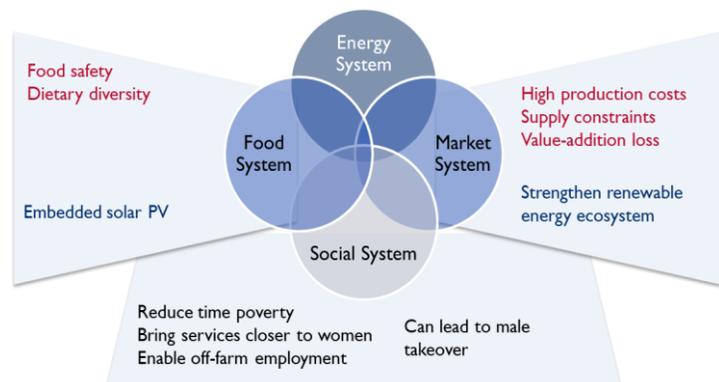


ENERGY OPPORTUNITIES FOR AGRICULTURE SYSTEMS AND FOOD SECURITY PROJECT: Identifying Opportunities Along the Post-Harvest Agriculture Value Chain

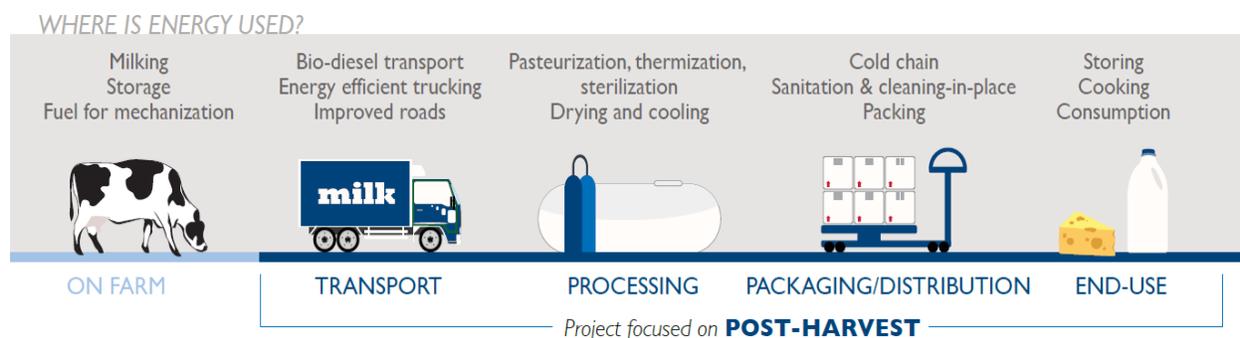
Solutions to food security challenges in Sub-Saharan Africa (SSA) should consider the complex interrelationships of value chains, social and gender dynamics, and enabling environment factors: detailing post-harvest inefficiencies and improving the nexus between agriculture and energy systems that link farms to consumers. The need for reliable distribution, storage, and processing facilities is creating new energy markets within agricultural value chains and food systems. Under USAID’s **Energy Opportunities for Agriculture Systems and Food Security Project (E4AS)** (2017-2018), a team of energy and agriculture and market systems experts, respectively from **Green Powered Technology** and **ACDI VOCA**, worked with USAID program offices and mission representatives in Senegal and Kenya to identify key challenges and opportunities related to access, efficiency, and reliability of energy in agriculture processes that bridge rural agriculture production and urban food demand.

E4AS examined these opportunities through an energy-food-social-market systems lens and combined extensive research and literature review with case study site visits and stakeholder consultations in Senegal and Kenya. The E4AS team examined three key questions:

- What are the key opportunities to increase energy efficiency (EE) and renewable energy (RE) within the agricultural value chains that bridge rural production and urban food demand or export markets?
- How can these opportunities be integrated into policy, partnerships, and planning?
- What role can these opportunities for low-carbon energy use in post-harvest agriculture systems play in achieving a country’s low emission development goals?



Through a detailed scoping process, project selected the **dairy value chain** as the representative focus and Kenya and Senegal as case study countries and emphasizing the **post-farmgate** segments of the value chain, as illustrated below. Dairy was selected partly because dairy products require continuous, reliable temperature and humidity control during processing, storage, transportation, and sale. Interruption of temperature/humidity along the value chain can result in spoilage and loss. Improved energy efficiency or reliable renewable energy solutions at the grid-level, minigrid, or standalone off-grid level can provide reliability, cost efficiencies, and reduce post-harvest loss.



With the capital investment costs of renewable energy technologies continuing to decrease while access to energy services in Sub-Saharan Africa severely lacking in many rural areas, there are opportunities for deployment of renewables, both on-grid and off-grid, exist from a technical and financial feasibility perspective within each segment of the value chain. For the dairy VC segments (milk production, transportation, collection/reception, processing), examples of both on and off-grid include, among others:

Energy Efficiency:

- Variable Frequency Drive (Vfd) Motors
- Improved efficiency of pumps and equipment
- Solar-powered evaporative cooling
- Pre-cooling with ground source heat pumps
- Improved refrigeration efficiency
- Pre-cooling with contra-flow cold water
- Pre-heat using energy from processed milk

- Heating with power from waste heat
- Improved packing equipment efficiency

Renewable Energy

- Solar generated power
- Biofuel generated power
- Solar powered refrigeration
- Solar thermal heating
- Solar drying
- Pre-heating water with solar energy
- Cool with waste heat from biofueled combined heat & power
- Biodiesel-fueled transportation
- Bio-based packing materials

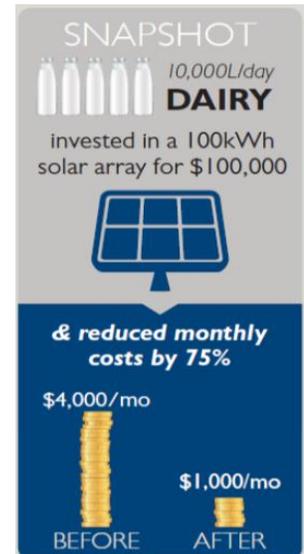
The E4AS team prepared **implementation and technical brief documents** and an **Infographic** to further illustrate several of technical opportunities and related project focal areas, as follows:

- (1) Using solar thermal to lower energy costs for small scale dairy processors
- (2) Solar PV options for small-scale dairy aggregators
- (3) Generating three-phase electrical power from a single-phase source
- (4) Implementation Brief: Assessing Renewable Feasibility for Value Chain Partners

From a **market** perspective, the E4AS team examine the market structures for the dairy value chains, both the formal and informal markets in Kenya and Senegal, looking at market-based opportunities for increased clean energy uptakes. E4AS considered factors such as how private and impact capital investments can fill renewable energy financing gap left by commercial banks and examined before and after scenarios of potential costs savings from clean energy investments, as illustrated in the adjacent figure. Moreover, with an overarching **gender-sensitive** lens, the project also examined how clean energy opportunities in the value chain can provide opportunities to further women’s empowerment, improve livelihood and business opportunities for women, address mobility issues, and further gender equality opportunities.

The E4AS Final Project Report and related deliverables also provided information on opportunities on how potential energy savings from these clean energy opportunities can contribute to low emissions goals of these countries, such as Kenya’s Nationally Appropriate Mitigation Actions (NAMA) in the dairy sector, as well as potential partnerships with ongoing donor and private sector initiatives. Opportunities for integration of an energy considerations into national policy initiatives were also identified.

Additional technical opportunities were detailed in the E4AS Final Project Report and project documents. The Final Report, technical and implementation briefs, and the Infographic are available on the [AgriLinks website](#).

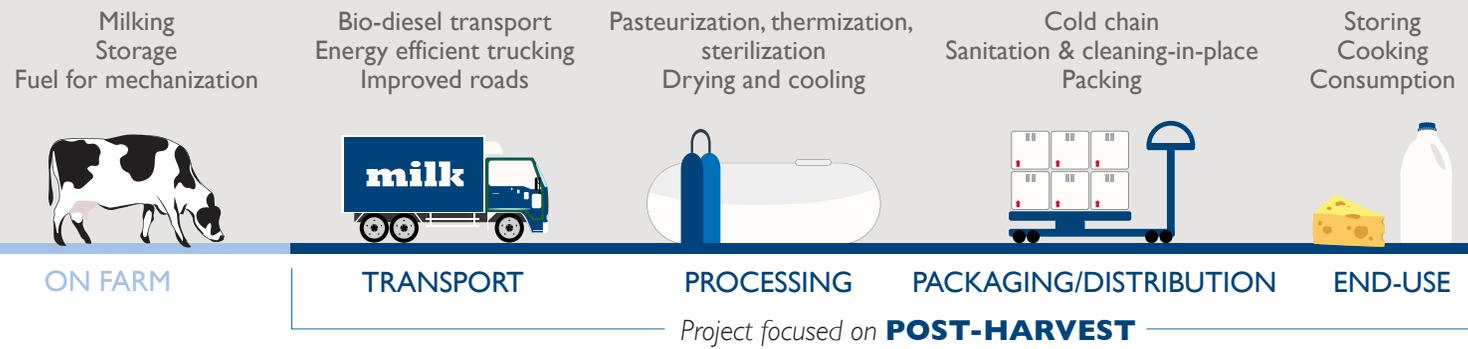


CLEAN AND RENEWABLE ENERGY FOR PRODUCTIVE USE: SPOTLIGHT ON DAIRY

Key Findings from the Energy for Agriculture and Food Security Project

Addressing Energy Constraints in Off-farm Dairy Segments is Critical to Inclusive Growth in Africa

WHERE IS ENERGY USED?



