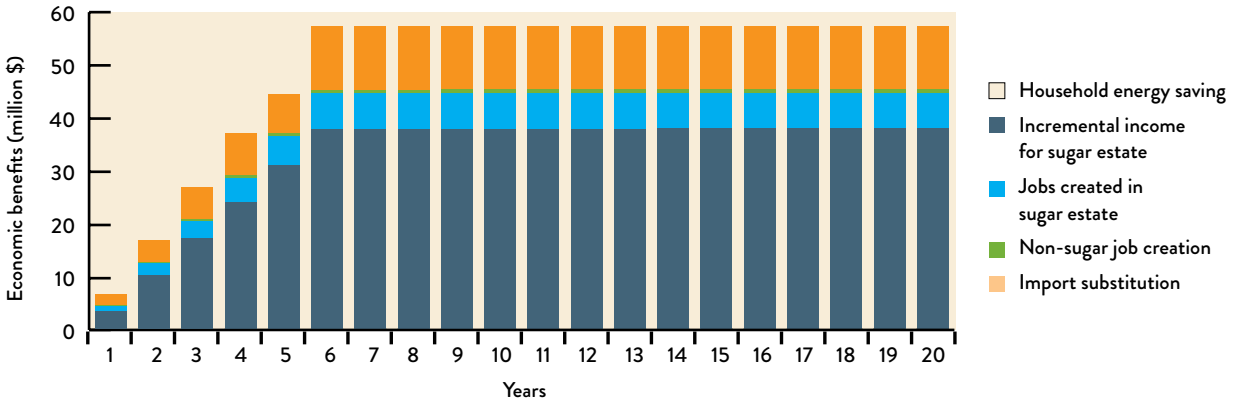
| Benefits | Year 1 | Year 5 | Year 20 |
|---|---|---|---|
| **Household energy savings** | | | |
| Electrification rate (%) | 21 | 85 | 85 |
| Households electrified (no.) | 1,479 | 6,752 | 9,964[a] |
| Savings from grid electrification per household ($/month) | 17 | | |
| **Total savings on energy consumption (million $)** | **0.025** | **0.12** | **0.17** |
| **Incremental income to the sugar estate** | | | |
| Production revenues (million $) | 14.8 | 74.2 | 89.2 |
| Production costs (million $) | 11.0 | 39.5 | 46.7 |
| **Sugar estate's profit (million $)** | **3.8** | **34.7** | **42.5** |
| **Sugar estate jobs created** | | | |
| Monthly salary ($/month) | 100 | | |
| Permanent jobs created (no.) | 933 | 4,663[b] | 5,595 |
| Temporary jobs created (no.) | 1,588 | 7,939 | 9,527 |
| **Total salaries (million $)** | **2.2** | **11.1** | **13.4** |
| **Non-sugar jobs created** | | | |
| Jobs created (no.) | 1,260 | 6,301 | 7,561 |
| **Salaries paid (million $)** | **0.13** | **0.63** | **0.76** |
| **Import substitution** | | | |
| New production of sugar (MT) | 42,000 | 210,000 | 252,000 |
| **Value of import substitution (million $)** | **1.3** | **6.3** | **7.6** |
| **Total economic benefits (million $)** | **7.5** | **52.9** | **64.4** |

*Source:* ECA and Prorustica (2015).

a. The difference in the number of connected households between years 5 and 20 is related to population growth, which is expected to increase by 2.89 percent.

b. Assumes 0.37 permanent job and 0.67 temporary job (working 7 months a year) created by hectare—Estimation based on the number of employees in Metehara sugar factory in Ethiopia.

**FIGURE 5.4:** NET SOCIAL BENEFITS OF GRID EXTENSION TO SUGAR ESTATE (YEARS 1–20)




*Source:* ECA and Prorustica (2015).

**TABLE 5.10:** ECONOMIC NET PRESENT VALUE OF EXTENDING THE GRID TO THE SUGAR ESTATE

| Item | Value (million US$) |
|---|---|
| Financial NPV of Ethiopian Electric Power Corporation (EEPCO) | −1.5 |
| Present value of investment cost of sugar estate | −41.9 |
| Net social benefits | 410.0 |
| **Economic NPV** | **367** |

*Source:* ECA and Prorustica (2015).
*Note:* The discount rate is 10 percent over the 20-year period.

In 2015, it has 255 operating concessions, with a total installed capacity of 22 MW. However, mini-grid operators face key challenges, including the saturated capacity of their schemes and low revenues, which hinder investment in capacity expansion. Limited power-generation capacity has constrained the mini-grids' ability to supply households and serve productive users. The current service level—limited daily hours (typically in the evenings) and tariffs that are higher than on-site diesel generators (usually above US$0.50 per kWh)—are inappropriate for meeting agro-industry power requirements. As a result, productive users in off-grid areas use their own diesel generators as a more competitive power supply option (table 5.11).

**TABLE 5.11:** MALI MINI-GRID EXPANSION FOR PRODUCTIVE USERS AT A GLANCE

| | |
|---|---|
| **PROJECT OVERVIEW** | Capacity expansion of an existing hybrid mini-grid (diesel-solar PV) to serve productive users. |
| **COMMODITIES** | Agro-industrial activities. |
| **DESCRIPTION** | The Koury mini-grid is reaching a point of near saturation as generation capacity is fully taken up by existing household demand. However, small-scale commercial and agro-industrial activities in Koury (milling, water pumping, and bakeries) present significant opportunities for supplying unmet power demand. Attracting powered small businesses as mini-grid customers would require incentives to (i) lower tariffs, (ii) supply electricity during the daytime, and (iii) replace manual equipment with electricity powered machinery. |
| **FINANCIAL VIABILITY** | From the perspective of SSD Yeelen Kura, the rural energy services company, the Koury mini-grid is in a fragile financial situation. However, the capacity expansion project is profitable, thanks to a higher payment rate, additional revenues, and proportionally low capital expenditure and operating expense (with a NPV of €103,000). |
| **ECONOMIC VIABILITY** | The economic NPV for the expansion project is slightly negative (−€18,000) as no significant savings are expected from agro-industrial customers, who currently use individual diesel generators. However, the project could become economically viable if other economic, environmental, and social benefits were considered (e.g., reduction in $CO_2$ emissions, reduced reliance on imported fuels, and exposure to price fluctuations). |

Based on a representative example of an existing mini-grid, this simulation study analyzes how agro-industrial activities may improve mini-grids' financial viability, while benefiting from a more sustainable and competitive source of electricity. Based on the potentially lower costs of hybrid solar photovoltaic (PV) projects, the study explores the potential for attracting agro-industrial power demand to mini-grids. Given that there is no precedent for tying medium- or large-scale industrial processing to private mini-grid projects, an expansion project has been designed to assess the viability of supplying agro-industrial loads. The simulated study also evaluates the potential for adding value to agricultural activities in rural areas through mini-grid supplied power. Powered agricultural activities can indeed improve rural communities' revenues and therefore potentially increase mini-grid operators' profit (box 5.1).

### BOX 5.1: ISOLATED MINI-GRID SYSTEMS IN MALI: EXISTING AND POTENTIAL POWER DEMAND

In Mali, large-scale irrigation schemes are gravity fed, with electric power used only for small diesel or petrol-powered pumps. Four key commodities that could benefit from greater access to electricity are mango, rice, shallot, and shea kernel.

**Mango.** Mali's Bamako and Sikasso regions are particularly favorable for growing mango. But to export larger volumes, Mali must handle various issues related to market transport and product handling, notably reliance on cold chains (e.g., fixed and mobile chilling facilities). Considered a production hub, Sikasso would be the logical location to set up a temperature-controlled mango packing house. Areas outside Sikasso not yet connected to the main grid have limited potential for extending or replacing cold-chain packing-house facilities; such areas are mainly served by isolated mini-grids or diesel gensets.

An alternative value chain to fresh mango is processing mango pulp or nectar. Mali has only lightly exploited this value chain due to the lack of transforming infrastructure, irregular sourcing from small-scale farmers, and distance to markets. Excess mango production can be used for dried mango or canning. However, high start-up costs and working capital would be required; this is not economically viable, given Mali's low margins and small scale.

**Rice.** Mali is a net importer of rice. Its rice production system uses gravity-based irrigation without mechanized bulk water pumping or infield irrigation. On the processing end, rice milling (husking) occurs throughout small-scale private milling operations, using both diesel-powered mobile or fixed husking machines and fixed-site mills. However, Malian milled rice is of low quality, with a high volume of broken rice. In some high production areas connected to the main grid (e.g., the 100,000 ha Office du Niger), larger-scale, fixed-site mills have been developed with higher quality rollers that reduce broken rice, thereby adding value to the volume of rice sold.

In addition to pure processing activities, post-hulling bran-hull biomass is used to generate power for the mill and related activities, as well as lighting on the premises and for staff housing facilities.

**Shallot.** Mali could potentially become a major West African exporter of shallot, thanks to favorable growing conditions. Shallot is grown on small-scale farms across the country, and 90 percent of production ends up in local urban markets. Shallots can be provided fresh or variously processed (e.g., dried, crushed, or machine sliced, [potentially] using solar drying panels or improved solar heaters). Electricity is required for only two processes: (i) pounding and drying and (ii) slicing and drying.

Since consumers prefer the fresh form of shallot, the market for transformed shallots is limited, and higher production costs induced by processing cannot be justified. The main opportunity is extending the market season for fresh shallot, capturing value from price fluctuations due to reduced market volumes. More efficient stocking and drying techniques would make fresh shallot available 4–6 months beyond the regular growing season and

over a year for its dried form. Because storage and drying processes require small amounts of power, there is little opportunity for power to add value to the commodity's value chain, especially in areas not yet connected to the main grid.

**Shea kernel.** Mali is a minor market player in kernels and butter, capturing less than 10 percent of global demand. Penalized for poor quality and yield, unreliable supply, and higher costs, Malian kernel exporters can hardly compete with other West African producing countries. Vegetable oil firms in Europe, India, and Japan dominate the global market, while West Africa accounts for only a handful of industrial extraction facilities, some of which work on a toll basis for global companies. Though Malian farmers have an incentive to produce higher quality kernels, they have little incentive to expand their kernel processing capacity, given the limited potential benefits (Derks and Lusby 2006).

Manual processing of shea fruit includes kernel removal from pits; drying, moulding, and grinding kernels into paste; and kneading paste into separate solids and oils. These activities could benefit from mechanization, but weighed against the required investments, the benefits are not obvious, especially given the low labor costs and limited access to capital.

*Sources:* FAO and Authors.

### *POWER DEMAND FROM MINI-GRIDS*

In Mali, households consume 90 percent of mini-grid electricity, which is mainly used for lighting, with peak load occurring during evening hours. The Koury mini-grid, located in a rural community of Yorosso circle (cercle) in the Sikasso region, is operated by SSD Yeelen Kura, a private operator that manages 21 concessions[12] and has started to hybridize its mini-grids with solar PV. In 2012, Yeelen Kura added 100 kWp of solar PV to the existing 112 kW of thermal capacity, making power available 10 hours a day (typically from 3 P.M. to 1 A.M.). Because of the mini-grid demand profile, the solar output produced by PV generators is stored in batteries, which increases energy losses and capital expenditure (figure 5.5).

The Koury mini-grid currently supplies 180 MWh per year, mostly for households. Out of 3,371 households living in the area, 556 are already connected to the mini-grid, at an average consumption level of about 24 kWh per month.

The opportunities for supplying unmet power demand from small-scale commercial and agro-industrial activities in Koury are significant. Although such activities rely mainly on their own diesel or petrol engines or generators, they represent a total potential energy demand of 7,755 kWh per month—about a 50 percent addition to the existing energy production of the mini-grid power plant (table 5.12). Irrigation is not expected to play a significant role for the mini-grids, given that most irrigation in Mali utilizes gravity fed schemes, and small-scale schemes that require water pumping rely on decentralized pumps spread over large areas.

