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Powering agrifood systems

Review of enabling policies Kenya, Uganda, and India

Beryl Ajwang, Lanvin Concessao, Preeti Kumari, Namrata Ginoya, and Vandita Sahay

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Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues.

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Highlights

- Agrifood systems produce nearly 11 billion tonnes of food annually and employ 4 billion people, playing an important role in economic growth, food security, and employment opportunities. Significant electricity is consumed by farm mechanization activities such as irrigation, agrifood storage, and processing.
- The addition of electricity infrastructure in agrifood systems has the potential to increase crop cultivation, value addition, and income generation while mitigating the challenges associated with food loss across processing, storage, and transport.
- This study reviews 100 national policies, programs, and regulations from India, Kenya, and Uganda to understand the level of integration of electricity in existing policies in the agrifood sectors, especially in areas where mechanization is most needed: access to water for agrifood production, storage, and postharvest handling and processing across the agriculture, dairy, and fishery sectors.
- For improved effectiveness, policies need to establish time-bound mandates, promote interministerial coordination, articulate roles and responsibilities, improve synergy with other allied sectors, build financial incentives, establish appliance standards, foster public-private partnerships, and define ways to monitor and measure targeted outcomes. Such an enabling environment coupled with clean energy and efficient use of resources (water, land, and electricity) can strengthen climate resilience and align agrifood systems with sustainability goals.

Executive Summary

Linkages between agrifood systems and electricity

Food and energy systems are central to impacting human lives and the environment for achieving equitable development. Globally, agrifood systems produce nearly 11 billion tonnes of food annually and employ 4 billion people directly or indirectly (FAO 2021b). From an environmental standpoint, global agrifood systems accounted for nearly one-third of the greenhouse gas (GHG) emissions generated in 2022 (FAO 2024). In 2022, 13 percent of the world's food was lost in the supply chain, and 19 percent of food available to consumers was wasted at the retail and household levels (FAO 2023b; UNEP 2024).

Electrifying agrifood systems through reliable, affordable, and sustainable energy can support higher crop yields, boost income, lower food losses, and enhance climate resilience (IRENA and FAO 2021). Energy in the form of electricity to mechanize various value chain processes in agrifood systems—through productive use of electricity (PUE) applications such as irrigation water pumps, cold storage, and food processing, especially through renewable energy—have been gaining traction from donors, private sector, and governments. For electricity to play a transformative role in agrifood systems, governments must establish supportive policies that integrate electricity across all stages of agrifood systems, from production to consumption.

However, siloed planning and policymaking within the electricity and agriculture sectors has impeded the development of synergies between energy and agrifood systems, especially in developing countries, where agrifood systems are underdeveloped yet closely tied to socioeconomic development outcomes (IRENA and FAO 2021). Hence, there is a need to explore how national policies articulate the role of electricity in agrifood system policies toward achieving equitable development outcomes.

Approach

This study reviews national policies across three countries: India, Kenya, and Uganda. It comprises an extensive review of policy documents, programs, plans, and vision documents (hereinafter referred to as "policies") that are publicly available on government portals.

This study reviews policies that address the development of infrastructure for agrifood systems and the integration of electricity as an input to create this infrastructure, specifically during agricultural production and postharvest storage and processing. It examines whether existing policies in the three countries mention, adopt, budget for, or integrate electricity needs. **Along with a review of such national policies, it documents some of the enabling policies that integrate electricity needs meaningfully in agrifood systems.** This study attempts to draw parallels between the institutional mechanisms in the three countries, wherever feasible, by evaluating policy practices that can be replicated in other geographies with similar agro-economic settings.

Although energy could encompass other areas of agrifood systems, including cooking fuels, clean cooking, and biogas, the scope of this paper is limited to analyzing electricity as an input to policy interventions rather than broader energy interventions in agrifood system policies. The electricity supply options include both grid-connected and off-grid electricity supply and span different power supply options, such as renewable energy (e.g., solar), grid electricity, and fuel-based generators.