BUSINESS IMPLICATIONS (field work findings)

Reliability

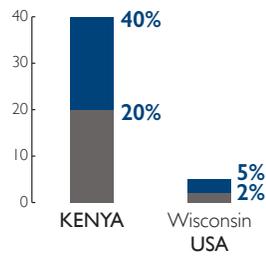
28% rural **SENEGAL** access to electricity

3-5x /week **KENYA** power outages in dairies

+ Many solar products have oversized inverters and batteries, affecting product efficiencies and lifespan.

Expense

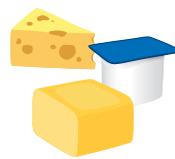
Electricity consumes 20-40% of operating costs in Kenyan small-scale dairies



Outages increase operating costs by: (1) requiring dairies to invest in backup power systems; (2) increasing wear and tear on equipment through frequent stops and starts; and (3) spills and jams on packing lines, with wasted product and labor clean up costs.

Value addition & market access

Yogurt, cheese, & butter require energy to chill and/or heat products



+ Tight delivery times restrict rural market access, divert fresh into fermented milk

Employment



Power outages reduced hiring

24% SMEs, 15% large enterprises in **SENEGAL**

High energy operating costs are a major factor limiting business growth, hiring, or diversification

dairies in **KENYA**

Energy cost savings would go to increased wages

3 of 5 dairies in **KENYA**

Long-term competitiveness



Kenya's dairy sector is formalizing for food safety—energy is required all along this shift. Without it, small operations will struggle to remain competitive.

Hidden Impacts

Energy's hidden impact is on **business growth, food safety, and value addition**. This affects farm-gate prices and demand for producers, employment, and retail prices and product availability for consumers.

The Time is Ripe for Energy-Fueled Agricultural Transformation

MARKET-BASED OPPORTUNITIES TO INCREASE UPTAKE OF CLEAN ENERGY



Small-scale solar chillers extend delivery windows from farm to collection center & refrigerate transport by bicycle, bus or donkey



Solar minigrids increase rural electricity access off-grid and minimize costs and power disruption for those on-grid



Energy efficiency audits for SMEs identify tailored options (e.g. blended solar and on-grid energy models)



Private and impact capital investments can fill renewable energy financing gap left by commercial banks—key due to high upfront RE costs



Infrastructure: Well-maintained, networked roads reduce travel time and fuel use. Access to electricity and potable water reduces spoilage



Waste heat recovery is a relatively simple, inexpensive process that uses pumps, pipes, and heat exchangers to recover waste heat from the chilling process, using it to reduce energy in pasteurization and sterilization. WHR can reduce total energy use by up to 19%.

SME SNAPSHOT

10,000L/day **DAIRY**
invested in a 100kWh solar array for \$100,000



& reduced monthly costs by 75%

\$4,000/mo



\$1,000/mo

BEFORE

AFTER

Empowering Women Through Energy in Dairy? A Complex Reality

ENERGY SOLUTIONS CAN:



Reduce women's time poverty



Create jobs for women as businesses expand
Beyond the farm gate, women mostly work in cleaning, packaging, retail; jobs less at risk of automation as businesses grow

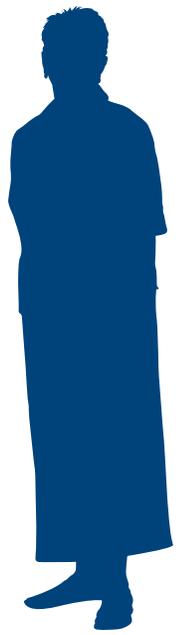


Address women's mobility constraints
i.e. solar-powered chilling on motorized transport enables collection at farm gate



Trigger male takeover of functions and income
as milk becomes more commercial and value-added

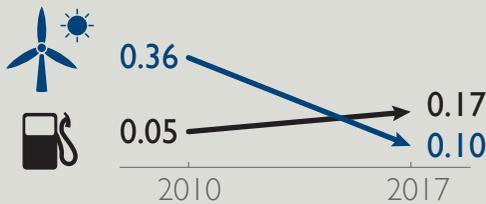
Understand this risk and how it will influence technology adoption and growth



Clean and Renewable Energy Can Reduce Greenhouse Gases and Contribute to Low Emission Development

RENEWABLES INCREASINGLY BEAT FOSSIL FUELS ON COST

Change in average cost of utility-scale renewables (\$/kWh)



CONTINUE TO INVEST IN IMPROVED GHG DATA FOR TRANSPORT, PROCESSING, AND RETAIL



Energy consumption data post-harvest is often lacking; better quantifying energy savings and GHG emissions and reductions can inform future policy and illustrate policy impacts

CONTEXT MATTERS

% fossil fuel in power generation mix



Off-set high fossil fuels by targeting on-grid, larger dairies. In off-grid areas, dairy is currently highly informal and therefore does not use significant energy



Dairies use more energy. GoK's NEMA plans to reduce GHGs in dairy, but must improve livestock emission estimation methods to monitor mitigation and trends

Policy and Partnership Opportunities



1. Embrace a systems approach to analysis and design

Exciting ideas can fail to have systemic impact; many energy opportunities struggle with widescale adoption and market penetration. Systems approaches help us understand the broader ecosystem, social and economic dynamics that will influence impact, and design smarter policies and programs



4. Reduce or eliminate tariffs on solar products (as in Kenya) and provide subsidies (guarantees, subsidized debt interest, tax incentives) to spur investment, adoption and reduce user costs



2. Leverage partnerships with solar and energy innovators and programs to synergize investments, support scale-up and commercialization, and apply lessons learned. E.g. Powering Ag, USAID's Photovoltaics for Sustainable Milk for Africa through Refrigeration Technology (PV-SMART) project; Strathmore Univ's Energy Research Centre in Kenya



5. Support user education campaigns on energy efficient best practices



3. Net metering incentivizes distributed storage and increases total supply of RE



6. Strengthen the solar energy ecosystem e.g:

- Installation and maintenance: strengthen vocational and enterprise skills, alternative delivery models (e.g. layered service onto rural agent networks)
- Support alternative financing and directed investment for companies and end customers to minimize upfront costs. (e.g. alternative collateral, bundled investments, business accelerators)
- Expand access and availability of appropriately sized inverters, batteries, and chargers
- Build industry platforms for collaboration, advocacy and co-creation



Interested in more?

Visit www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work for more E4Ag resources, including briefs on solar thermal and solar PV for small scale dairies; single to three phase electrical conversion; and energy-sensitive value chain development design, plus a series of gender-focused blogs.

The Energy Opportunities for Agricultural Systems and Food Security Project (E4AS) expands and focuses information on how clean energy and energy efficiency can strengthen post-harvest value chains and reduce loss in sub-Saharan Africa, while also contributing to LED goals and incorporating gender considerations. E4AS is funded by USAID's Africa Bureau and implemented by Green Powered Technology in partnership with ACIDI/VOCA.

ENERGY OPPORTUNITIES FOR AGRICULTURAL SYSTEMS AND FOOD SECURITY PROJECT

POWERING THREE-PHASE ELECTRICAL DEVICES FROM A SINGLE-PHASE SOURCE

Technical Brief #1

Introduction

Field work during the Energy Opportunities for Agricultural Systems and Food Security Project (E4AS), found that access to 3-phase electrical power was a limiting constraint to value chain development in the Kenyan dairy sector.

Unfortunately, most electrical supply across the developing world is not 3-phase, it is single-phase (for explanation of the difference between the two, see text box next page). The E4AS project found that this lack of 3-phase supply significantly restricts the use of more efficient 3-phase equipment by agro-processing firms. Beyond very small scale, most industrial equipment, including dairy or any other agro-processing equipment, have three-phase motors that require three-phase supply.

Electrical utilities in most countries can provide a 3-phase connection, but it can require significant financial investment, months of bureaucratic hurdles and coordination of electrical installation. This was the situation faced by some of the dairies visited by E4AS. They were faced with significant delays in opening and significant additional costs from the public utility company to extend three-phase supply to their operation locations. This brief summarizes several simple and inexpensive alternatives to create or simulate three-phase electrical supply at point of use.

This brief is the first of four practical guides developed by the Energy Opportunities for Agricultural Systems and Food Security Project (E4AS). Funded by USAID's Africa Bureau with field work in Senegal and Kenya, E4AS is implemented by Green Powered Technology in partnership with ACDI/VOCA. The objective of E4AS is to expand and focus information related to how clean energy (CE) and energy efficiency (EE) can strengthen post-harvest value chains and reduce loss in sub-Saharan Africa, while also contributing to low emission development strategies (LEDS) and incorporating gender-aware strategies. Visit www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work to access additional briefs and an integrated literature review with field work findings.

Options for providing 3-phase power from a single-phase source

Several relatively simple and inexpensive alternatives exist to provide 3-phase power where only single-phase service is available. These alternatives include:

- Static 3-phase Converter
- Rotary 3-phase Converter
- Digital 3-phase Converter
- Variable Frequency Drive (VFD)

Before considering one of these choices, it is recommended to evaluate the feasibility of replacing 3-phase motors with single-phase motors. If a substitution is possible, this may be the least expensive alternative. However, this may not be possible due

to motor mount sizing, special mounting brackets, special shaft sizing or design, overall space, or the required horsepower rating. If that is the case, then consider one of the four converter technologies discussed below.

3-Phase vs. Single Phase

Electric current is the flow of an electric charge. There are two primary types of electrical current: Direct and alternating (DC and AC). Direct current moves in one direction, alternating current periodically reverses its direction depending on its frequency. Alternating current is available as single-phase (typically for residential applications) and as 3-phase (typically for industrial applications).