### *POWER SUPPLY OPTIONS AND COMMERCIAL ARRANGEMENTS*

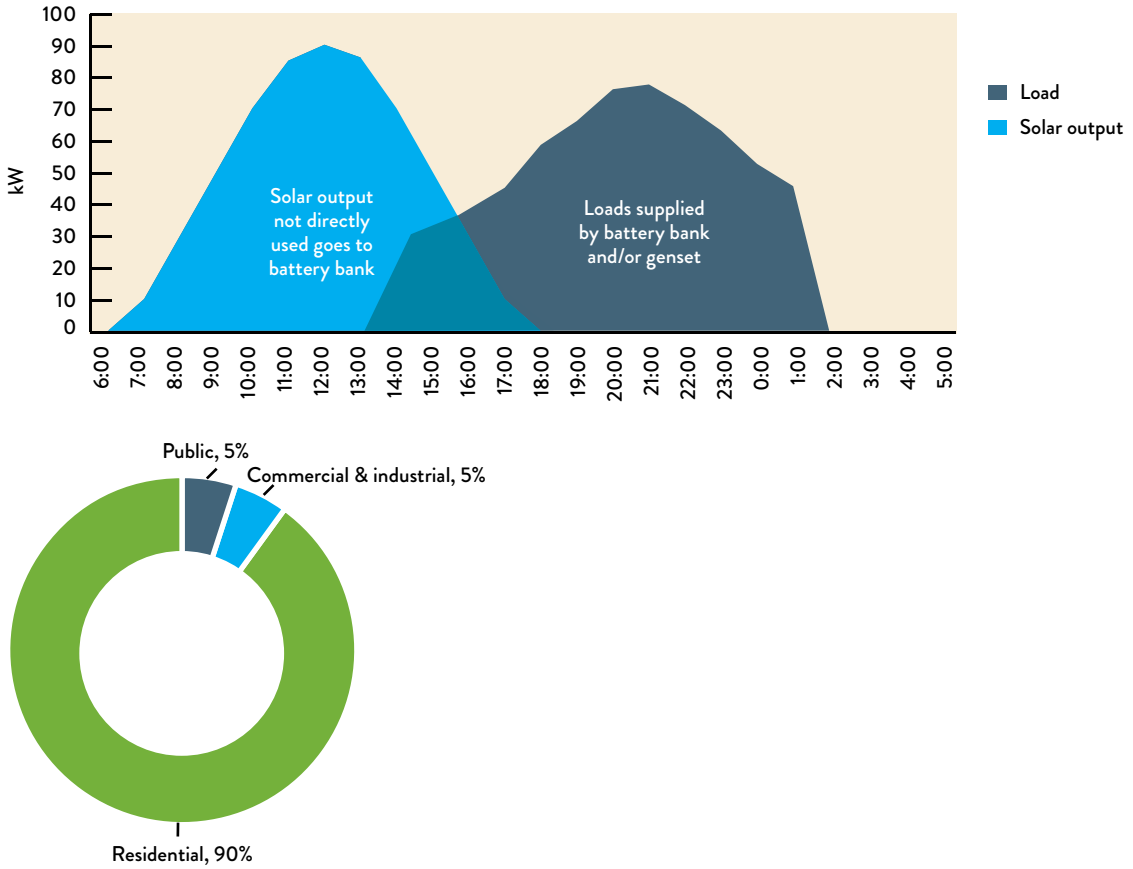
The Koury mini-grid is reaching a near saturation point as generation capacity is fully taken up by current demand. More than 20 percent of the generated electricity is from diesel generators (figure 5.6). The variable cost of thermal generation, at €0.40 per kWh,[13] and the cost of direct consumption (below €0.20 per kWh) suggest the advantages of expanding solar PV capacity.

Notably, expansion of solar PV could enable the electricity provision for productive activities since they require power mainly during the daytime. Direct consumption of solar output would (i) avoid energy losses in the battery bank and (ii) reduce the battery bank size relative to capacity of the solar PV generator.

To attract businesses as mini-grid customers, incentives would be needed to (i) lower tariffs, (ii) supply electricity during the daytime, and (iii) replace manual equipment with electricity powered equipment. Figure 5.7 shows the impact of adding the daytime loads of productive users, along with a 50 kWp matching capacity expansion of the solar PV system (totaling 150 kWp) on the Koury mini-grid load profile.[14]

This capacity expansion is assumed to fall under the existing rural electrification program of the Malian Agency for Development of Household Energy and Rural Electrification (AMADER) and therefore benefits

**FIGURE 5.5:** KOURY MINI-GRID: ELECTRICITY CONSUMPTION PATTERNS



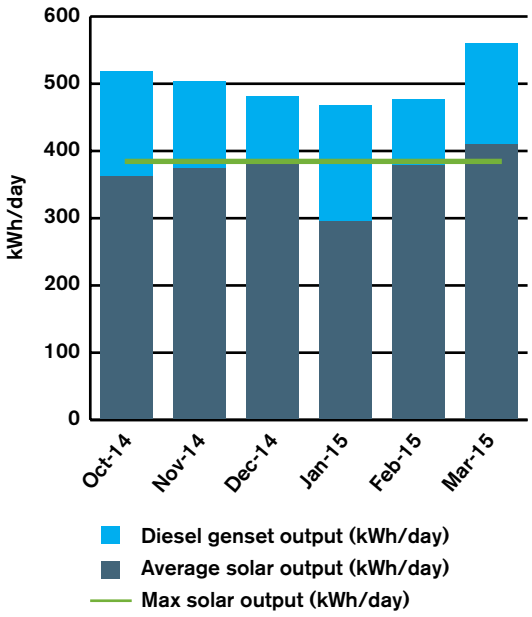

*Source:* SSD Yeelen Kura.

**TABLE 5.12:** POTENTIAL ADDITION OF SMALL AGRO-INDUSTRIAL ACTIVITIES AND OTHER BUSINESSES

| Business Type | Number | Typical Energy Consumption (kWh/month) | Total Consumption (kWh/month) |
|---|---|---|---|
| Milling or grinding (maize, rice, shea kernel) | 6 | 300 | 1,800 |
| Water pumping | 2 | 300 | 2,520 |
| Bakery (electric mixer) | 1 | 300 | 450 |
| Mechanical workshop (welding, grinding, drilling) | 2 | 1,260 | 300 |
| Media center (computer, printer) | 1 | 450 | 135 |
| Petrol station (pumps) | 1 | 150 | 300 |
| Small shops (refrigerators, freezers, TV, lighting) | 10 | 135 | 2,250 |
| **Total** | | | **7,755** |

*Source:* GERES and SSD Yeelen Kura.

**FIGURE 5.6:** ENERGY GENERATION PROFILE AT KOURY SITE




*Source:* SSD Yeelen Kura.

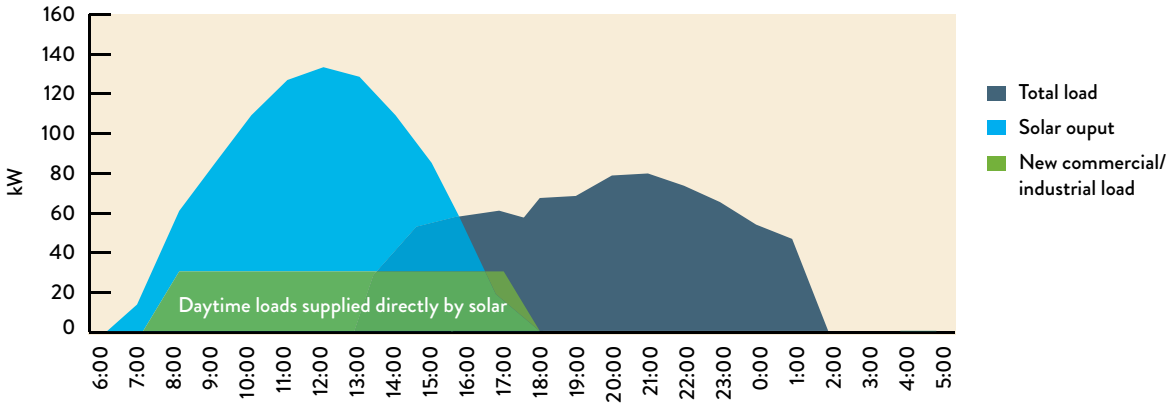
from capital expenditure subsidies, with ownership of infrastructure remaining with the government and the operator regulated under contract.

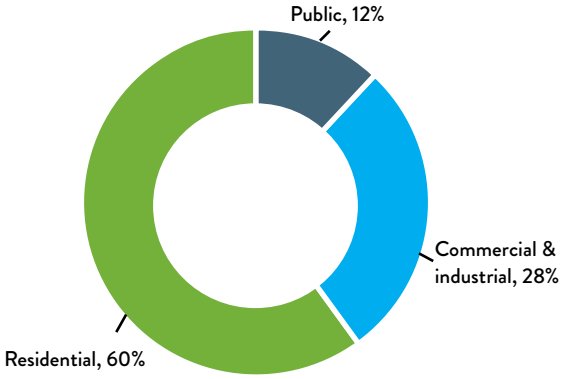
Taking a conservative approach, it is assumed that agro-industrial customers' willingness to pay will be capped at the costs of running individual diesel gensets. This implies that the tariffs needed would be lower than current household tariffs.

### *FINANCIAL ANALYSIS*

From the perspective of SSD Yeelen Kura, the current financial situation of the Koury mini-grid is somewhat precarious (table 5.13, figure 5.8). Although operating expenses are covered by revenues, the 20 percent capital expenditure contribution of the private operator is not recovered through tariffs. In order to achieve a 10–15 percent return, the project receives up to 80 percent of capital expenditure subsidy from the government. Equity investment and reinvestment in capacity expansion and replacement of major parts (e.g., batteries and gensets) cannot be recovered.

**FIGURE 5.7:** KOURY MINI-GRID PROFILE: ADDITIONAL COMMERCIAL AND INDUSTRIAL LOADS




*Source:* SDD Yeelen Kura.

Economies of scale, daytime energy use, and falling solar PV prices imply that the expansion project could be attractive as it allows for additional revenue with relatively low capital expenditure and operating expense. The operating costs will marginally increase due to higher expenses in maintenance and administration, but will be offset by a lower level of generation losses due to direct consumption of solar power (reducing the need for storage) and lower use of thermal generation. Along with the capital subsidy to the developer, this implies a lower average tariff and creates the incentive for new customers to switch from their current diesel generators to daytime electricity consumption from the mini-grid. Largely as a result of the significant capital subsidies, the expansion in generation capacity is financially viable from the perspective of SSD Yeelen Kura, with a positive NPV (table 5.14). However, if viewed from the perspective of AMADER or the Government of Mali, the asset owners, the financial returns are negative (essentially including the subsidy costs in the calculation).

**TABLE 5.13:** CURRENT FINANCIAL SITUATION OF KOURY MINI-GRID

| Item | Amount |
|---|---|
| Households served (no.) | 556 |
| Average total consumption (MWh/year) | 160 |
| Average retail tariff (€/kWh) | 0.55 |
| Payment rate (%) | 80 |
| **Revenues (€)** | **70,500** |
| **Operating costs (€)**[a] | **55,400** |
| **Capital costs before subsidy (€)**[b] | **831,000** |
| **Capital costs after 80% subsidy (€)** | **166,200** |
| **NPV after subsidy (€)** | **(259,700)** |

a. Including corporate overhead and fuel, maintenance, and administrative expenses; excluding depreciation.
b. Including the cost of solar and diesel powered generation and battery storage, as well as costs of the distribution network, civil and electrical works, and engineering; current (2015) costs are used (i.e., €5,300 /kWp, excluding the distribution network).