Findings

- **Integrative policies involve effective collaboration between multiple government ministries.** The roles and responsibilities of various ministries need to be clearly defined for proper implementation of policies. This could be through the co-development of policies by multiple departments (such as Uganda's National Irrigation Policy by the Ministry of Agriculture, Animal Industry and Fisheries and the Ministry of Water and Environment) or by gathering inputs from different stakeholders during policy development (such as agricultural policies in Kenya featuring inputs from multiple ministries or the productively used renewable energy roadmaps in Kenya and Uganda, developed with inputs from multiple actors such as industry associations, the private sector, implementing organizations, and financing institutions).
- **National policies are often adopted and adapted by subnational governments to fit local contexts.** Kenya's governance reforms allow counties to develop their own County Energy Plans that align with their unique needs and priorities on the ground, ensuring local relevance and equitable resource distribution.
- **Implementation of policies depends heavily on adequate budgetary allocations. India has numerous policies with strong financial incentives, whereas Kenya and Uganda focus more on overarching strategies without dedicated budgets, relying on multiple programs and private investments.** International financial assistance provided to governments is often directed to a single ministry in most cases, thereby fragmenting potential collaboration between ministries.
- **Financial incentives, such as subsidies, grants, and tax incentives, are crucial for making PUE technologies affordable for farmers, particularly smallholder farmers.**

Uganda's Micro-scale Irrigation Program provides targeted subsidies for irrigation equipment. Such financial support helps farmers adopt PUE applications, thereby enhancing their productivity.

- **Defined technical standards and cost benchmarking for PUE technologies are essential to ensure quality and performance while improving consumer awareness of technology selection.** India has established standards for solar irrigation pumps and solar cold storage. Kenya and Uganda need similar region- or country-specific standards for PUE applications to ensure reliable technology adoption.
- **A sustained policy ecosystem requires ongoing monitoring and evaluation (M&E) to assess progress and inform future policies.** For example, Uganda's National Development Plan III includes a detailed M&E framework with specified outputs, time frames, and lead departments.
- **National policies in India, Kenya, and Uganda recognize the agriculture sector's role in addressing climate challenges, in particular, emphasizing the use of solar power for irrigation and cold storage.** Kenya's Climate Smart Agriculture Strategy and Uganda's Green Growth Development Strategy promote renewable energy technologies, and India's policy framework supports decentralized renewable energy (DRE) for various livelihood purposes.

Recommendations

- **Although formulating integrative policies is necessary to integrate electricity into agricultural livelihoods, there is a need for policy instruments to implement the policies, particularly through budgetary allocations, financial incentives, capacity-building and awareness, coordination, and technology standards.**
- **Multisectoral collaboration is essential to ensure that policies reflect diverse views on energy and agrifood systems.** This offers an opportunity to converge existing policies, providing a viable and more resource-efficient alternative to creating new policies. Additionally, policies should adopt a bottom-up approach that considers inputs from subnational governments to create national policies that are responsive to multiple contexts.
- **Balancing innovation with performance standards is key to wider agricultural mechanization and adoption of PUE technologies.** Policies should encourage the development of high-quality, efficient agricultural equipment by investing in research and development and offering fiscal incentives that align with improved performance standards.
- **Continuous policy review and revision based on monitoring outcomes ensures that policies remain effective and relevant.** This iterative process helps identify and address implementation challenges, fostering a dynamic and responsive policy environment.
- **Agrifood systems policies should promote climate-smart agriculture practices that reduce carbon emissions, promote efficient use of resources (water, land, and electricity), and strengthen the resilience and adaptive capacity of climate-vulnerable communities.**

Introduction

Agrifood systems

Agrifood systems "*encompass the entire range of actors, and their interlinked value-adding activities, engaged in the primary production of food and non-food agricultural products, as well as in storage, aggregation, post-harvest handling, transportation, processing, distribution, marketing, disposal and consumption*" (FAO 2021b). Agrifood systems are categorized into the following subsectors: crops, livestock, fishery, and forestry (FAO 2021b). They reflect the interests and values of different actors operating in varying landscapes, adapt to agroecological conditions, and are driven by resource availability (land, labor, and capital), market forces, climate change, consumer preferences, and the policy and institutional environment (Campanhola and Pandey 2019; Hall and Dijkman 2019; Conti et al. 2024).