When using alternating current, in a single-phase circuit, power is equal to the product of voltage, current and the phase angle between them. In a 3-phase circuit this product is multiplied by the square root of 3, or 1.73.

As a result, single-phase circuits require 1.73 times more current (Amps) to provide the same amount of power:

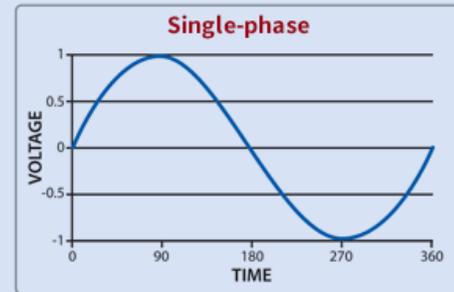
Single-phase: $Power = V \times I \times \phi$

3-Phase: $Power = V \times I \times \phi \times 1.73$

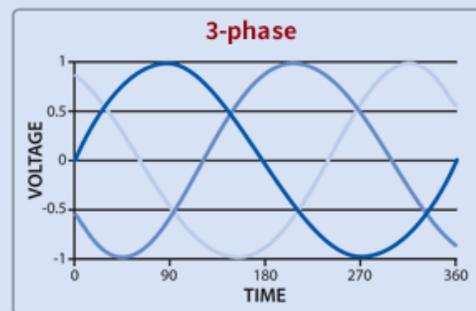
Since current carrying capacity is directly related to the size of the conductor, this means that for a single-phase circuit, more conductor material is required at a higher cost.

In an alternating current electric circuit, voltage and current take the form of sine waves (see below). For single-phase power this occurs with a single oscillating wave—hence the name. For 3-phase power there are three waves, staggered by 120 degrees to allow more consistent delivery of power.

In the case of single-phase delivery there are times when then the voltage or current is equal to zero. Due to the equation above, this results in instances when power is also equal to zero. This occurs with each oscillation of the wave, between 50-60 times per second. This is suitable for home, small business



With the wave form of single-phase power, when the wave passes through zero, the power supplied at that moment is zero. The wave cycles 50-60 times per second depending on your location.



3-phase power has 3 distinct wave cycles that overlap. Each phase reaches its peak 120 degrees apart from the others so the level of power supplied remains consistent.

applications and for motors up to about 5 HP. However, most motors used with industrial machinery require 3-phase electrical power to ensure consistency of power supply. When power is repeatedly lost at micro-intervals under a single-phase application, motors must rely on their own inertia to coast and continue to operate. This impacts overall power output causes wear to the motor.

Three-phase power smooths these losses to ensure the peak level of power never drops to zero. Motors that operate with a 3-phase supply do not require the same rotational mass to coast when there is no power, can deliver more power for a given physical size, and are generally less expensive and more efficient for a given horsepower than a single-phase motor.

Static 3-phase Converter

A static converter is the least expensive alternative for 3-phase conversion. It has no moving parts; however, it needs to be sized to match the motor size (i.e. horsepower). The major disadvantage of a static converter is that it reduces a motor's available horsepower by about one third. It also has difficulty in starting motors with high starting loads (e.g. compressors, dust collectors, large fans, etc.). To overcome this, a lightly loaded motor can be started first to act as an electrical flywheel to improve the starting ability of other motors. An "idler" motor (a spare motor connected to the same system) can also be used to provide this electrical flywheel, but this adds to the overall system cost.

Note, not all motors can run using a static phase converter. Static phase converters are not recommended for welders, heaters, two speed motors, air compressors, pumps, fans, CNC machines, plasma cutters, refrigeration trucks, blowers, large flywheels and large lathes¹.

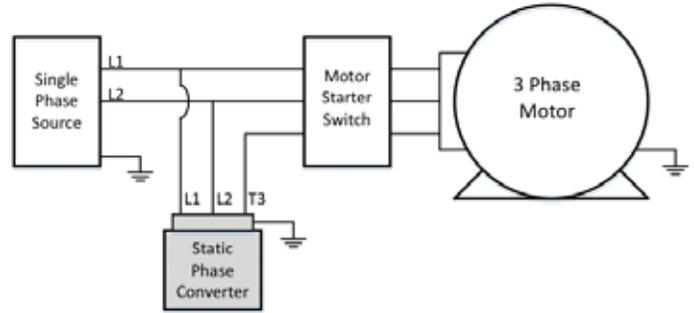


Figure 1. Schematic of 3-phase static converter installation



Typical single-phase to 3-phase static converters from American Rotary Phase Converters (left) and Phase-A-Matic (right)

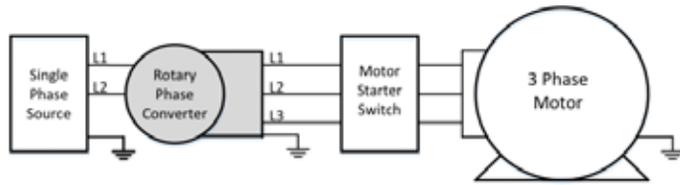


Figure 2. Schematic of 3-phase rotary converter installation

Rotary 3-phase Converter

A rotary converter functions as both a motor and a generator using a single-phase motor to drive a generator to produce 3-phase power. A rotary converter looks like a large motor with a large junction box attached. It is more expensive than a static converter but doesn't have the starting and reduced power problems that occur with a static converter. A major advantage is that a suitably sized rotary converter can be used to supply 3-phase power to all—or multiple—3-phase motors in a facility.



Typical single-phase to 3-phase Rotary Converters from North American Phase Converter Co. (left), Phoenix Phase Converters (center), and American Rotary Phase Converters (right)

¹ How to size a Static Phase Converter - www.northamericaphaseconverters.com/how-to-size-a-static-phase-converter

Digital 3-phase Converter
(often called 3-phase Inverter)

A digital phase converter uses a rectifier and inverter to create a single voltage. This is done using power electronics, added to the two legs of the incoming single-phase source. The new single voltage can match both the voltage and frequency of the incoming single-phase power, resulting in an output that is a well-balanced 3-phase sine wave, not a stepped waveform typical of a variable frequency drive (VFD). Digital converters are more efficient than rotary converters. In contrast to a standard rotary converter, a digital converter only uses power when a load is present and has minimal internal power use. The digital 3-phase converter cannot vary frequency and motor speed like a VFD (discussed below), which may be a better choice as cost are relatively the same.

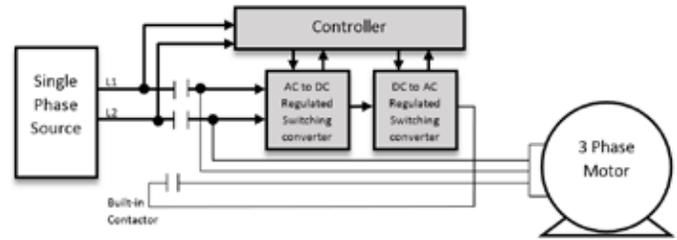


Figure 3. Schematic of digital 3-phase converter



Typical single-phase to 3-phase Digital Phase Converters from North American Phase Converter Co. (left), and American Rotary Phase Converters (right)

Variable Frequency Drive (VFD)

A Variable Frequency Drive (VFD or VSD or electronic 3-phase inverter) changes single-phase power into direct current and then inverts the direct current to 3-phase power. This is done using electronic controls to simulate 3-phase alternating current.

The electronics in the converter allow control of motor speed, torque and direction of rotation, and often allow for a soft start to bring the motor up to speed gradually. Since it must be programmed, a VFD typically is dedicated to running only one motor. VFDs can be more affordable than rotary converters for lower horsepower motors, however above 10 HP the savings decline (see relative cost chart).

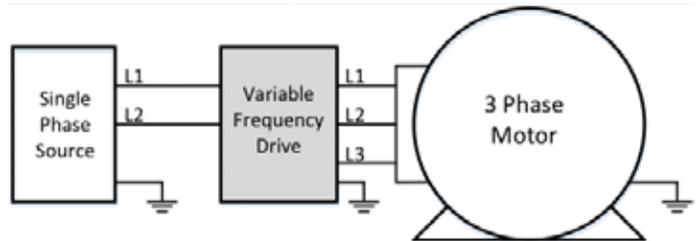


Figure 4. Schematic of Variable Frequency Drive



Variable Frequency drives from DURApulse (left), and Hitachi (right)

Relative Costs

The following relative costs are based on currently available equipment in the USA. The ranges in pricing reflect equipment from different manufacturers and suppliers in early April, 2018.

EQUIPMENT TYPE	MOTOR SIZE				
	3 H.P.	5 H.P.	10 H.P.	15 H.P.	20 H.P.
Static 3-phase Converter	\$180 - 500	\$300 - 600	\$550 - 750	\$750 - 1,000	\$750 - 1,200
Rotary 3-phase Converter	\$450 - 1,000	\$450 - 1,500	\$820 - 1,900	\$1,250 - 2,500	\$1,350 - 2,500
Digital 3-phase Converter	\$400 - 600	\$500 - 800	\$1,500 - 2,250	\$2,000 - 3,000	\$2,500 - 4,000
Variable Frequency Drive	\$450 - 600	\$600 - 850	\$1,750 - 2,500	\$2,500 - 3,200	\$2,750 - 4,000

Prices are in US Dollars and are based on equipment available from several different suppliers in April 2018.

Phase Converter or Variable Frequency Drive?

A **phase converter** is the easiest “plug and play” solution. It requires the least programming, can be selected based on the motor size, and is simple to install. It is most suitable for 3-phase motors where speed and torque control are not required (e.g. refrigeration equipment, freezers, etc.) and where a machine has numerous low voltage internal controls. **Variable frequency drives** are well suited for phase conversion when control of speed, motor torque and soft starting are needed for such applications as pumps, fans, compressors and process machinery.