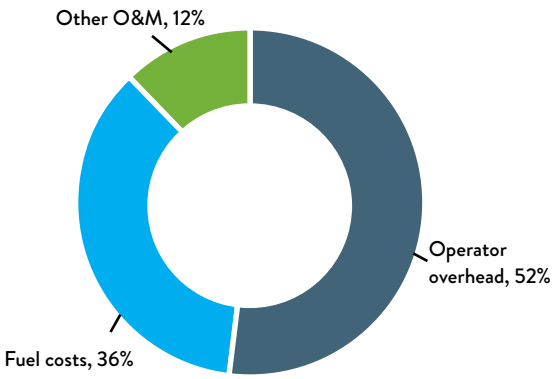
**TABLE 5.14:** FINANCIAL ANALYSIS OF CAPACITY EXPANSION OF KOURY MINI-GRID

| Item | Amount |
|---|---|
| Commercial and industrial customers served (no.) | 20 |
| Average total consumption (MWh/year) | 80 |
| Average retail tariff (€/kWh) | 0.40 |
| Payment rate (%) | 90 |
| **Additional revenues (€)** | **28,800** |
| **Operating costs (€)**[a] | **5,600** |
| **Capital costs before subsidy (€)**[b] | **189,000** |
| **Capital costs after 80% subsidy (€)** | **37,800** |
| **Project cash flows NPV after subsidy (€)**[c] | **103,000** |
| **Project IRR (%)** | **56** |

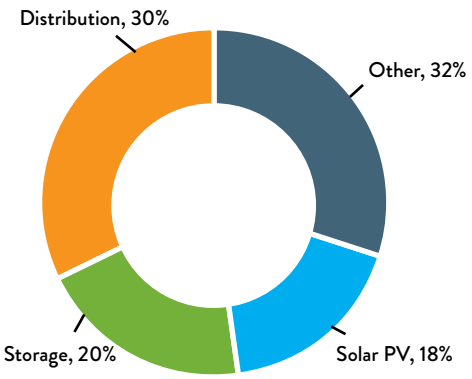
a. Including the cost of fuel and increased maintenance and administrative expenses; excluding depreciation.
b. Including an additional investment of 50 kWp of solar PV; assumes no additional expense in the distribution network.
c. Additional parameters affecting cash flows and thus the calculation of NPV include (i) reinvestment in batteries (every 6 years) and inverters (every 12 years), which are not subsidized; (ii) increased fuel costs, given a PV system degradation rate of 0.5 percent per year; and (iii) a 10 percent weighted average cost of capital (WACC).

**FIGURE 5.8:** OPERATING EXPENSE AND CAPITAL EXPENDITURE DISTRIBUTION

a. Operating expenses




b. Capital expenditures



Similar to most other mini-grid projects in Mali, the Koury mini-grid is not financially viable without large subsidies. While capacity expansion to integrate commercial and agro-industrial loads would improve the financial performance slightly, it is unlikely to be enough to make the grid financially sustainable without subsidies. Some measures that could improve mini-grid performance include implementing better load management practices to reduce energy storage needs, reducing administrative expenses, and enhancing revenue collection through prepaid meters and remote monitoring. Despite these potential improvements, the profitability for hybrid solar-diesel mini-grids would require a revision of the subsidy structure and current tariff levels.

To reach financial viability while serving productive users, capital expenditure subsidy requirements, under assumptions for a greenfield mini-grid similar to Koury, would have to reach 96 percent of a one-off capital expenditure subsidy for initial development and replacement of major parts. With more optimistic assumptions (e.g., a better load management to reduce solar PV losses, improved revenue collection, and lower battery-replacement costs), the subsidy requirement could be reduced to 77 percent of capital investment.[15]

### *ECONOMIC ANALYSIS*

Solar PV capacity expansion to supply productive users has limited economic benefits. For households and existing customers, the cost of supply would remain the same. No significant benefits are expected to accrue to agro-industrial customers as most would not save significantly on electricity costs by switching from marginally more costly individual generators to the mini-grid. This is unlikely to lead to an expansion in processing activity and thus would have little associated economic benefits, as reflected in the slightly negative economic NPV for the expansion project (−€18,000). However, including additional economic, environmental, and social benefits that are not quantified (e.g., reduction in $CO_2$ emissions and other pollutants or reduced reliance on imported fuels and exposure to price fluctuations) could make the project economically viable with a positive NPV. Benefits could also accrue to the agriculture sector if it has suppressed electricity demand, which can be met much easier through mini-grid capacity expansion rather than expansion in the size of the individual generator.

### *MAIN INFERENCES AND INSTITUTIONAL ARRANGEMENTS*

In order for the potential large-scale opportunities to integrate productive users into Mali's mini-grids to succeed, several major barriers need to be overcome (box 5.2). Available financing for rural electrification is a crucial issue for both AMADER and the mini-grid operators. Insufficient and uncertain availability of funding for capital cost grants has limited AMADER, while private operators cannot afford to scale up on their own.

### BOX 5.2: LARGE-SCALE OPPORTUNITIES FOR POWER-AGRICULTURE INTEGRATION IN MALI

Agribusiness development in Mali could have a critical impact on job creation and poverty reduction. With over 40 million ha of arable land and an irrigation potential of 560,000 ha, Mali's agribusiness sector could benefit from favorable agro-ecological conditions and regional food demand. But constraints along the agribusiness value chain (e.g., lack of access to energy and other basic infrastructure, lack of access to finance, and poor sector governance) limit its development. Beyond developing a value-chain strategy, a spatial approach is promoted to boost productivity growth, diversification, and value addition. Since Mali is a vast country, the creation of growth poles, clusters, and trade corridors in the agribusiness sector has real significance. In the Sikasso region, conversion of the Randgold Resources–operated Morila gold mine into an agro-industrial cluster is an example of opportunities to realize large-scale power-agriculture integration.

Currently, the mine's power demand is covered by cumulative available capacity of about 26 MW, with 187,000 MWh of potential production from 10 diesel generators. Once closed and replaced by the agropole in 2017, estimated power needs may drop to 8–10 MW (Randgold Resources estimate), and Randgold Resources plans

(*continued*)

### BOX 5.2: CONTINUED

to hybridize the generation plant and set up a mini-grid aiming to power medium-voltage agribusiness activities, including the following:

- Henhouse (installed capacity of 130 kW with a monthly consumption of 21,000 kWh).
- Juice production and packaging (installed capacity of 1 MW for 4,000 bottles per hour and 30–60 packets per minute).
- Air-conditioned logistic facility (installed capacity of 20 kW with a monthly consumption between 700 kWh in freshness period and 1,250 kWh in peak season).
- Slaughterhouse (installed capacity of 100 kW with a daily consumption of 2,200 kWh).
- Fish preservation units (installed capacity of 200 kW per unit).
- Carton packaging unit (installed capacity of 2.5 MW).
- Other activities (e.g., aquaculture, mango production, and beekeeping).

The mini-grid also aims to connect 100 small- and medium-sized enterprises (SMEs) that require low-voltage, unitary power below 30 kW for transforming and cooling crops (e.g., cereal, shea kernel, and vegetables). Powering SME activities will also facilitate the connection of 15,000 surrounding households and community facilities. This integrated solution optimizes the use of infrastructure to support large-scale agro-industry projects and secure raw materials and supply inputs through a partnership between smallholders and large players. It can also play a role in bringing rural power to the surrounding community.

*Source:* Randgold.

One way to improve the financial viability of mini-grid operators would be through diversification of the service offering to include other energy solutions (e.g., stand-alone systems).[16] Also, clear regulations with scope for tariff-setting flexibility would improve the ability and incentives for supplying productive customers. In addition, differentiated tariffs by customer type or time of use would allow operators to cross-subsidize between customer categories. Finally, access to capital for productive users is critical. Indeed, agribusiness players willing to connect to mini-grids will have to invest in electric machinery to replace manual equipment.

## ENDNOTES

1. The highly stylized setting of the model is thus less appropriate for considering such value chains as milk, poultry, and even floriculture, which have a different spatial distribution of production. While it is possible to adapt the model to these and other settings, it is considered beyond the scope of the present analysis and left for future work.

2. Based on the model assumptions, irrigation load demand is about one-and-a-half times that of all other power demand combined.

3. Assumes an average mill requires 35 kWh to process 1 MT of sugarcane. For other sugar estates in Africa, per hectare power demand could be significantly higher if the potential for gravity fed flood irrigation is not as high.

4. Assumes 3,000 irrigation hours per year.

5. Assumes that the same operating hours as for processing are applied and that a modern inverter driven batch centrifugal consumes about 1 kWh per MT of sugarcane processed.

6. Using a metric of 0.37 employees per ha and considering 4 workers per house (with no family), there are 233 houses in year 1, which rise to 1,399 houses from year 6 onward.

7. The area occupied (300 $km^2$), average rural population density (94 people per $km^2$), and average population growth rate (2.9 percent per year) are used to estimate the surrounding population.

8. On average, each household has 5 members; the number of households totals 5,700 in year 1, rising to 10,077 by year 20.

9. Assumes that total power demand is half that of residential demand and that nonresidential consumers use electricity roughly 4,368 hours a year.

10. A grid connection is essential for exporting power.

11. Domestic tariff is US¢2.3 per kWh.

12. 2015.

13. Analysis was done in Euro (€) currency since the local currency (CFA Francs) is pegged to the Euro, using a diesel price of 650 FCFA per liter (1€ per liter); consumption of 0.33 liters per kWh; and 20 percent in auxiliary losses, lubricants, and other maintenance costs.

14. Assumes no need for further investments in the distribution network or additional diesel generators.

15. Assumes that integration of at least one-third of daytime commercial and industrial loads, 10 percent reduction in solar PV losses from current levels through better load management, 90 percent revenue collection, 20 percent reduction in administrative expenses, and a 20 percent reduction in battery replacement costs within the next 4–5 years due to battery technology development.

16. Partnerships with suppliers of solar pumps or solar mills could also be attractive since many operators are progressively building on an expertise in solar PV technologies.

# Conclusions

## CHAPTER 6

This chapter highlights the study's key findings on Sub-Saharan Africa's potential for leveraging complementary investments in agriculture and electricity to contribute to the region's rural poverty reduction; these include overall results of the study and case studies, along with key learnings from the common challenges encountered by the case study projects (chapters 4 and 5). It then recommends steps that can be taken to maximize the joint benefits of expanded electricity access and increased value added along the agricultural value chains.

## KEY FINDINGS

### *OVERALL RESULTS*

This study finds that creating opportunities to piggyback viable rural electrification onto local agricultural development depends on a variety of site-specific factors (e.g., scale and profitability of agricultural operations, crop, terrain, type of processing activity, and other local conditions). Rural electrification opportunities will be best created by agro-processing activities that generate electricity demand close to rural population centers, generate adequate income to cover electricity supply costs, are sufficiently large in relation to household demand, and have relatively low seasonal variation.

By 2030, electricity demand from agriculture is estimated to double from its level today, to about 9 GW. Between 2016 and 2030, irrigation is expected to provide about three-fourths of the incremental demand (3.1 GW), with agro-processing accounting for the remainder (1.1 GW). The overall magnitude of electricity demand gives a sense of the investment in generation capacity that will be required to meet agricultural needs and the addition to rural electricity demand that is expected owing to the agriculture sector.

For the 13 agricultural value chains selected, electricity demand could increase by 2 GW by 2030, representing nearly half of the 4.2 GW of potential incremental increase in electricity demand from agriculture. Among the value chains examined, poultry has the largest per hectare electricity demand. Together, maize, rice, and cassava account for 83 percent of total incremental demand in agro-processing to 2030. The largest source of electricity demand for the 13 commodities is commercial irrigation, which has the greatest potential to develop large power loads across a range of farm sizes.

### *CASE STUDY FINDINGS*

The case studies show that power supply options for agriculture and rural electrification benefit from economies of scale. Small-scale power systems (less than 5 MW), which may provide a useful source of power service for agricultural processing and household connections, are rarely financially viable without subsidies.[1] When financial viability is not a key driver (or constraint), a full range of activities can benefit from electric power. Once economic benefits are considered, a strong case can be made for providing effective subsidies to cover gaps in financial viability.