Agrifood systems produce nearly 11 billion tonnes of food annually and employ 4 billion people directly or indirectly, helping achieve the SDGs on poverty, economic growth, resource and energy efficiency, cleaner economies, inequality reduction, healthy aquatic ecosystems, hunger, health, and responsible production and consumption (FAO 2021b). Table 1 provides a contextual snapshot of agricultural and food data on the three countries considered in this study: India, Kenya, and Uganda.

The role of energy in agrifood systems

Globally, agrifood systems consume 30 percent of the world's energy (IRENA and FAO 2021). Calculations by Bajan et al. (2020) for the period 2000–2014 indicate that energy consumption in food production systems has been on the rise globally, with the maximum increase being witnessed in developing countries (e.g., 73 percent in India). Banerjee et al. (2017) estimate that by 2030 the energy requirement in Sub-Saharan Africa (SSA) for agriculture will double to 9 gigawatts (GW). The greatest energy demand will come from irrigation, which will account for 75 percent of the increase, and the rest will come from cold storage and agro-processing. Agrifood systems contribute to one-third of total anthropogenic GHG emissions; that is, 16.2 billion tonnes (FAO

Table 1 | **Key data points from the literature review and the FAOSTAT database**

INDICATOR	INDIA	KENYA	UGANDA	YEAR OF DATA	DATA SOURCE & YEAR
Total population (millions)	1,438	55.3	48.7	2023	FAO 2023c
Rural population (%)	63	73	77	2023	FAO 2023c
Value added (agriculture, forestry, and fishing) as a percentage of GDP in local currency (%)	16.37	20.61	24.11	2023	FAO 2024b
Total land area (1,000 ha)	297,319	56,914	20,052	2021	FAO 2024a
Agricultural land (1,000 ha)	178,528	28,302	14,415	2021	FAO 2024a
Percentage of agricultural land in land area (%)	60.05	49.73	71.89	2021	FAO 2024a
Land area equipped for irrigation (1,000 ha)	75,500	150.6	11.14	2021	FAO 2024a
Total agrifood produced (in 1,000 tonnes)	1,552,831	36,429	35,771	2022	FAO 2024c
Energy use in agriculture: Electricity (GWh)	214,994	56.5	2.11	2021	FAO 2023a
Energy use in agriculture: Petroleum products (GWh)	11,676	313.5	1,974	2021	FAO 2023a

Note: FAO = Food and Agriculture Organization of the United Nations. FAOSTAT = Food and Agriculture Organization Statistics. GDP = gross domestic product. GWh = gigawatt-hour. ha = hectare. The table presents a profile of agricultural indicators across the three countries for comparison, not to show a correlation. To ensure uniform data representation, the year of data assigned is the latest year for which data are available across all the three countries.

2024). The growing population, which is projected to reach 9.7 billion by 2050, will necessitate an increase in agricultural energy demand and emissions to meet the rising needs, especially in Africa and South Asia, unless action is taken.

Agrifood value chains have lengthened over time through the increased physical distance between farm and fork, particularly in developing countries. This increase is due to rapid urbanization, globalization of value chains, increasing incomes, and the emergence and expansion of activities in the "middle" of the value chain in the form of greater processing, distribution, and transportation (Gómez and Ricketts 2013; Vos and Cattaneo 2020). This has created opportunities for value addition and increased production due to the need for processing, storing, and packaging of food (Campanhola and Pandey 2019). As agrifood systems expand, integration of productive use of electricity (PUE) technologies can help increase food production, reduce food losses, and improve livelihoods. Stakeholders use different interpretations of PUE—based on the type of energy use: renewable energy, electricity, solar energy, or sectors for PUE interventions such as agriculture, commerce, and micro, small, and medium enterprises (MSMEs)—depending on the focus of the project (EnDev 2020). For this paper, *PUE refers to agricultural activities in the crop, livestock, and fisheries sector that utilize electricity as a direct input in the production of goods or services to facilitate income generation, reduce drudgery, improve productivity, and support livelihoods.*

This mechanization of agrifood systems adds value to agrifood produce and enhances overall productivity (B. Sims and Kienzle 2016). Electricity applications along the agrifood value chain include water pumps for irrigation; on-farm mechanization for input application and harvesting; cold storage, sorting, drying, grinding, milling, and packaging for processing and storage needs; and e-mobility for agricultural logistics. For all agrifood chains, product value tends to increase with the degree of processing, and correspondingly greater quantities of additional inputs (electricity, water, and packaging materials) are consumed. For example, electricity used for milling of paddy rice (to remove bran and husks) increases its value, as does postharvest treatment of fruits and vegetables; for example, to keep fresh products cool and thus maintain their quality until they reach the consumer (R. Sims et al. 2015).