Voltage

Phase converters are not transformers. Unless a transformer is included in the system, outgoing 3-phase voltage will equal the incoming single-phase supply voltage. Therefore, a transformer may be required to match the supply voltage required for the 3-phase application.

Suppliers

There are numerous suppliers of phase converters and VFDs. The following list provides the website address of some examples of suppliers:

www.phoenixphaseconverters.com

www.americanrotary.com

www.northamericaphaseconverters.com

www.phase-a-matic.com

www.schneider-electric.us

eaton.com

technoelectric.com (Kenya)

sollatek.co.ke (Kenya)

www.parker.com

ENERGY OPPORTUNITIES FOR AGRICULTURAL SYSTEMS AND FOOD SECURITY PROJECT

SOLAR PV OPTIONS FOR SMALL-SCALE DAIRY AGGREGATORS

Technical Brief #2

Introduction

Field work during the Energy Opportunities for Agricultural Systems and Food Security Project (E4AS) found that power interruptions and local power costs affect the profitability of fresh camel and cattle milk sales. While project observations centered around primary chilling at small-scale cooperative dairies in Kenya, the key issues and lessons learned are applicable to broader small-scale cold chain aggregation applications.

E4AS' report *Clean Energy for Productive Use in Post Harvest Value Chains: An Integrated Literature Review with Field Work for the Kenya and Senegal Dairy Sectors*¹ highlighted a number of different solar photovoltaics (PV) products as promising opportunities to improve uptake of clean energy in sub-Saharan Africa. PVs offer an alternative power supply that can improve reliability of electric supply and lower overall electric costs. This brief expands on this finding by highlighting a series of technical factors specific to uptake by small-scale dairy aggregators of PV technologies.

This brief is the second of four practical guides developed by the **Energy Opportunities for Agricultural Systems and Food Security Project (E4AS)**. Funded by USAID's Africa Bureau with field work in Senegal and Kenya, E4AS is implemented by Green Powered Technology in partnership with ACDI/VOCA. The objective of E4AS is to expand and focus information related to how clean energy (CE) and energy efficiency (EE) can strengthen post-harvest value chains and reduce loss in sub-Saharan Africa, while also contributing to low emission development strategies (LEDS) and incorporating gender-aware strategies. Visit www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work to access additional briefs and an integrated literature review with field work findings.

Solar thermal explained

Cooperative dairies collect and chill milk in rural areas and transport it to urban centers where they sell the “fresh” product. To avoid the milk warming and spoiling on this journey, cooperatives chill it as much as possible before transport. Upon receipt, warm milk is poured into 20L jerry cans and placed inside chest freezers to chill and partially freeze overnight. The milk is then transport in a highly

chilled - if not frozen - state, allowing it to be as fresh a possible when arriving at market. This process presents two primary problems: the energy costs required to adequately chill large quantities of warm liquid; and insufficient cooling due to common short and long duration power interruptions.

¹ To access the report as well as other E4AS briefs, visit: www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work

Energy Costs

Cooperatives typically power freezers for chilling with energy purchased from a local power utility, or from energy produced by diesel generators. In Kenya, the power purchased from the utility by dairy cooperatives typically ranges from 35,000 KSh (US\$ 350) to 40,000 KSh (US\$ 400) depending on the season. Other than the cost for the raw milk, this power bill is the single largest expense faced by cooperatives.

Power Interruptions

Daily power interruptions can be a common occurrence in developing economies. While not only inconvenient, these outages can be costly for cooperatives and other business that rely on cold chain integrity. In the case of dairy, milk that is insufficiently chilled overnight, may not remain fresh during transport to an urban market. In the case of longer outages, milk may even spoil prior to transport. If fresh milk spoils during the journey, it is still sold, however at a discounted price that may not cover the costs of transportation and the initial purchase of raw milk.

Alternative Supply Through Photovoltaics

The installation of photovoltaic (PV) systems to generate power and battery storage can allow cooperatives to improve the surety and consistency of energy supply and lower overall energy costs. A solar powered system with battery storage can provide either a complete off-grid power supply or a system to provide back-up power during utility interruptions.

Complete off-grid solar power supply

A 100% solar power supply would include sufficient photovoltaic panels to generate power throughout the daylight hours to provide the immediate power requirements and to charge batteries to provide power throughout the nighttime hours. An appropriate investment would allow a cooperative to provide all its own power and minimize any interruptions resulting in spoiled milk or insufficiently chilled milk.

In the case of a Kenyan cooperative with 11 chest freezers and an average utility bill of 39,400 KSh for 2.74Kwh/hr, the estimated cost to provide a 100% solar power supply with 16 hours of battery storage is 4.7 million KSh (US\$47,000).

Given chilling loads may vary regardless of installed capacity, past utility bills offer the best estimation of average energy consumption.

The avoided annual power costs can be calculated based on past utility bills. In this example they are estimated at US\$4,600 annually. The reduction of costs due to milk spoilage must also be considered. This is difficult to estimate without exact records. Interviews with cooperative members showed it reasonable to assume that utility power interruptions and outages result in at least one loss of fresh milk (still sold as spoiled milk) per month. This costs the cooperative approximately US\$4,200/year².

Therefore, the total annual savings with a 100% solar powered system with 16 hours of battery storage would be approximately US\$8,800/year for an investment of approximately US\$47,000. This would result in a simple payback of just over five years³.

² 150 KSh/litre (fresh) – 80 KSh/litre (spoiled) x 500 litres x 12 months = 420,000 KSh/year; this assumption may be conservative, and if in fact it occurs more frequently, then the payback period would be reduced.

³ Simple payback does not account for slight degradation of panels and batteries over time and any maintenance costs.

Partial Backup Power Storage

The largest cost component of a complete solar power supply as described above are the batteries necessary for power storage. Reducing the total amount hours of required storage, while continuing to supplement with power purchased from a utility, will reduce the overall installation cost. For example, a reduction in the storage capacity outlined above from 16 hours to 8 hours would reduce installation costs by US\$15,000 to US\$32,000⁴. Such an approach would still require the purchase of power from a utility. Using the same costs from our example above, if 8 hours per day were required to still be purchased, the annual cost would be US\$1,530, resulting in a total energy bill savings of US\$3,070 per year. The same reduction of milk spoilage costs is also applicable under this scenario (US\$4,200/year). Total annual savings of a partial backup system would result in a simple payback in 2.8 years.

⁴ Reduction in number of batteries from 24 to 12, reduction in number of pv panels required as they are not required to charge the batteries, and various other savings.

ENERGY OPPORTUNITIES FOR AGRICULTURAL SYSTEMS AND FOOD SECURITY PROJECT

USING SOLAR THERMAL TO LOWER ENERGY COSTS FOR SMALL SCALE DAIRY PROCESSORS

Technical Brief #3

Introduction

Solar energy from the sun can be captured to generate both electricity (solar electric) and heat (solar thermal). Solar electric can be used to provide renewable power to replace traditional fossil fuel based forms of power generation. Solar thermal energy can be used to provide primary and supplemental heat in a wide range of applications from space conditioning in buildings and heating of swimming pools, to specific applications in a variety of industrial processing operations.

This technical brief discusses the use of solar thermal in the dairy processing industry and how solar thermal can reduce milk pasteurizing and processing costs, particularly for small-scale processors in a sub-Saharan African context.

Solar thermal explained

Electromagnetic radiation from the sun provides both light and heat on Earth. Much of this radiation is invisible to the human eye, but its impact causes the molecular structure of materials to vibrate which results in heat. This is how the Earth is heated. Capturing that heat provides a renewable and useful source of thermal energy.

A simple example of a garden hosepipe on a sunny day demonstrates this. The water temperature in a hosepipe left out in bright sun, even for a few minutes, can increase to scalding temperatures because the sun's infrared radiation heats the water in the hose. Solar thermal panels operate in the same way, with the sun's infrared radiation heating

This brief is the third of four practical guides developed by the **Energy Opportunities for Agricultural Systems and Food Security Project (E4AS)**. Funded by USAID's Africa Bureau with field work in Senegal and Kenya, E4AS is implemented by Green Powered Technology in partnership with ACDI/VOCA. The objective of E4AS is to expand and focus information related to how clean energy (CE) and energy efficiency (EE) can strengthen post-harvest value chains and reduce loss in sub-Saharan Africa, while also contributing to low emission development strategies (LEDS) and incorporating gender-aware strategies. Visit www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work to access additional briefs and an integrated literature review with field work findings.



Figure 1. Roof Mounted Solar Thermal Panel at Moi's Bridge Muungano Farmer's Cooperative Society Ltd., Moi's Bridge, Kenya

a fluid (usually water or a water glycol mixture) in a solar collector or panel. These panels are typically flat and mounted in an unshaded area on a roof or the ground. They often have glass covers under which there are multiple interconnected black tubes through which the heat transfer fluid is pumped. Hot fluid is stored in insulated tanks for later use. In some designs thermo-siphoning of the fluid to and from the panel obviates the need for a pump.

Solar thermal in small-scale dairy processing operations

Solar thermal energy can be used in a number of applications in dairy processing operations, including:

- providing hot water for CIP (clean-in-place) and sanitary use
- pre-heating boiler feedwater
- directly heating milk in the pasteurizing process

Each of these are discussed briefly below, and their relative economics examined.