The case studies also confirm that irrigation constitutes the largest power demand from agriculture; without it, demand from agricultural activities (except sugar processing) tends to be small. Large land areas are needed to support a major irrigation load. Economic viability is

likely for all except the most expensive sources of power generation for small loads. Power supplies generate proportionally high economic value, primarily through social and indirect economic benefits.

Among the agriculture schemes examined, only large-scale development of irrigation-based agriculture and sugar estates could justify a large grid connection on a purely financial basis. Their requirements—not all of which are readily available in Sub-Saharan Africa—include relatively clear and empty land with good quality soils, reliable supplies of sufficient water, and high quality physical and market infrastructure. Suitable commodities include those typically cultivated on large-scale farms: maize, wheat, sugar, rice, soybean and barley.

The projects show that successful integration of agriculture and power system development requires physical and market infrastructure to facilitate market access for inputs and produce. In Zambia, for example, the strategic location of the Mkushi farming block has improved its development viability. The farming block is situated alongside the main T2 Highway and Tazara Railway, which connect Lusaka and the Copperbelt in Zambia to Tanzania and on to the Dar es Salaam commercial port, providing access to markets for both inputs and produce (chapter 4, case study 3). In Tanzania, the site of the Mwenga mini-hydro generator is situated far from the main TANZAM Highway between Dar es Salaam and the Zambian border; however, the Tunduma, Mufindi Tea Estates, which drove the mini-grid's development, is located only 10–15 km from the main road (chapter 4, case study 2).

**Key learnings from common challenges.** The main barriers faced by the case study projects are linked to the regulatory environment, electrification planning, and institutional and financial capacity. To succeed, projects must be implemented within a stable legal environment that imposes requirements and provides protection. The right degree of regulation must then be found. Viewing the absence of regulations as an opportunity to reduce costs increases risks considerably because of uncertainty. Light-handed regulation of small-scale electricity systems is generally more favorable to developers and operators. In Tanzania, the small power producer (SPP) framework allows private operators to function as power distributors and retailers, charging fully cost-reflective tariffs.[2] This type of regulation should tackle the economic barriers of unaffordability and uneconomic supply. In Kenya, developers have been reluctant to pursue the opportunity to implement electricity distribution and retail schemes because of untested procedures and lack of precedents, notably concerning retail tariff approbation.

Another major barrier to development is the lack of clear electrification plans (e.g., Tanzania and Kenya). Information about future developments of the national grid and concession protection is crucial for dispelling developers' reluctance and avoiding potential friction from tariff differences between customers. The case of large-scale, mini-grid development in Mali shows how regulation and strong government buy-in can, despite large subsidies, allow for development (chapter 5, case study 2). This example also illustrates that clear power regulations are a necessary, but insufficient, condition for successful project development. For example, Tanzania's Mwenga mini-hydro mini-grid—one of the first projects of its kind to deal with regulations about water rights, land access, import laws, and building permits—has entailed significant delays. This experience highlights the need to extend regulations beyond the power sector to include related sectors (e.g., trade, water, land, and environmental management).

For every case study analyzed, the technical and financial capacity of key institutions—the utility, regulator, and rural energy agency—to implement and permit development is perceived as a challenge. The weak financial status of the utilities prevents them from being able to develop financially viable projects without external support. Furthermore, their cash-strapped situation increases the risk of nonpayment for the power supplied by private developers, which negatively impacts project costs and tariffs and, as a result, power affordability. If feed-in-tariffs (FiTs) are not capped at the utility's avoided costs, the situation could worsen, further deteriorating the utility's viability. From the perspective of power-sector regulators, the extra cost and delays resulting from inexperience in negotiating various supply arrangements may be a hindrance to developing private power generation, distribution, and supply.

In **Tanzania,** grid extension planning is generally a transparent and efficient process, largely included in the Power System Master Plan. Although grid densification is currently the priority for the Rural Energy Agency (REA),[3] grid extension projects, such as the one in Sumbawanga, are also part of the plan, considering the potential economic benefits. However, TANESCO (Tanzania Electric Supply Company Limited) has a fragile financial situation, which has consequences for new project investments.

As the mini-hydro project illustrates, dealing with the social and environmental considerations that any project of this nature raises (e.g., water resource management, forestry, village lands, land acquisition, and environmental management) is still lacking in transparency and coordination. Both the regulatory framework and the processes for project development are open to political interference. Coupled with transmission planning, generation capacity must be developed sufficiently and consistently to support grid extension.

Tanzania generally provides developers clear guidance on tariffs, concession security, and system registration; however, the Mwenga experience shows that application of the SPP framework, particularly in setting tariff levels, continues to place unnecessary pressure on developers. For mini-grid developers, especially those that sell power to TANESCO, the risk comes more from the off-taker. Late payments create financial pressure for the operator. Third-party support can therefore help by providing bridging loans. Land access, another obstacle for project developers, can be overcome by developing mutually symbiotic relationships with the local community and district authorities and gaining their support. Project development is still a complex process. The developer, Rift Valley Energy (RVE), expects to sign about 3,000 agreements to access land over which its network runs.

Tariff affordability for consumers continues as one of the most critical issues for mini-grid development. Although RVE is free to set up its tariffs under the SPP framework, pressure from social and political interests continues to make it difficult to do so. The profitability of projects is therefore supported by significant capital subsidies.

In **Zambia,** favorable conditions have facilitated the design and implementation of the Mkushi farming block and the Mwomboshi Irrigation Development and Support Project (chapter 4, case studies 3 and 4, respectively). At a national level, the Mkushi grid-extension process was efficient and transparent; the Zambia Electricity Supply Corporation (ZESCO) led the feasibility study, with the support of a consulting company. Also, land management was clarified by the 1995 Land Act, which gave investors more visibility and reduced the risks of long-term projects. In addition, some solutions were put in place to improve the financial feasibility of both projects. To overcome the utility's cash-strapped situation, the investment costs of grid extension in Mkushi were shared between ZESCO and commercial farmers. Given the extra profits potentially generated by a more reliable power connection, 10 large-scale farmers agreed to fund half of the capital costs.

Beyond these key success factors, some hurdles still need to be overcome. The inability of national generation capacity to support higher peak load and the resulting load shedding create a major risk for farmers. In response, backup diesel solutions were bought to secure production, and irrigation activities were carefully planned to avoid under-voltage. Even though the irrigation project in Mwomboshi will increase peak load slightly, it will require an increase in national capacity in order to reduce risks. Conscious about the critical role played by agriculture in Zambia's economy, central authorities are actively intending to expand the national installed generation capacity so as to limit shortages and load shedding.[4]

In **Kenya,** small-scale, private-sector renewable energy projects have had little success, despite the large number of FiT applications, owing to their high development and transaction costs. Although permits for self-generation are straightforward and allow industrial firms, notably in the agribusiness sector, to lead renewable energy projects, it may take up to three years to acquire licensing and securing of land. The power regulator is working to streamline licensing procedures for projects relying on FiTs. Also, land and way-leave issues can be mitigated thanks to the involvement of project beneficiaries.

A second major concern in Kenya is related to the private sector's involvement in electricity distribution and supply. Currently, Kenya Power and Lighting Company (KPLC) is the only licensed company undertaking distribution and supply activities. The regulatory framework is still unclear on whether other companies are legally allowed to enter this business. Other obstacles concern tariffs and subsidies. Although not explicitly required under the regulations, retail tariffs cannot be higher than KPLC's tariff schedule. This principle could jeopardize the financial viability of any small-scale initiative. Moreover, subsidies are not available for private companies.

## RECOMMENDED ACTIONS TO PROMOTE POWER-AGRICULTURE INTEGRATION

Power utilities in Africa, like those elsewhere in the world, often focus exclusively on their own business, rarely

venturing outside their limited realm of expertise. But a narrow institutional approach—focused only on wires, poles, and consumer billing—means that many of the potential development benefits from electricity remain unrealized. When used by a combination of households, commercial businesses, industry, and agriculture, electricity provides a wide array of benefits and revenue. Ignoring these broader possibilities not only limits the possible benefits for communities and the country overall; most importantly, it neglects the potential revenue for power producers from the increased electricity sales.

### *IMPROVE INSTITUTIONAL COORDINATION*

In order to realize their full potential as providers of electricity service, power companies need to engage with related programs to develop complementary strategies. In the case of agriculture-power integration, this means establishing electricity expansion strategies in collaboration with rural development, agriculture, and other institutions and agencies.

Such complementary strategies can take several forms. One is to provide electricity to those rural areas with the most potential for commercial activities, which is typically the case. For example, electricity can be prioritized in areas with a large irrigation potential, combined with access to markets for agricultural goods. Machinery used in agricultural production, including small threshers, can be promoted as part of a package to encourage electricity use in agriculture. For areas receiving electricity for the first time, agricultural fairs can be set up by local governments to demonstrate the possible machinery that can be used in agriculture.

### *INTEGRATE PLANNING OF POWER, AGRICULTURE, AND RURAL DEVELOPMENT*

Coordination with related institutions and agencies can also benefit the electricity companies. Once a rural development agency realizes that an area is to receive electricity, it may make plans to include those communities in its program, meaning that the region would have access to electricity in conjunction with other inputs important for rural development. Thus, institutional cooperation can work both ways; that is, electricity companies can prioritize certain regions with existing or potentially high levels of agricultural production, while rural development or agricultural agencies can also target areas that will be able to take advantage of the many possible productive use impacts of electricity. The benefits of breaking down institutional barriers between power, agriculture, and rural development programs result in higher revenues for the utility companies and higher levels of development for regions and countries.

### *PROMOTE FARMERS' PRODUCTIVITY*

For their part, the electricity companies can promote internal units responsible for demand-side management and encourage the productive and efficient use of electricity. Productive use units can be responsible for promoting the adoption of productivity enhancing machinery in agriculture, from planting to irrigation and harvest. Such units can coordinate with other organizations, such as farmer associations, nongovernmental organizations (NGOs), and various other local- and regional-level organizations already working closely with farmers to increase productivity.

The barriers to farmers' productively using electricity in rural areas are relatively easy to overcome. They typically include a lack of simple knowledge about available machinery, lack of a local vendor, and inability to purchase machinery on credit. Given the high expense of using diesel-powered engines for grain processing, campaigns could be developed by local governments to promote the substitution of electricity for diesel engines among farmers in areas just gaining access to electricity.

In many countries of Sub-Saharan Africa, lines of credit to farmers and other agricultural entrepreneurs could be augmented by local banks so as to enable the adoption of new machinery (e.g., irrigation pumps, mills, and small stationary threshers). In many cases, existing lines of credit are mainly for seed and other supplies provided at the beginning of the growing season, with loans paid off after harvest. The electricity companies could work with banks and other credit agencies to set up credit lines specifically for the purchase of electric machinery.

## ENDNOTES

1. Exceptions may include hydropower and biomass. Under favorable geographical conditions, low-cost hydropower can be provided; also, biomass can support agricultural activities, but seldom beyond those of the agriculture estate.

2 Especially for systems under 100 kW, for which no approval is required from the Energy and Water Utilities Regulatory Authority (EWURA), Tanzania's sector regulator.

3. Tanzania's rural electrification planning is led by the REA, with the operational support of TANESCO and support of development partners. The July 2014 National Electrification Program Prospectus identified key development centers for connection to the main grid, which will not be effectively initiated before 2016. While the prospectus suggests that some flexibility in identifying additional centers could be considered in order to develop synergies between power and agriculture, such uncertainty can be unhelpful to planners of rural electrification projects.

4. In addition to these technical issues, environmental considerations must be taken into account. The impacts of these projects on the environment, especially those that involve dam construction, have a non-negligible significance.

# ANNEXES

# Annex A: Business Models for Agricultural Development

Attaining productivity increases by focusing on small-scale agriculture and small- and medium-sized agribusiness enterprises, as compared to larger scale commercial systems, is a major challenge. Larger scale farming provides economies of scale in production and input supply, including finance. This is particularly observable for relatively large, uneven investments (e.g., machinery, irrigation, and electricity installation) or working capital needs. Smaller farms tend to be less efficient when collateral requirements affect their ability to raise working capital (Collier and Dercon 2009).

However, this does not mean that one farming system should entirely preclude the other as there are examples of successful crop-specific, small-scale projects, particularly in the higher value commodities. Meeting growing demand will require improved performance of informal value chains and their linkage with formal value chains to gain much needed capital, knowledge and skills, and market contacts. Achieving this will require a more flexible approach to farming systems, currently being evaluated, whereby farming is seen as a business, with small-scale farmers and their communities forging stronger linkages with modern agribusiness. The key is to ensure economies of scale around aggregated small-scale farmer models linked to larger commercial agribusiness. For example, new integrated small-scale farmer models are being tested in northern Ghana with the development of a commercially run, professionally managed maize farmers association, Masara N'Arziki. Such small-scale farmers associations are being developed with the technical help and financial support of commercial inputs and commodity marketing companies; Masara N'Arziki currently has more than 10,000 small-scale members producing over 100,000 MT of maize for local and regional markets.

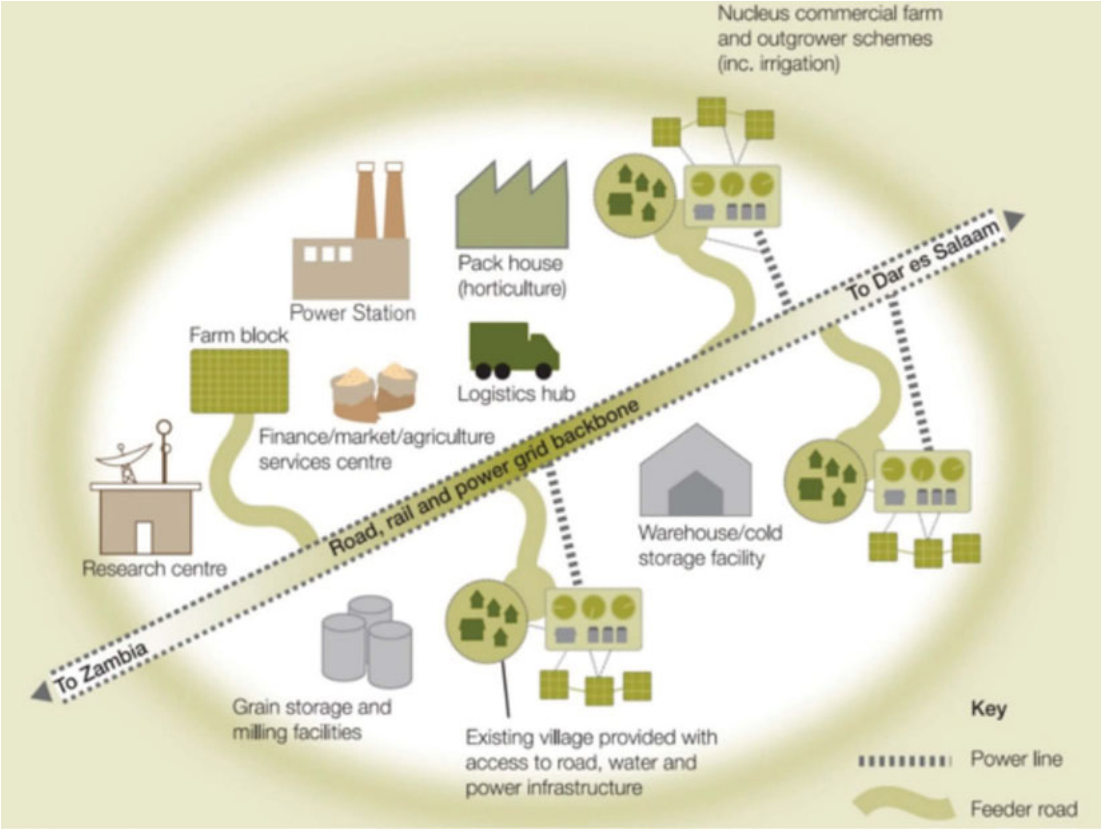
Other models that create scale include the **nucleus farm hub and outgrower models**. These allow small-scale and emergent farmers to benefit from access to infrastructure, including irrigation, lower cost inputs, processing and storage facilities, finance, and markets. Adjacent villages can be linked to water and power supplies at low marginal cost. In cases where nucleus farms and outgrower schemes incorporate community-owned land on a leasehold basis, local residents can be given an equity share in the farming business, as well as access to low-cost irrigation. Likewise, farmer producer associations can be integrated into commercial value chains through outgrower or contract farming models.

Other evolving agribusiness models enable the **"crowding in"** of both public and private **investment into defined areas** of a country. Due to economies of scale, farmers and agribusinesses are most likely to be successful when they are located in proximity of each other and related service providers. Such programs as the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) is focusing initially on 5–6 **clusters** within the southern corridor where there is potential, over time, for profitable groupings of farming and processing to emerge.[1] Each cluster requires investment along the full agriculture value chain. Some of these investments are public goods (e.g., rural infrastructure and electrification) that must come from the **government and its development partners**; others can expect to earn a financial return and will come from the **private sector** (figure A.1).

Building on existing operations and planned investments, the clusters are likely to bring together agricultural research stations, larger nucleus farms and ranches with outgrower schemes, commercially focused farmer associations (like those described above), irrigated block-farming operations, processing and storage facilities, transport and logistics hubs, and improved "last mile" infrastructure to farms and local communities.

When occurring in the same geographical area, these investments result in strong synergies across the agriculture value chain, helping create the conditions for a competitive, low-cost industry. Similar corridor programs are operational in Mozambique (e.g., Beira Agricultural Growth Corridor), while others, such as the Lakaji Corridor in Nigeria, are still in the design stage.

**FIGURE A.1:** EXAMPLE OF AN AGRIBUSINESS CLUSTER




*Source:* SAGCOT Investment Blueprint, AgDevCo, and Prorustica.

The aim of creating simultaneous coordinated investments can also be found in the concept of **growth poles**. Rather than being oriented around addressing identified market failures, growth pole projects center on exploiting opportunities that already exist. The underlying assumption about the benefits of growth poles is that they increase market size so that it becomes profitable for firms to invest, with the resulting higher wages and economies of scale. Notable agriculture-related growth pole programs include those now being developed in Burkina Faso (e.g., Bagre Growth Pole Project) and the Democratic Republic of the Congo (e.g., Western Growth Poles Project). The Western Growth Poles Project also includes development of a special economic zone to provide land equipped with critical infrastructure and a more conducive business environment for investors and private-sector operators.

The forces driving the evolution of the design and development of these types of programs are the demands of modern agribusiness and commercial agriculture for new technology, finance, and logistics. To ensure their success, larger agricultural systems are needed, be they stand-alone commercial farming and agribusiness enterprises or those linked to business focused, integrated small-scale organizations. All of these agricultural systems require viable and reliable power sources. The primary power requirement of commercial agribusiness clusters is **irrigation**, which can increase yields, reduce risk, and allow for winter cropping and **post-harvest processing and storage** activities; locating these activities closer to production can reduce transport costs and allow for increased value capture closer to the point of production.

With a focus on particular regions for agribusiness development in place, the aim of governments should be

to **encourage anchor investments that require reliable sources of power**. Building up a critical mass of such investments should lead to a trigger point, whereby investments in grid extension and cluster electrification are financially and economically feasible. Reaching this tipping point will allow for the "crowding in" of additional related investments into the region to exploit the value-chain opportunities and economies of scale. These activities, in turn, will lead to **opportunities to electrify local businesses and community customers**, whose low levels of power consumption would not otherwise have justified electrification.

## ENDNOTE

1. Kilimo Kwanza Executive Committee, *Investment Blueprint* (Dar es Salaam: SAGCOT, 2011).

# Annex B: Agriculture Fuels for Power Generation

In addition to providing demand for power, certain agriculture activities provide a supply of power. Agricultural products that may be used as fuels for power generation can be categorized as direct burning fuels or fuels that are the product of chemical conversions. This annex outlines three of the more common forms of power supply from agricultural activities.

## BIOMASS

Biomass is biological material derived from living or decaying organisms. In the context of biomass energy, the term often refers to plant-based material; however, biomass can apply equally to animal- and vegetable-derived material. As it is growing, biomass takes carbon out of the atmosphere, and returns it as it is burned. Biomass for energy can include a wide range of materials. High-value material, such as good quality large timber, is unlikely to become available for energy applications. However, resources of residues and waste could potentially become available, in quantity, at relatively low cost. In the context of Sub-Saharan Africa, the main categories include agricultural residues from harvesting and processing and high-yield crops grown specifically for energy applications. Plant-based material include**s wood (sawmill waste), nutshells, agricultural wastes (e.g., rice husks), corn stover, and cassava peels.**

An assessment for the West African Economic and Monetary Union (UEOMA) countries suggests that agricultural residues amount to about 10 metric tons (MT) of stubble per ha of maize, 5 MT of dry matter per ha of sorghum, 4 MT of straw, 2.5 MT of bran per ha of rice, and 2 MT of tops per ha of groundnut and cowpea (UEMOA 2008). In many countries, these are sources for traditional, as well as modern, utilization of biomass energy.

## BAGASSE

Bagasse—the fibrous matter that remains after sugarcane or sorghum stalks are crushed to extract their juice—is used as a biofuel in many sugar estates around the world. In sugar production, every 10 MT of cane crushed produces nearly 3 MT of wet bagasse. The high moisture content of bagasse, typically 40–50 percent, is detrimental to its use as a fuel. For electricity production, it is stored wet, and the combination of the mild exothermic reaction resulting from the degradation of residual sugars, along with exposure to air, light, and heat, dries the bagasse pile slightly.

Bagasse is used primarily as a fuel source for sugar mills. When burned in quantity, it produces sufficient heat energy to provide both electricity and heat (including steam) to supply all the needs of a typical sugar mill, with energy to spare. At some sites, surplus electricity is sold to third parties (including feeding in to main grids).

## BIOGAS

Anaerobic digestion is a natural process, whereby plant and animal materials (biomass) are broken down by microorganisms in the absence of air. The process begins when biomass is placed inside a sealed tank or digester. Naturally occurring microorganisms digest the biomass, which releases a methane-rich gas (biogas) that can be used to generate renewable heat and power. The remaining material (digestate) is rich in nutrients, so it can be used as a fertilizer.

A biogas plant can be fed with such crops as maize silage or biodegradable wastes, including sewage sludge (animal and human) and food waste.

Four types of technology can be used to convert the chemical energy found in biogas into electricity. In biogas conversion, the chemical energy is converted into mechanical energy in a controlled combustion system. The mechanical energy activates a generator, producing electrical power. Gas turbines and internal combustion engines are the most common technologies used in this type of energy conversion.

At the village level, biogas plants can be built to convert livestock manure into biogas and slurry, the fermented manure. For small-scale farmers, the technology is feasible for those with livestock producing 50 kg of manure per day, an equivalent of about 6 pigs or 3 cows. This manure is collected and mixed with water and fed into the plant.

# Annex C: Description of Processing Activities

## POST-HARVEST AND PRIMARY PROCESSING

**Cleaning drying**. Many of the basic drying techniques rely on solar energy through sun drying (e.g., such cereals as wheat and maize). Slightly more rigorous drying technologies use energy input for heating boilers; this energy may be in the form of electricity, but often is biomass (farm waste) or liquefied petroleum gas (LPG). The latter techniques are more common for fruits, vegetables, and meats with a high moisture content (i.e., about 60–80 percent) which must be reduced to a range of 10–25 percent to prevent spoilage.