Costs of electricity and equipment used in these economics are based on actual costs found in Kenya, but the applications would be applicable in any country with suitable adjustment for local economics. Because the costs of the alternative fuels used for heating such as oil and biomass can vary considerably between countries and regions within countries, for the summary economic analysis discussed below, it has been assumed that electricity at a cost of 20.0 Kenyan Shillings per kilowatthour (20.0 KSh/kWh or US\$0.20/kWh) is used in all heating applications. Local Kenyan equipment supplier costs of 121,000 KSh (US\$1,210) for a 3.5 m² solar thermal panel (equipment only) were also used in these calculations.

Clean-in-place (CIP) and sanitary water heating with solar thermal

All equipment used in food processing needs to be cleaned and sanitized on a regular basis. This is especially important in milk processing where bacterial contamination can quickly cause product spoilage and consumer illness. Processing equipment used in milk processing, including the pasteurizing equipment, must be washed and sanitized using warm water, detergents and disinfectants. Typically the water temperature used with the detergents and disinfectants is the same as the temperature used in pasteurizing, but for the initial equipment rinse, milk fat solids that are deposited within the processing equipment will be flushed better using warm water (<55 °C or 131 °F) so proteins in the milk do not coagulate.

- The energy required to raise water temperature from ambient of 16 °C (61 °F) to 55 °C (131 °F) is 0.045 kWh/litre (= 587 Btu/US Gal or 704 Btu/Imp Gal).
- A single flat glass panel solar thermal collector of 3.5 m² in a high solar radiation region (i.e. > 6.3 kWh/m²/day or 2,000 Btu/ft²/day) such as Eldoret, Kenya can heat approximately 200 litres/day (53 US Gal/day or 44 Imp Gal/day) from 16 °C (61 °F) to 55 °C (131 °F).
- If this same heat energy is provided by an electric heater, the electric heater would consume approximately 10 kWh/day or 3,650 kWh/year at a cost in Kenya of 20 KSh/kWh (US\$0.20/kWh) or 73,000 KSh/year (US\$730).

An installed cost of a single 3.5 m² solar thermal panel is estimated at approximately 140,000 – 150,000 KSh (US\$1,400 – 1,500). Although this upfront cost is higher than a monthly electric bill (straight-lined monthly average of US\$60.80, or \$730 a year), the solar thermal panel pays for itself with a payback period of approximately two years, providing long-term cost savings.

The number of panels installed would depend on available capital, suitable available space (e.g. available roof space or nearby land), and the total volume of

warm water required for CIP and sanitation each day. In a system used to heat CIP and sanitation water in an area where there is no chance of freezing, the actual CIP and sanitation water could flow directly through the solar thermal panel.

Where there is a chance of freezing, a water glycol mixture would be required in the solar thermal panel, so a **heat exchanger** would be required to exchange heat between the water/glycol mix and the CIP and sanitation water. This would add to the installed capital cost and increase the estimated payback by approximately 50%.

Boiler feedwater pre-heating with solar thermal

In a similar way to heating water for CIP, boiler feedwater used for heating milk prior to and during pasteurization can also be heated using solar thermal. A heat exchanger would be used between the fluid flowing in the solar thermal panel and the boiler feedwater to minimize chemical fouling of the solar thermal panel. **Savings, costs and payback are similar to those for the CIP and sanitation water heating.**

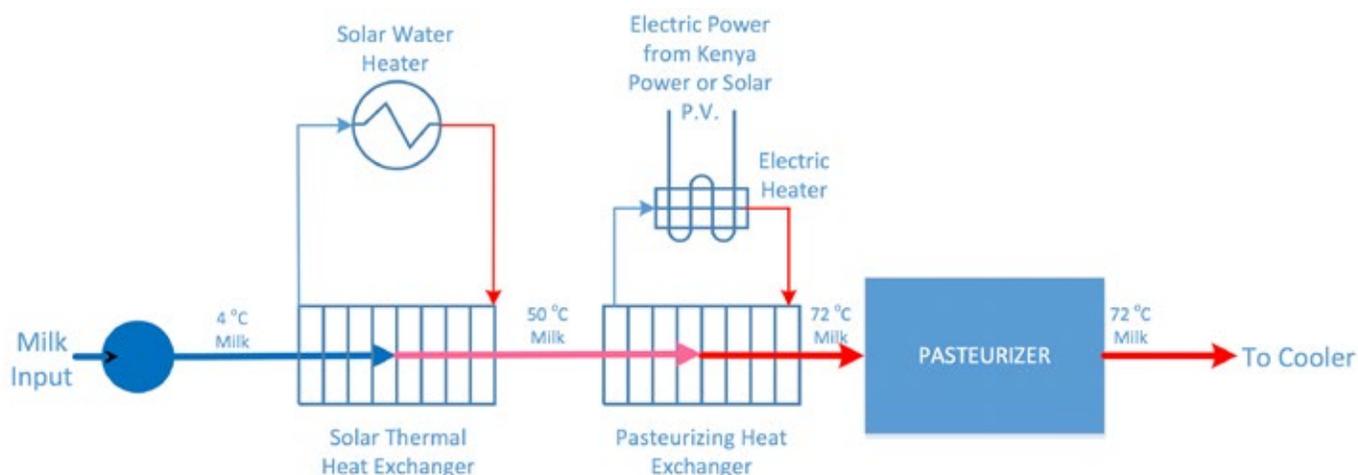
Pre-heating and heating of milk for pasteurizing

Solar thermal can also be used to partially or completely heat the milk input into the pasteurizing equipment.

Depending on the pasteurizing process used and the duration the milk is held at the pasteurizing temperature, the actual input temperature required for the milk may vary. However, the typical flash pasteurizing or High-temperature Short-time (HTST) pasteurizing requires a temperature of 72 °C (161.6 °F) for 15 seconds. Milk stored at 4 °C (40 °F) requires a heat input of 0.0785 kWh/litre (1,015 Btu/US Gal or 1,218 Btu/Imp Gal) to raise it to that pasteurizing temperature.

The figure below illustrates the use of solar thermal to heat the milk completely.

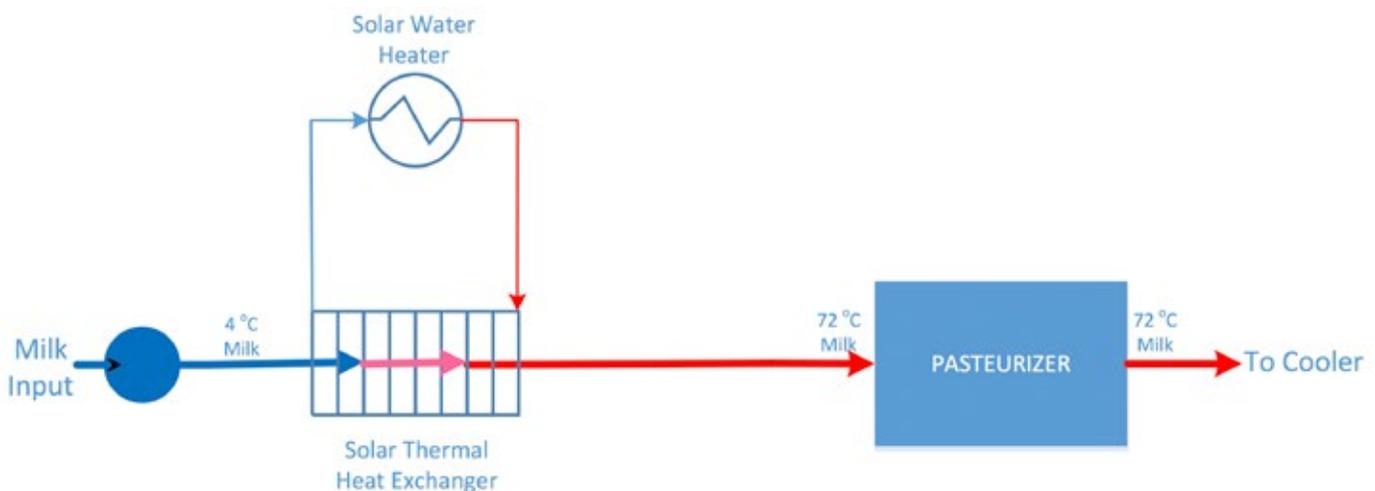
- Because of the higher differential (input to output) temperatures required, a **single flat glass panel solar thermal collector** of 3.5 m² in a high solar radiation region (i.e. > 6.3 kWh/m²/day or 2,000 Btu/ft²/day) can heat approximately 50 litres/day (13 US Gal/day or 11 Imp Gal/day) from 4 °C (40 °F) to 72 °C (161.6 °F).
- If this same heat energy is provided by an electric heater, the **electric heater** would consume approximately 4 kWh/day or 1,460 kWh/year at a cost in Kenya of 20 KSh/kWh (US\$0.20/kWh) or 29,200 KSh/year (US\$292).



- The installed cost of a single 3.5 m² solar thermal panel with heat exchanger and pumps is estimated at approximately 160,000 – 175,000 KSh (US\$1,600 – 1,750). Although this upfront cost is higher than a monthly electric bill (straight-lined monthly average of US\$24.33), the solar thermal panel pays for itself with a payback period of approximately six years—providing long-term cost savings.
- For a milk processing plant in a high solar radiance region that flash pasteurizes 10,000 litres of raw milk per day with no heat recovery from the hot pasteurizer output milk, the heat required for pasteurizing could be produced by approximately 200 flat glass panel solar thermal collectors at a cost of approximately 30,000,000 - 35,000,000 KSh (US\$300,000 - 350,000). This would require 700 m² of flat glass panel solar thermal collectors.

Blended solar/electric model: instead of heating the milk to the full required pasteurizing temperature, solar thermal can be used to partially heat the milk and then the remainder of the heat is provided by the existing electric heaters, as shown in the figure below.