**Milling**. Mills are used for processing in the value chains of maize, wheat, and rice. Smaller mills may be powered with diesel or electricity, and larger units with electricity only. For maize, the main choice of milling is either a plate mill or hammer mill (often supplied by India and China, and increasingly from local craftsmen). The plate mill can grind both wet and dry products, while the hammer mill is restricted to dry products. Hammer mills are the more prevalent of the two although plate mills are popular in West Africa and Sudan and operate with a greater component of shear than compression. As a rule of thumb, about 1 kW can mill 25–30 kg of produce per hour. Hammer mills have a power requirement in a range of 2–50 kW, while motor-driven plate mills generally demand less power; 0.5–12 kW is usually sufficient. Larger scale hammer mills, with a capacity of 4.5–5 MT per hour, have a power consumption of approximately 75 kW; for fully integrated milling systems, with a capacity range of 2.5–25 MT per hour, power demand is 120–650 kW. These systems can operate year-round, often at nearly constant rates.

The power demand of wheat mills ranges from 20 kW for smaller units up to 600–700 kW for larger ones. Small-scale rice mills can remove the hard husk and polish the kernel. A full rice processing production line (excluding the polisher), with a daily output of 20–30 MT, has a total power demand of approximately 38 kW, whereas a processing line with polishers requires 60–90 kW.

Commercial-scale mills are usually found along main roads with access to national grid power supplies. Diesel power supplies are too expensive for commercial operators to remain competitive, and other sources of power can be unreliable. In many countries, a mill may have a backup diesel generator to compensate for the unreliability of national grid supplies.

**Cold storage**. Control temperature storage is used to reduce the temperature of foods and flowers post-harvest. Cooling or chilling a food product reduces the risk of bacterial growth and allows longer storage of produce without spoilage.[1] In principle, this process enables farmers in relatively remote locations to harvest and store produce for shipment to large demand centers beyond the local markets (including exports). A cold chain is thus a necessary asset for many high-value agricultural products (e.g., milk and dairy products, fish and other seafood, fruit and vegetables, meat and prepared foods) and high-value horticulture and floriculture industries, especially those that are export-oriented. Large storage hubs are often centrally located at transportation centers; however, more localized facilities are often necessary since products deteriorate quite rapidly post-harvest and must be cooled/dried or processed immediately.[2] While grid power is more cost effective, alternative energy sources, including solar power, can be used.[3] For commodities transported fresh to market, cooling systems are often temporary or movable, with commodities packed straight into refrigerated reefers before being moved within days. Reefers can be plugged into any power supply for the short term, and, once in transit, are often powered with diesel gensets.

**Cassava processing**. Roots and tubers (e.g., cassava, potatoes, and yams) have high moisture content, which makes them hard to store and bulky to transport. Cassava is the most perishable of the roots and tubers and can deteriorate within a couple of days of harvesting. This implies that cassava is mostly sold in processed form, and processing facilities and machinery need to be located at relatively short distances from the agricultural lands. The more important traditionally processed products include dried chips, flours/starches, and gari. Most small-scale

chippers and graters are petrol driven, with capacities of 1 MT per hour and a power drive of 3.5 hp, equivalent to 2.6 kW. Large-scale cassava factories are usually located in the vicinity of cassava farms.

**Meat processing**. The core processing equipment consists of hoists for lifting, which can be operated manually or electrically; meat grinders; bowel cutters; cooking vats; smokehouses; and chillers. Refrigeration is generally the most energy-intensive activity in meat-processing facilities. Other uses of electricity include on-site water pumping for washing, electrical elevators, and hoists and stunning guns, with scalding tanks (electrical heating) for pig processing. Modern abattoirs consume energy in livestock holding; slaughtering and processing; monitoring and testing; cleaning; and packing.

**Oil extraction**. Oil extraction from a variety of oilseeds (e.g., sunflower, soybean, sesame, palm oil, and groundnut) results in significant value addition to the final product. While smaller scale extraction is done using a manual press, larger scale commercial systems use motorized presses that rely on electric input. Oil filter presses are used for larger, electricity-powered oil-extraction systems for sunflower, groundnut, and soybean. Once cleaned and de-hulled, the seed is placed under increasing pressure as it is conveyed through a tapered chamber (expelling). Mini extruders, typically with a capacity of 125 kg per hour, require a power drive of about 10 kW, while 400 kg per hr power requirements are approximately 23 kW. Capacity depends on the quality and type of seed (e.g., groundnut capacity is 120–180 kg per hour, compared to sunflower capacity of 280–320 kg per hour using a similar 15–18.5 kW motor).

## SECONDARY PROCESSING

**Thermal treating**. Thermal treating of foods (either heating or cooling) is necessary to destroy microorganisms that could adversely alter food properties or deactivate enzyme action and optimize the retention of certain quality factors at minimum cost, including such processes as pasteurization (e.g., of milk and some fruit juices) and sterilization. Heat exchangers are used on a wide variety of products, including pasteurization of cheese, milk, and other beverages; ultrahigh temperature sterilization; bottled water treatment; and heating of soups, sauces, and starches.

**Canning, bottling, and packaging**. A growing number of foods are packaged to increase their shelf life. Prior to packaging (or canning or bottling), food may be processed (by juicing, peeling, or slicing) to increase value and prevent deterioration (through pasteurization, boiling, refrigeration, freezing, or drying). Each of these processes creates demand for electricity. Packing requires electricity to run machines for vacuum sealing, heat sealing, and bottling; in larger facilities, electricity is needed to power conveyor belts, as well as to run filling, weighing, wrapping, boxing, coding, and printing equipment.

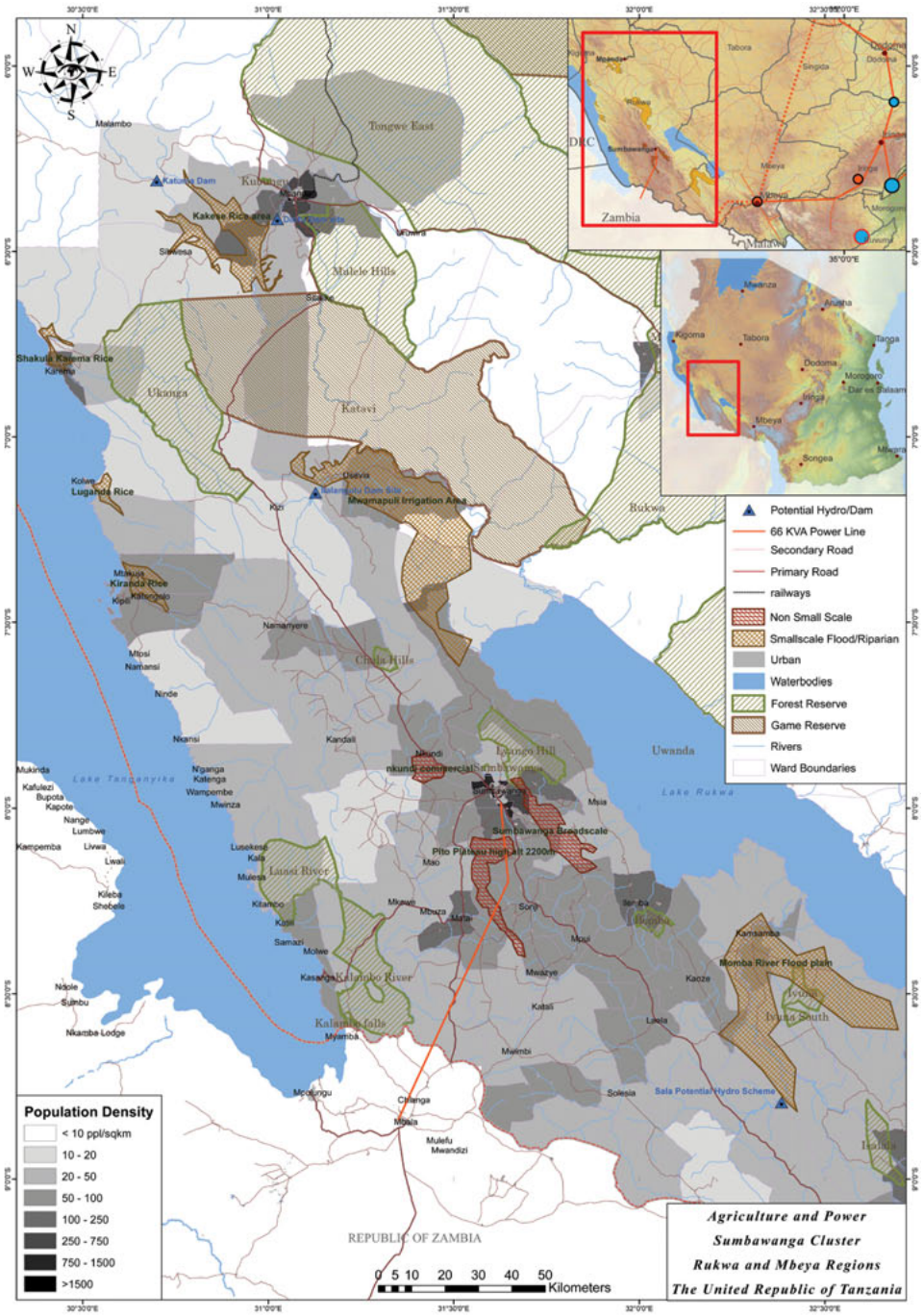
Many of Sub-Saharan Africa's canning and bottling factories are situated in areas where electric power is available and reliable.[4] Modern packing lines require reliable electricity supplies to operate efficiently. As with other secondary processing plants, packaging plants are often supplied with main grid power. The power requirements for juicing and canning is quite low. For example, a juicing machine that can process up to 5 MT of raw fruit per hour may have a peak power load of 5–22 kW. A canning machine with a per-hour capacity of 250 cans (approximately 125 kg) has a power-load range of 5.5–7.5 kW.[5] Given the scale efficiencies of larger facilities, it is difficult to extrapolate to determine the load of a much larger commercial plant without information on the capacity and power demand.

## ENDNOTES

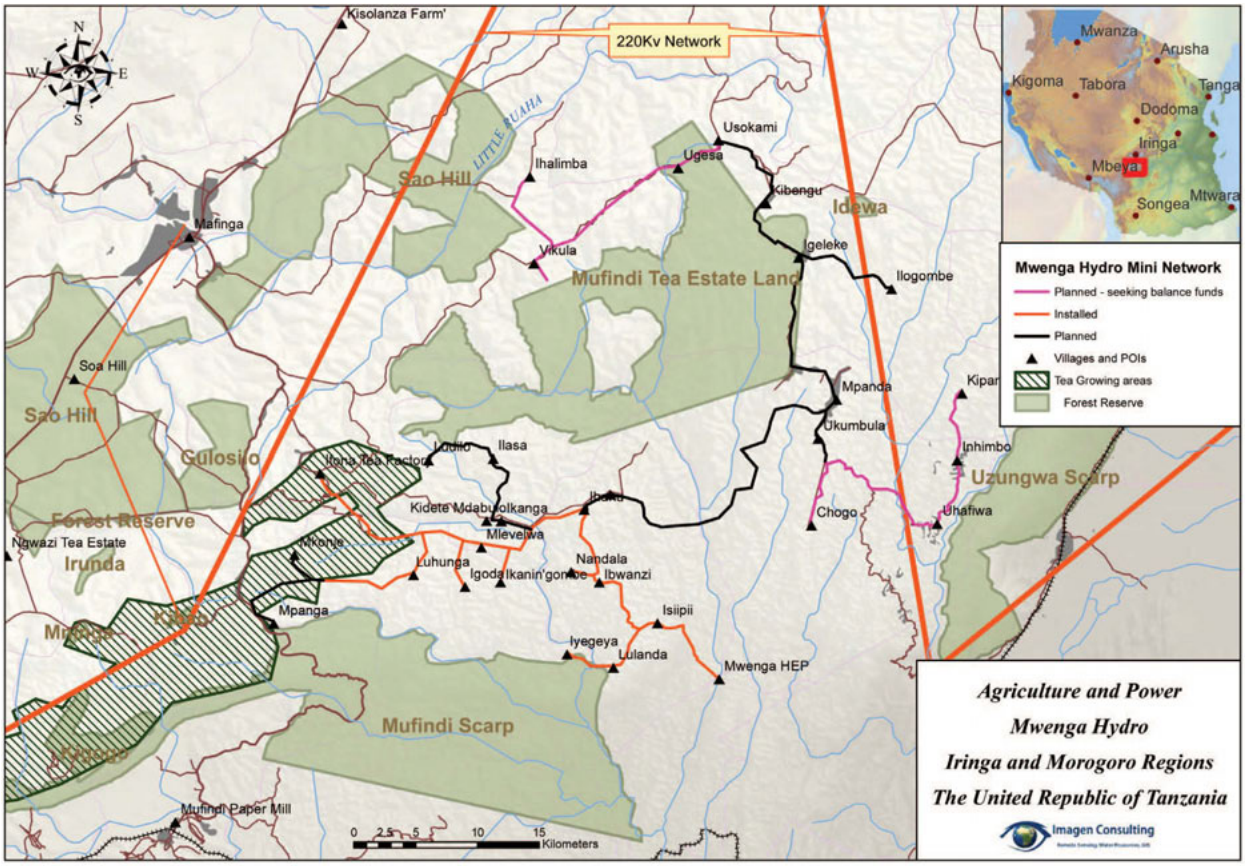
1. Rapid chilling—also known as flash freezing—lowers this risk even further.
2. For some products, the shelf life may be diminished by a factor of eight times the length of delay between harvesting and cooling.
3. With peak demand during daylight hours matching the generation profile of solar power, freezing systems can be switched off overnight when outside temperatures are cooler.
4. Notable canned foods prevalent in Sub-Saharan Africa include pineapple, grapefruit, and tomato.
5. References come from data on plants available for sale on Alibaba.