- With this, because the differential temperature between the input and output ($\Delta T = T_{\text{Output}} - T_{\text{Input}}$) of the solar thermal panel would be less, and because a solar panel's efficiency is generally greater the lower the differential temperature from input to output, **the number of panels, the capital cost, and the payback would be reduced.**



ENERGY OPPORTUNITIES FOR AGRICULTURAL SYSTEMS AND FOOD SECURITY PROJECT

ASSESSING THE FEASIBILITY OF RENEWABLE ENERGY & ENERGY EFFICIENCY FOR VALUE CHAIN PARTNERS

Technical Brief #4

Introduction

Solar energy from the sun can be captured to Field Energy is a critical and often neglected component of value chain development. On-farm mechanization, value addition processing, and supply chain improvements like cold chain expansion all hinge on the availability of affordable power sources. Rapidly expanding innovation in renewables (e.g. solar, thermal) and energy efficiency (e.g. waste heat recovery systems, variable-frequency drives) are providing novel and increasingly cost competitive energy opportunities to support these kinds of value chain upgrading. When appropriately designed and priced, productive energy solutions can also support inclusion through expanding the geographic footprint of rural supply chains and helping small and mid-size businesses remain competitive.

At the same time, the history of foreign aid is littered with donor-funded mills, cold storage facilities, and other value chain investments that sit idle, often in part because energy and other recurring costs were prohibitive, equipment was incompatible with local energy supply, or unconsidered gender and social dynamics affected uptake and use of the investment.

This brief provides value chain and market system development specialists with the basic tools and resources to integrate analysis of energy opportunities—particularly modeling costs and payback periods for RE or EE investments—into their design and implementation work. We present a six-step process that helps practitioners to:

- Rapidly identify energy constraints to market opportunities in a target value chain (steps 1 and 2);
- Identify energy demand needs by value chain partners and comparative energy supply options (steps 3 and 4);
- Assess the feasibility of these energy opportunities for firm investment (step 5)
- Recognize key gender and social considerations that could impact uptake, use, and benefit (integrated into all steps); and
- Design interventions to catalyze those opportunities for more broad-based, sustained impact (step 6).

This brief is the last of four practical guides developed by the **Energy Opportunities for Agricultural Systems and Food Security Project (E4AS)**. Funded by USAID's Africa Bureau with field work in Senegal and Kenya, E4AS is implemented by Green Powered Technology in partnership with ACDI/VOCA. The objective of E4AS is to expand and focus information related to how renewable energy (RE) and energy efficiency (EE) can strengthen post-harvest value chains and reduce loss in sub-Saharan Africa, while also contributing to low emission development strategies (LEDS) and incorporating gender-aware strategies. Visit www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work to access additional briefs and an integrated literature review with field work findings.

Guide

Below we provide a 6-step process to integrate energy opportunities into value chain and market system analysis and program design. Each step also includes an example case study in blue text boxes to show that step in action. In summary:



STEP 1: Map the Value Chain System and Target Pathways for Change

It is standard practice for market development practitioners to develop value chain system maps (especially as part of broader system analyses) that include key functions and actors such as: input supply, production activities, assembly/processing, packaging, transport, retail, export (if applicable), end consumer; along with support services (such as finance). Good visualizations and analysis reflect various market segments, overlay trade volumes, and consider how relationship/power dynamics, growth trends, and major enabling environment factors within these chain segments affect how the value chain is structured. In particular, look out for how these factors combine to create new market opportunities. For basics on how to map a value chain system, and use this to identify the best opportunities to target in order to affect positive change, see USAID's guidance on the Value Chain Wiki¹.

STEP 1 IN ACTION:

You are part of a team of value chain specialists starting up implementation on a new activity in Kenya with the goal of strengthening horticulture value chains to reduce poverty for those engaged in agriculture. You and your team map the horticulture system and its value chains (e.g. tomato, avocado, etc), identifying market opportunities as you go. Through interviews with stakeholders and reviewing trends in market data, you have identified growing and unmet demand for processed tomato products, including products requiring dried tomatoes, as well as strong relationships between this opportunity and its impact on both your target beneficiaries and positive market behaviors in the horticulture system overall.

You and your team decide to dig deeper into the potential for processed tomatoes as a pathway to strengthen the horticulture market

Note! This guide assumes the primary entry point into a market system is an agricultural value chain (e.g. dairy, tomatoes, maize); this guide helps you understand where energy is a constraint within that value chain, explore a range of options to address it, and calculate feasibility for investment in those options. However, development practitioners may also consider treating energy as a value chain system in and of itself, in addition to focusing on a specific agricultural system. Steps 1 and 2 will give you insight as to how significant energy is to transforming inclusive growth, and therefore help you prioritize how much resources you spend in treating energy as an interrelated system and set of value chains itself. Doing this would involve a different, more robust set of considerations than are focused on in this guide.

¹ www.marketlinks.org/good-practice-center/value-chain-wiki/value-chain-mapping-process

STEP 2: Overlay an Energy Lens: Identify Energy Constraints to Opportunities

Using the value chain system map and identified opportunities from Step 1 as a filter, identify where energy is used for the market opportunity-related points along the chain. This will involve a mix of consultations with teams involved in the VC system mapping as well as incorporating energy-specific questions into field surveys normally part of value chain analysis or other market research (see text box below for survey tips). For example, the adjacent figure, from Powering Agriculture’s² ‘*Opportunities for Agri-Food Chains to Become Energy Smart*’³, shows basic energy uses in the vegetables supply chain from the farm through retail. As shown, it is helpful to disaggregate energy needs by their use: heating, cooling, electricity, or moving materials from one place to another. This will enable you to match opportunities to technologies in steps 3—5 below. At this phase it is not critical that you have extremely detailed documentation on energy uses; you will only need those for points in the value chain where you will drill down for further cost estimation, as outlined in steps 3—5 below.

As part of this process, ask the firm or farm what their energy access is like—do they get power from the grid, or their own off-grid source, like solar PV or a diesel generator? What energy challenges do they have? For further examples, see text box below on field survey tips.



FIELD SURVEY TIPS: Identifying Energy Use by Value Chain Actors or Functions

Identifying energy use types and intensity can easily be integrated into value chain analysis or any other interview opportunity with beneficiaries. This information will provide inputs into Step 3.

- When visiting farms or firms, ask them to walk you through their process from when materials/inputs arrive to when they leave. Note steps that:
- Require machinery or other electrical devices (e.g. hammer mills or other processing equipment). Ask if you can record the make and model number of the equipment. Most manufacturers will have energy load profiles for their equipment available on request.
- Require product temperature changes (e.g. cooling or heating points for milk). Make sure to note total volumes that go through these processes, and total temperature changes (entry temperature, target chill/heating temperature, etc.).
- Require the pumping or conveyance of water, air or other medium.
- Involve substantial manual labor. Try to note the mechanical energy needs—i.e. what is the labor doing? Moving bags of rice from truck beds to a warehouse? Sorting vegetables by grade? Packaging yogurt? Record the number of people needed in these roles, and the distances/volumes or other magnitudes of work required.
- Note the products, processes, or technologies currently used for these steps.
- Ask firms or individuals to share recent electrical bills. Some firms will know their recurring energy costs off the top of their head, but it is always better to get a copy of a bill or other summary in writing.
- Ask about any energy challenges: Do they have blackouts? Do their energy bills seem to fluctuate wildly, even when their energy use remains stable? Any challenges related to access or price will be helpful in evaluating alternative energy options later.

² <https://poweringag.org>

³ www.fao.org/3/a-i5125e.pdf



Apply a gender and social inclusion lens:

Consider and document gender and social gaps or differences in use, access, and agency.⁴ Due to gaps in access to resources and lower levels of decision-making power, women, youth, and other members of marginalized groups tend to have: less access to technologies (including energy opportunities); less ability to upgrade to these technologies; greater reluctance to invest; and greater risks when they do. It is important to assess not just financial gaps (i.e., who pays, who can pay, and how much they can pay), but also gender and social norms, including which group has access to energy, what kind of energy, and how this is different. For one example of such risks, such as marginalization in enterprise as access to energy increases, see the Senegal Case Study in the

E4AS Integrated Literature Review and Field Work Report⁵.

Of course there can also be gender-specific positive benefits, which are equally important to understand and incorporate into design; for example, installing solar powered coolers on motor bikes expands access to cold storage to more smallholder milk producers who cannot travel to a central collection point, often a unique constraint for women.

STEP 2 IN ACTION:

Now that you have identified processed tomatoes as a key market opportunity, drill down further to get a clear sense of the range of energy uses, constraints, and opportunities to upgrade processes with renewable energy (RE) or energy efficient (EE) options.

One of the firms you interviewed during value chain mapping in step 1, The Tomato Fresh Company, mentioned that they are interested in developing a new product line, and have asked for help to determine its feasibility. Tomato Fresh currently creates ketchup and canned tomato preserves, but have reached capacity for their cold storage and processing line. They are interested in developing a new product line for dried tomatoes as a way to convert more tomatoes when market prices are low into a shelf stable, low volume product.

You work with Tomato Fresh to develop a list of all of their energy needs, from when tomatoes arrive at their facility through packaging and sale, which you list out as below. They also note that they have frequent blackouts, 2-3 times a week, and feel like their electricity is expensive.

Here is the list of energy uses at each phase in their production process—where relevant, you note where

women or men complete tasks, as this will be helpful later on in anticipating potential gendered effects of changes to production processes:

Produce intake:

- Manual labor to move produce from trucks to storage sheds (mostly done by men)

Storage:

- Electricity for cold storage coolers
- Washing, grading, sorting:
- Electric to run spray pumps and produce conveyor belts
- Manual labor to grade and sort produce (mostly completed by women)
- Processing:
- Electric for tomato juice extractors, pulpers, pre-heaters, conveyance pumps
- Heating for pasteurization
- Packaging:
- Electric for conveyor belts
- Manual labor for final packaging and labeling (mostly completed by women)

You are most interested in the heat energy requirements for the tomato drying process, which you will delve deeper into under step 3.

⁴ AgriProFocus Gender in Value Chains Toolkit (2014) has a section on gender sensitive value chain analysis. <https://agriprofocus.com/toolkit>. USAID's Promoting Equitable Opportunities for Women in Agricultural Value Chain Analysis (2009) also includes guidance on gender sensitive value chain analysis. https://pdf.usaid.gov/pdf_docs/pnaeb644.pdf

⁵ Available at www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work

Step 3: Determine total energy demand for value chain partners

Based on the energy constraints identified in Step 2, plot energy use over time by developing a rough load profile⁶ for the processes or technologies in the value chain that are targeted for improvement.

To do this, first determine the total energy demand of the new equipment or process. Energy requirements should be available from the manufacturer for

known/existing technology or machinery in watts per hour (or convertible equivalent). This can be used to determine total energy demand by multiplying by the operational duration needed to reach a set production goal.

STEP 3 IN ACTION:

Tomato Fresh has a production target to dry 400MT of tomatoes each year in 10MT batches. They have found a commercial dehydrator model with a 100kg per hour capacity, and will purchase 10 of them to give them a total production capacity of 1MT per hour.

However, as you determined during step 2, one of the key issues holding back Tomato Fresh's competitiveness are issues with electricity. They experience blackouts 2-3 times per week, and note that energy is one of their largest monthly expenses. A food safety specialist noted that this may be a problem for their new drying operation: If the power were to go out while tomatoes were insufficiently dry, they could spoil in the dryers, leading to wasted product at best, or poisoned customers at worst. Tomato Fresh wants your help to figure out two things:

1. What will their energy costs be for their new dried tomato processing line using the current, on-grid power supply?
2. What would it cost to replace their on-grid energy with an off-grid solar photovoltaic array?

To answer these questions, you need to first estimate their energy demand in this Step 3, then determine the cost with their current supply versus a renewable alternative. (You'll do this in Step 4).

Calculating energy demand first requires multiplying the kilowatts used by one machine per MT processed x number of machines. Tomato Fresh has sent photos of the electrical information plate on the dehydrator. The red box to the right gives you the total wattage—this is the total energy draw for the machine. They bought 10 machines—so multiply by 10—which gives 12,000 watts, or 12 kilowatts (KW) of total power needed per MT processed.

Model G2369
240V ~50Hz
1,200W

Recall that Tomato Fresh is planning to process 400MT in year, and want to process 10MT per 10 hour working day, so have decided to buy ten 100kg/hr units. Tomato Fresh will be running the units for 10 hour days, 40 days a year to process the full 400MT. So total KWH needed per year are $12\text{KW} \times 10 \text{ hrs/day} \times 40 \text{ days/year} = 4,800 \text{ KWH}$ per year. This is their energy demand.

⁶ A load profile is a table, chart, or graph that plots energy use over time—this is the industry standard method for capturing total energy requirements over a given period of time.

Step 4: Determine availability and costs of energy supply options

For On-grid scenarios: Determining the extent of access to energy grids (i.e. 'on-grid') is important because it will significantly affect the financial and technical feasibility of energy-intensive investments. A good place to start is the World Bank's Africa Electricity Transmission and Distribution Grid Map⁷, which includes a map explorer tool⁸ showing current and planned grid access across the continent. For areas outside Africa, the Global Energy Network Institute maintains a repository of national and regional distribution maps⁹, of varying detail, quality, and currency. Any digital source should be cross-referenced with the national electrical utility company, who would be the most up to date authority on current and planned grid access. In addition to geographic coverage maps, most national

utilities maintain publicly available rate schedules that provide cost per KWH (kilowatt hour¹⁰) at different voltages.

Whether these schedules are available or not, it is still critical to verify actual energy costs from market actors on the ground. USAID or other donor projects may be a good source for general commercial energy costs, but to the extent possible costs should be validated with actuals. The Survey Tips text box under Step 2 provides a helpful starting point to gather firm-specific information of this nature. These costs will be a critical input in Step 4 and 5 below.

For Off-grid scenarios: Identifying off-grid oppor-

⁷ <https://energydata.info/dataset/africa-electricity-transmission-and-distribution-2017>

STEP 4 IN ACTION:

Step 4a: Determine on-grid energy costs:

The next step is to ask Tomato Fresh for their last year's energy bills. Looking at their bills, they've paid an average of \$0.15 USD/KWH. So we multiply $4,800\text{KWH} \times \$0.15 \text{ USD} = \720 USD/year estimated energy costs.

These costs assume that energy costs remain stable, and do not yet account for additional costs from blackouts. Based on their previous year's blackouts, you work with Tomato Fresh to estimate that 20% of their 40 days processing tomatoes would be interrupted by blackouts, resulting in a loss of 10%, or 4MT of purchased tomatoes, annually. On average, they are paying \$100 USD per MT for processing tomatoes, meaning blackout losses would most likely add \$400 per year in costs to their operations. This brings total estimated on-grid costs to $\$720 + \$400 = \$1,120$ per year.

Step 4b: Determine off-grid solar PV costs:

What would solar PV cost instead? Tomato Fresh will need to decide if they want battery storage to be able to use solar energy at night, or if they are fine with just using electricity when the sun is out. Given that they are only operating the dehydrators during daylight hours, they opt to forego battery storage and just

use the dehydrators when the sun is out.

How large of a solar PV array does Tomato Fresh need? Go back to step 1 above: remember that each unit requires 1,200 watts of power. So when all 10 dehydrators are running, they will need 12,000 watts (or 12KW) of power, which means they will need solar panels that collectively generate at least 12KW of power. So if each panel generated 270W, you would need at least 45 panels in the array.

You work with Tomato Fresh to get three quotes from solar PV service providers for a 12KW array, including the solar panels and all necessary inverters and other equipment. All three quotes come back at roughly the same price. This brings total estimated off-grid costs to \$12,000 USD for 12KW array; within 10 years, the system would pay for itself compared to on-grid costs.

In looking at both of these options, you conduct desk research and ask some of the female employees at Tomato Fresh about their energy constraints at home, and note that if the off-grid arrays were structured as mini-grids that could supply surrounding homes, they could have positive effects on replacing firewood fetching for cooking and light at night. This could reduce women's time poverty and increase their and their family's safety and health.

⁸ <http://africagrid.energydata.info>

⁹ www.geni.org/globalenergy/library/national_energy_grid/index.shtml

¹⁰ Kilowatt hours are the standard unit used to measure energy consumption. Guidance on determining KWH rates for specific equipment and processes are laid out under step 3 below.

tunities requires a more traditional sector mapping exercise. The best place to start is to identify local off-grid technology distributors and design-build firms. Other sources of potential innovative technologies include:

USAID's Powering Agriculture Program, which maintains a database¹¹ of emerging renewable energy technology providers with focus on USAID target markets.

The International Renewable Energy Agency (IRENA) maintains a public GIS database¹² showing wind and solar feasibility in different localities around the world.

In most of the world, diesel generators are the most common and default off-grid energy source. Generator and fuel costs can be determined by speaking with local service providers in the target region/districts.

Once the cost per KWH for energy is determined, it can be multiplied by the total energy demand (Step 3). This will be needed to model returns in Step 5 and ultimately determine the feasibility of the upgrading technology.



Apply a gender and social inclusion lens:

Consider whether on-grid or off-grid opportunities are more easily or less easily accessible to women, youth, and members of marginalized groups. In addition to comparing costs and determining whether these groups have the resources and information necessary to connect to these energy sources, assess whether there are other factors that may promote or deter access. This may include:

- Does the local service provider assess and include women or marginalized groups when advertising or educating about their services?
- Do they have local representatives that are female?
- Are there policies or procedures that make accessing these services challenging for women, youth, or marginalized groups (i.e., Can women sign a legal contract in this context? Is collateral required? Is a bank account required? Are there any legal or policy requirements, such as tax incentives or requirements, that they need to be informed about)?

¹¹ <https://poweringag.org/innovators>

¹² www.irena.org/documentdownloads/publications/ga_booklet_web.pdf

Step 5: Model Returns (Feasibility) of Energy Investment

Combine the load profile information from Step 3 with the cost data collected in Step 4 to model the financial feasibility of the proposed technology upgrade opportunity. In doing this, it is necessary to identify gaps between energy demand needs and energy supply.

There are many metrics to do this, but one of the most common is internal rate of return (IRR¹³), a way to evaluate different uses of cash at any given point of time against one another. There are many good resources that can walk you through how to calculate IRR so we will not go through them here, but instead will simply give the final values.

Note: For the purpose of identifying opportunities to integrate renewable energy technologies into a market systems or value chain strengthening programs, it is sufficient to use the information resources and process laid out in this brief. However, we stress the importance of consulting with qualified electrical engineers and other specialists as relevant before advising firms on or subsidizing investment in actual equipment purchases. There are many nuances, safety, financial, and other technical considerations too varied to cover in this brief that should be addressed as part of any energy investment.

STEP 5 IN ACTION:

We can simply add up how long it would take for Tomato Fresh to recoup its solar PV investment through electrical bill savings and avoiding wasted produce, which would be about 10.7 years. Since the solar PV system comes with a 20 year warranty and expected lifespan of 30 years, this would make it a very good investment.

However, the different cost structures of renewable energy sources and legacy technologies require a different set of calculations. For solar PV or wind, all of your costs are up front, whereas for grid power, or diesel-powered generators costs are spread out over time.