# Annex D: Maps of Case Study Project Areas

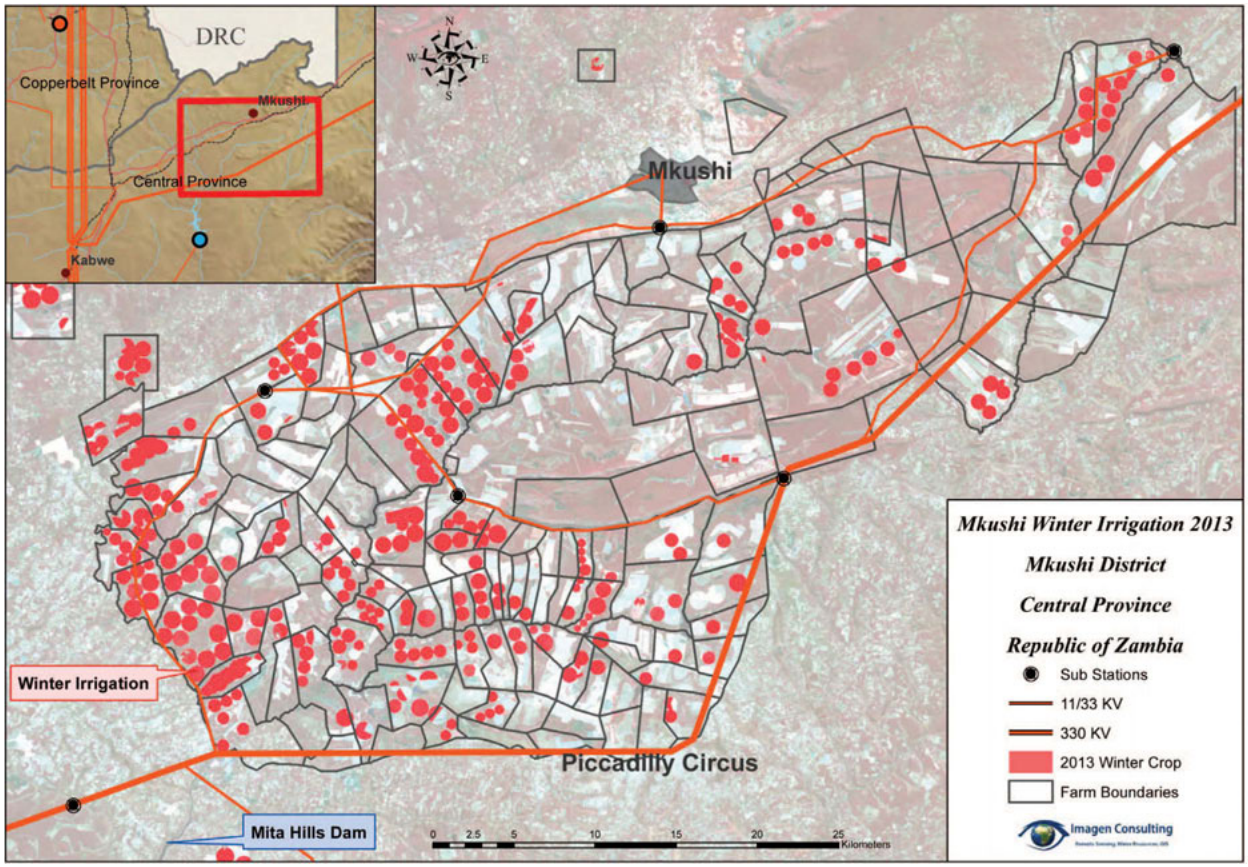
**MAP D.1:** TANZANIA: POWER AND AGRICULTURE IN THE SUMBAWANGA AGRICULTURE CLUSTER



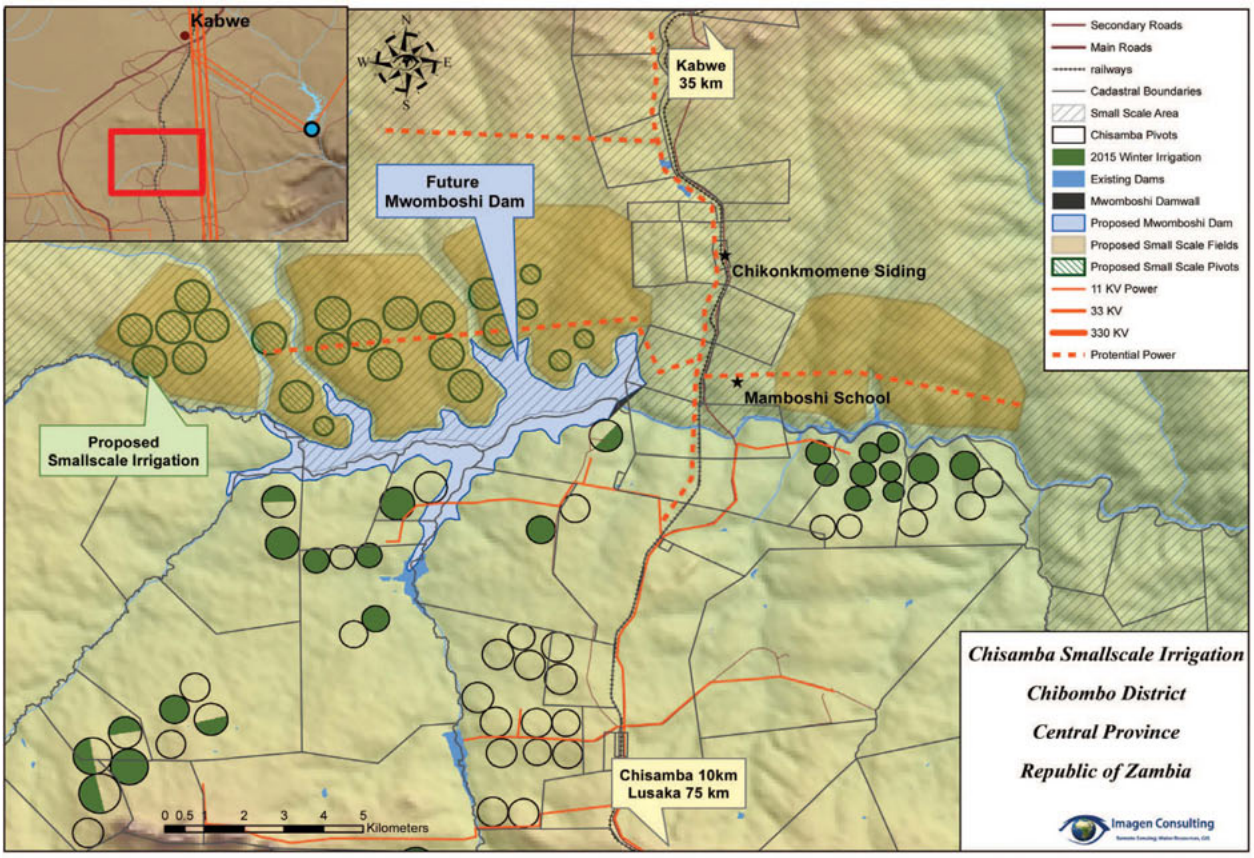
**MAP D.2:** TANZANIA: MWENGA MINI-HYDRO MINI-GRID



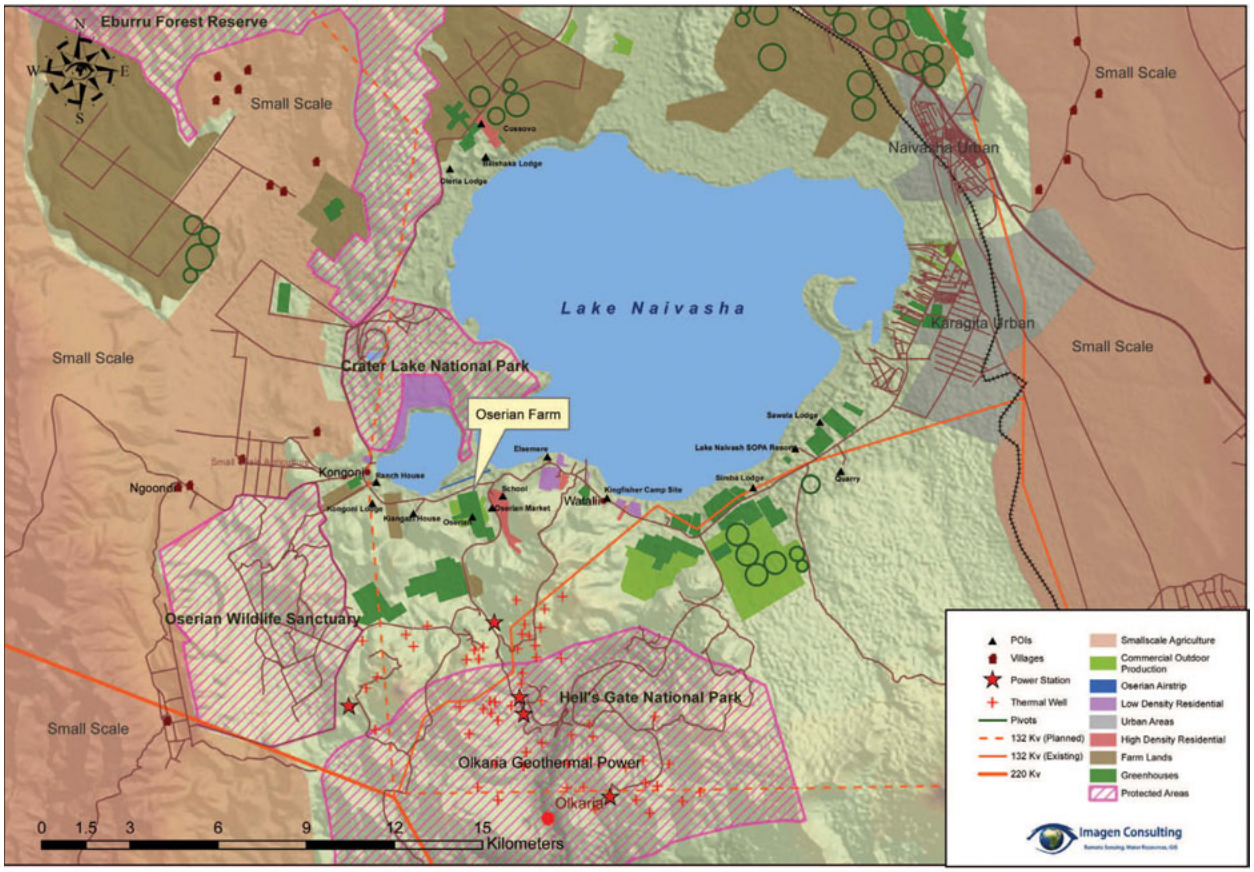
**MAP D.3:** ZAMBIA: MKUSHI FARMING BLOCK