Using the internal rate of return (IRR) referenced above, we can evaluate the best use of cash for Tomato Fresh: are the electrical savings worth it, or should they invest it in another line of business?

If we take the above numbers, we would assume that in Year 1 Tomato Fresh spends \$12,000 on a solar PV system, which would save them \$1,120 a year over the next 20 years (while the system is fully under warranty). The IRR in this scenario would be 6.52%. In other words, this would be equivalent to investing the \$12,000 in the stock market, and getting an average return of 6.52% per year for 20 years straight; all in all a good investment.

Step 6: Design Systemic, Sustainable Interventions to Catalyze on Identified Opportunities

This brief provides a practical roadmap to understand energy constraints, costs, and opportunities for partners involved in core agricultural value chain functions (e.g. processors, producers, transporters). This is an important piece of information for design. However, to act on this information and design appropriate interventions requires a much broader view of the agriculture and energy systems. Many good programmatic investments fail to have any sustainable, scalable impact because the interventions were in the wrong place to leverage broad-based impact; root causes weren't considered and target-

ed and thus only short term 'band-aids' get applied; or critical relationships and partnerships fall apart once the project ended. With this in mind, this step provides some basic tips to consider as programs move into the intervention design phase, within the broader context of a value chain development or market systems approach.

The most foundational best practice involves understanding the broader system of actors, forces, norms, and networks that shape incentives, behaviors, and patterns¹⁴. Systems thinking helps us 'zoom

¹³ For example, see step by step guides at www.mathsisfun.com/money/internal-rate-return.html, www.accountingtools.com/articles/how-to-calculate-the-internal-rate-of-return.html, or www.investopedia.com/ask/answers/022615/what-formula-calculating-internal-rate-return-irr-excel.asp.

¹⁴ For one take on systems thinking within a development context, see USAID's "5Rs Framework in the Program Cycle" at https://usaidlearninglab.org/sites/default/files/resource/files/5rs_techncial_note_ver_2_1_final.pdf; Oxfam also has a helpful video accessible at www.youtube.com/watch?v=WfyWgp95kgA

out’ to understand other systems and forces that influence the core outcome we want to see (e.g. increased uptake of energy solution X by small firms in region Y of value chain Z), and then ‘zoom in’ to more deeply understand the root causes that drive key behaviors and changes we are targeting (not only by individual firms or consumers but also at the system-wide level).

In designing a programmatic response to identified energy opportunities, we must consider the broader ecosystem and other dynamics that influence behaviors, rate of uptake, and more. For example, the best way to address these constraints and support these opportunities will not necessarily involve direct engagement with the core value chain firm (i.e. the end user of a technology). The best ‘bang for buck’—or the leverage point for truly sustainable, system-wide impact—may actually lie in support to a totally separate group of actors, or in tackling an underlying norm that shapes behavior across the system.

For example, to help firms increase uptake of solar PV technologies for small scale dairy cool chain, our programmatic response may actually focus on strengthening industry groups to pressure the government to reduce tariffs or subsidies on the materials that go into engineering and manufacturing that product locally. Or, we may support energy firms to conduct more tailored market research so they can better design, price, market and service their products to rural clients. Or, we may informally partner with various media platforms to amplify the voices of businesses who have successfully adopted solar PV, encouraging others to copy or crowd in a behavior. Or, we may work with financial institutions or impact investors to co-create and pilot tailored, bundled alternative financing options that reduces the upfront cost consumers pay and therefore nurtures more widespread uptake. Our response will depend on the insights from our systems analysis, which helps us uncover the real reasons (or ‘root causes’) driving negative or positive outcomes, and the best leverage points for change.

Here are some additional considerations which draw from market systems approach best practice:

- identify opportunities to co-create and co-own interventions with partners
- embrace a phased test—reflect—adapt timeline that allows models and assumptions to evolve, and for partners to take increasing ownership and investment roles
- in co-creating, be cognizant of embracing diverse perspectives through diverse representation—see the Gender & Social Inclusion box below)
- be sensitive to distorting market incentives and price thresholds through large program subsidies or ‘brokering’, at both the firm and customer levels;
- use grant funds in more systemic ways—don’t just jump to giving a series of in-kind grants to individual businesses so they can upgrade a technology. Consider other types of market facilitation support: funding market research or willingness to pay surveys, sponsoring pay for performance competitions/contests with product suppliers, financiers, and/or service providers; supporting vocational development programs to address local service provision skills and service models; buying-down risk of investment or innovation by financiers by using grant funds as first-loss capital/guarantee funds; etc
- build networks amongst key industry actors and foster meaningful, repeated collaboration
- as noted under Step 1, consider treating energy as a value chain system in and of itself, given its relative importance to overall market system transformation and inclusive growth
- don’t work in isolation! There are many collaborators and partners innovating in the energy-agriculture nexus space.

STEP 6 IN ACTION:

Recall in Step 5 you identified that a solar PV array would be a good addition to Tomato Fresh's new tomato drying operation. At this point, many projects would simply give Tomato Fresh a grant to go out and purchase a solar array. And while this would be good for Tomato Fresh, and potentially good for their neighbors, its impact probably ends there. What will the next firm do?

So, you and your team take a different approach. You aim to ask 'why' a bit more, pushing deeper, to help uncover the underlying reasons at a systems level—not just the level of 2-3 actors—behind why uptake of solar PV is so low, even though the payback period makes business sense. You go out and identify the major solar equipment suppliers in Kenya and interview them about their business constraints. They highlight that even though selling to a customer like Tomato Fresh clearly makes good business sense, Tomato Fresh doesn't have the cash up front to pay for the solar pv system, and there are limited financing options out there for these sized firms. You interview financing firms to understand the reasons for this and discover there is limited information flows between tomato processors, clean and renewable energy providers, and investors—as well as poor incentives for finance staff to innovate. You combine this with the social and gender analyses on your project, which highlighted that women tended to congregate in smaller, more cash-strapped businesses and don't always have title to land and assets needed for collateral—further complicating access to large upfront cash investments, although energy-fueled enterprise growth would disproportionately benefit the primarily female workforce.

You and your team then sit down and, together with investors, processors, and service provider—co-design some pilot interventions, which you'll refine and scale up as you discover what works and how committed partners are. This includes:

1. Identifying a set of impact investors interested in renewable energy opportunities, working with them and the solar PV suppliers to bundle Tomato Fresh's venture with several similar upgrade opportunities.

The larger investment amount of these opportunities combined makes the investment worth it for investors, and solves Tomato Fresh's financing challenge. Through media and business networks, you support dissemination of learning from this model, building competitive pressure, perceptions of risk, and capacity for others to adapt it.

2. Facilitating investor visits to build direct relationships with solar PVs and end user processors, identifying a champion to host a feedback session

3. Support a joint advocacy effort by the horticulture industry and renewable energy providers to pressure the government to reduce tariffs or subsidies on the materials that go into engineering and manufacturing of solar PV technologies—to reduce the end customer cost.

4. Provide a small subsidy to a vocational school to train equal numbers of women and men in solar PV installation and maintenance, with training delivered by solar PV firms for quality control

5. Conduct a business feasibility assessment that helps set a modest pricing structure for neighboring homes to access the solar PV after working hours at Tomato Fresh and the other firms, decreasing women's time burdens for boiling water and enhancing social capital through enabling easier communication with family elsewhere.

As a result of these new business lines, the solar PV business develops a new dedicated sales and installation unit targeting small-scale agribusinesses—a new business line for them—and the increased information flows and pilot investments attract interest from other investors and entrepreneurs, amplifying the messages of the advocacy efforts. As a result of this approach, you and your team have successfully leveraged donor resources to in efficient, less distortionary ways that address deeper constraints at the systems level to sustainably expand access to energy, support the horticulture sector, and increase employment and decrease time poverty for women. This approach enhances the likelihood that development outcomes are broad-based and sustained.



Apply a gender and social inclusion lens:

- Ensure women's and youth participation in designing the activity—consultation and participation in identifying what is needed, what are the challenges and what are the potential solutions are the keys to designing inclusive and sustainable interventions.
- Facilitate women's and youth engagement in solutions that are attractive to market actors—support market research, sensitize market actors on the value of this approach and build their capacity, help them understand the business case for engaging women and youth in order to promote sustainable interventions.
- Assess gender and social factors such as time burdens, control over income, leadership, access to resources, and decision-making in value chain and energy assessments. These dynamics can both inhibit participation and benefit from energy upgrades so this information should factor into intervention selection and design. Meanwhile, increased access to and participation in energy upgrade activities can have positive or negative impact on these empowerment factors, so it is important to monitor, evaluation and respond to changes during implementation.
- Engage men and community leaders to understand the negative impacts of gender inequality and to promote female engagement and benefit from energy upgrades.
- Be informed—three of many resources include¹⁵:
 - Intervention Guide for the Women's Empowerment in Agriculture Index (WEAI): Practitioners' Guide to Selecting and Designing WEAI Interventions
 - Women's Economic Empowerment Briefs on Engaging Men and Women's Engagement Beyond Production

See the Step 6 in Action box for the Tomato Fresh case application. For more reflections on programmatic and policy implications of increasing CE and RE opportunities, see the full E4Ag integrated literature review and field work report, available at www.agrilinks.org/post/clean-energy-productive-use-post-harvest-value-chains-integrated-literature-review-field-work.

¹⁵ www.agrilinks.org/sites/default/files/resource/files/WEAI%20Intervention_Guide_Final%208.2016.pdf; and www.marketlinks.org/library/womens-economic-empowerment-briefs-suite-0