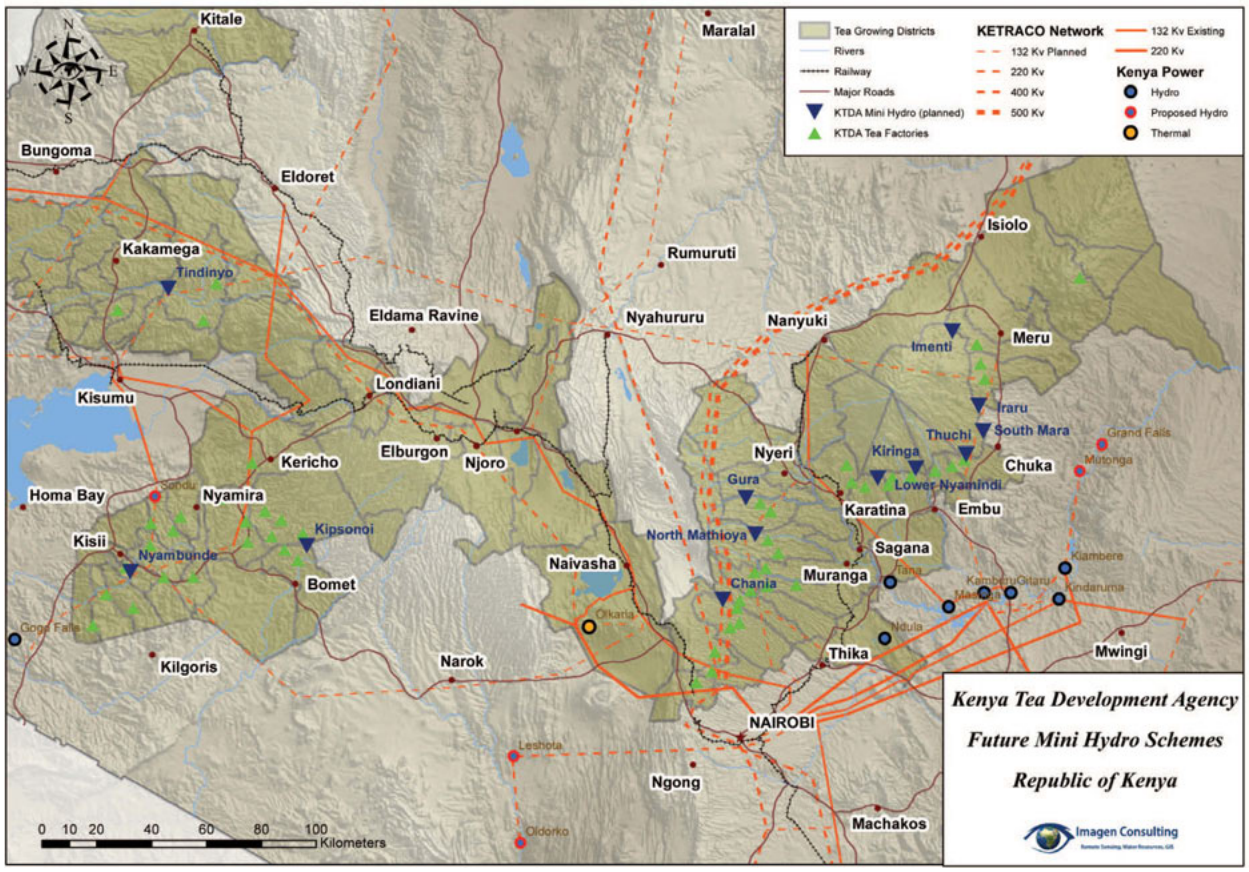
**MAP D.4:** ZAMBIA: MWOMBOSHI IRRIGATION DEVELOPMENT AND SUPPORT PROJECT



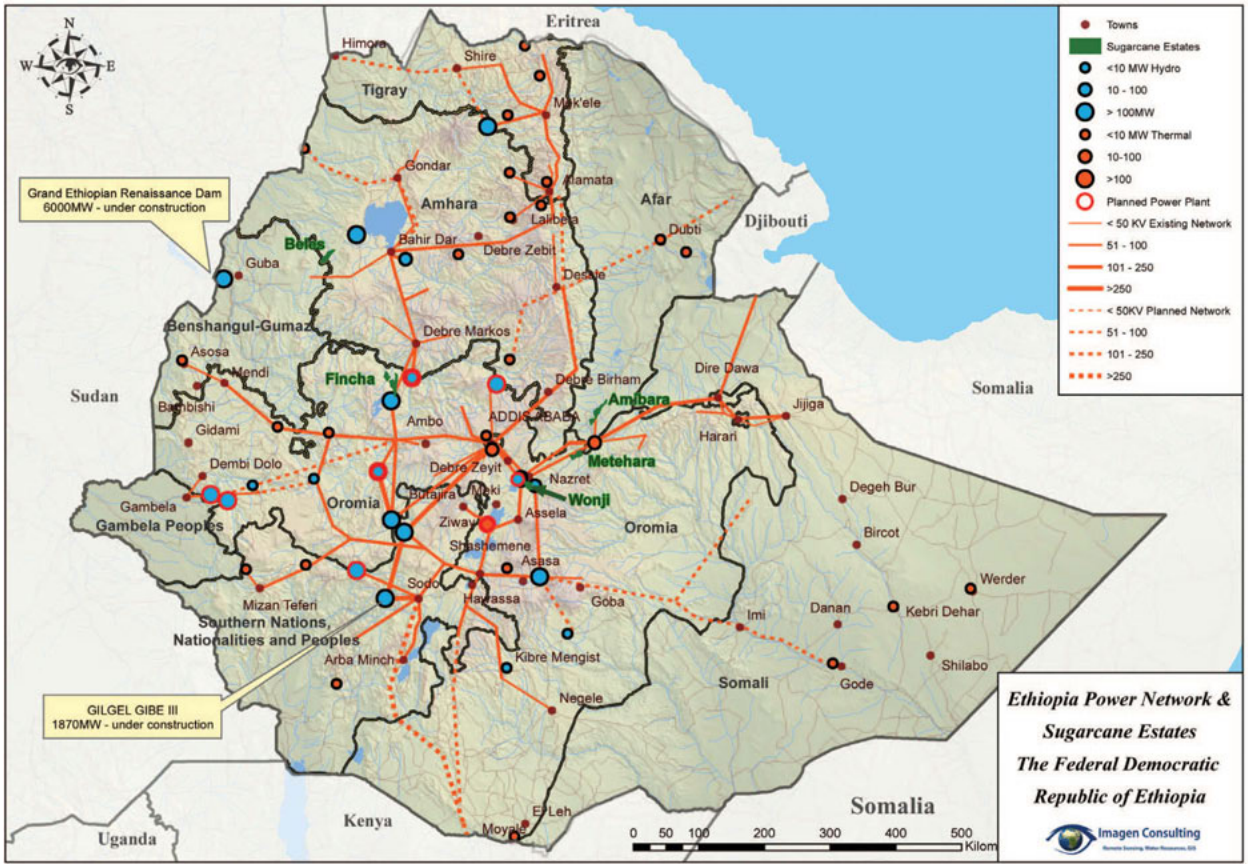
**MAP D.5:** KENYA: OSERIAN FLOWERS AND HARNESSING GEOTHERMAL POWER



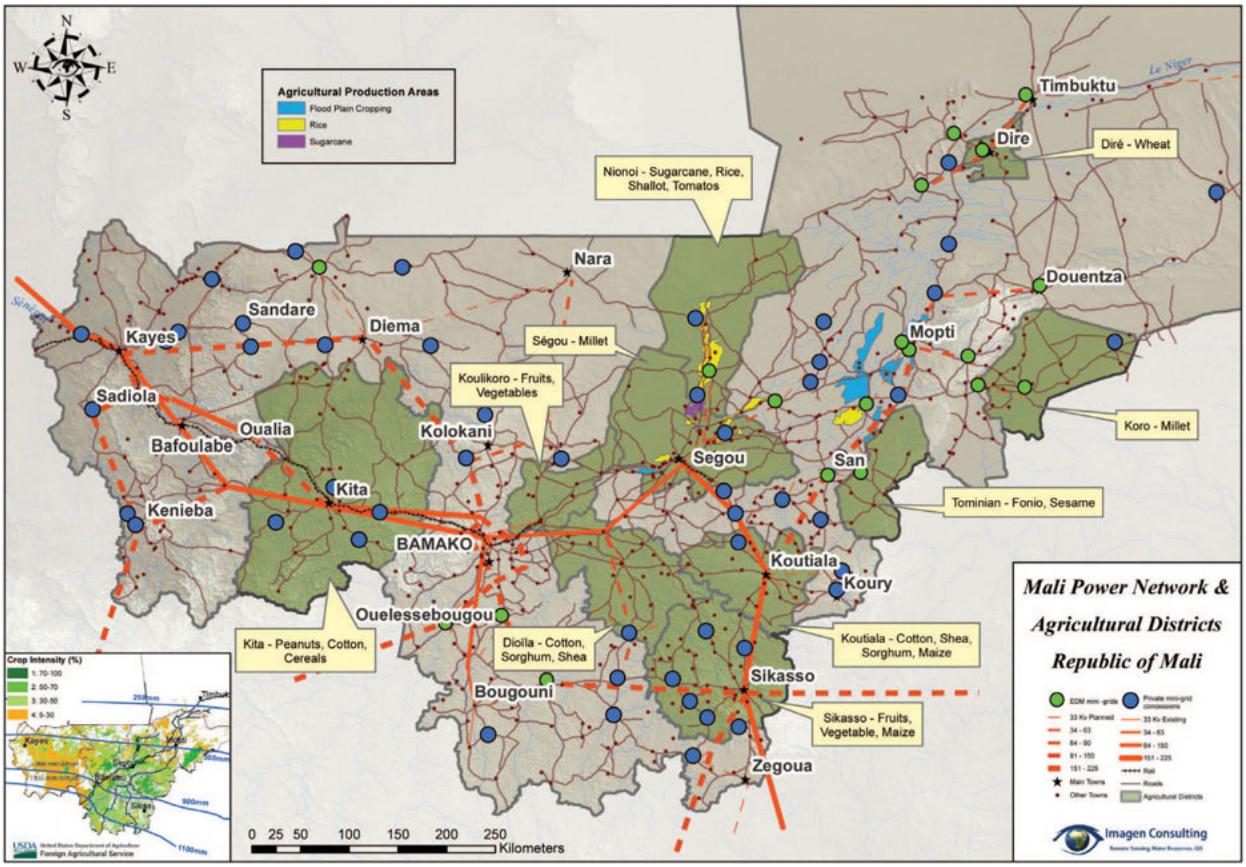
**MAP D.6:** KENYA TEA DEVELOPMENT AGENCY HOLDINGS MINI-HYDRO MINI-GRIDS



## **MAP D.7:** ETHIOPIA: SUGAR ESTATES



**MAP D.8:** MALI: POWER NETWORK AND AGRICULTURAL DISTRICTS



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The majority of households and enterprises in rural Africa cope without electricity, compromising socio-economic welfare and firm productivity. Africa, characterized by low electricity consumption and ability to pay, makes rural electrification commercially unviable.

Agriculture as the most important value added industry in rural areas presents a significant opportunity to improve commercial viability of grid and off-grid projects. This study explores the nexus between power and agriculture, challenges in scaling-up, and recommendations to harness this opportunity.

ESMAP

Africa Renewable Energy Access Program (AFREA)

WORLD BANK GROUP