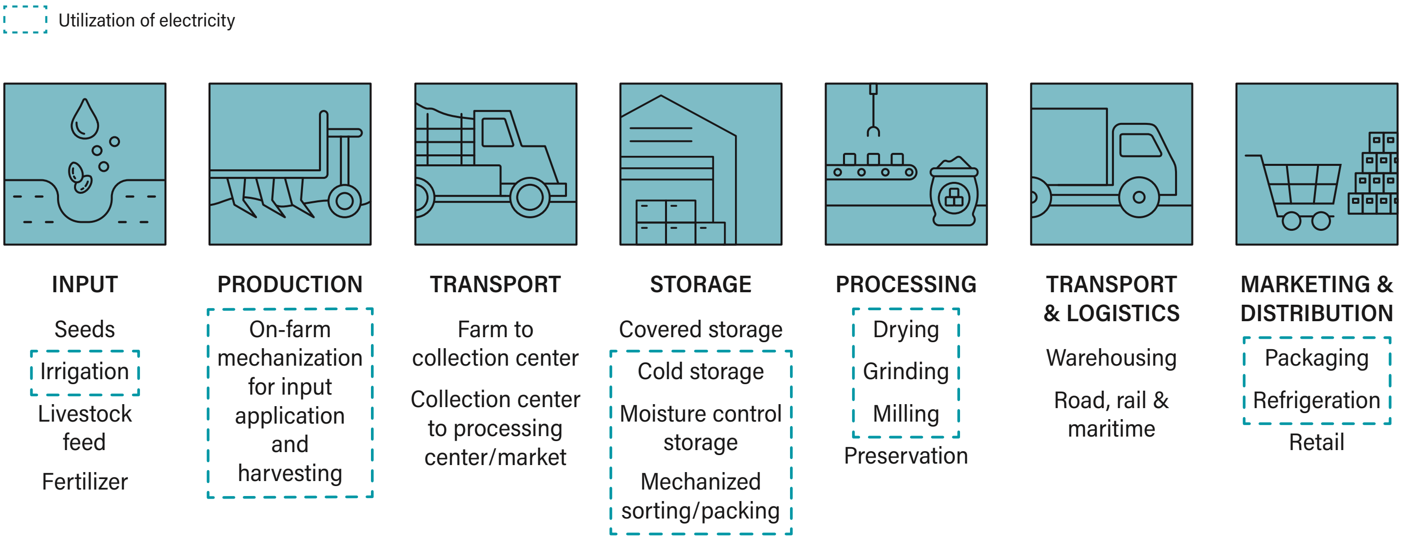
Figure 1 depicts the potential use of electricity interventions at various stages in the value chain. Activities inside blue boxes link electricity usage to power-specific value chain activities.

Given the importance of agrifood processing, value addition, and delivery in the economic growth of developing countries, a close examination of electricity interventions in its value chain becomes crucial.

Implications of electricity for food security

Agricultural production in India, Kenya, and Uganda is dominated by smallholder farmers who are heavily dependent on rainfed agriculture (Kalele et al. 2021; MAAIF and iNGO Alliance 2021; MoA&FW 2022). This, coupled with climate vulnerability and low use of technology, hinders the ability to enhance crop yields.

Figure 1 | **Use of electricity in various stages of the agrifood value chain process**



Notes: Direct energy (electricity and other fuels) and indirect energy use in the food value chain.
Source: Adapted from R. Sims et al. (2015).

Irrigation is considered a prominent tool for ensuring food security and market-oriented production around the world (Darko et al. 2016). In order to meet the growing needs of food production, groundwater irrigation has been rapidly increasing. Although electric and diesel pumps have been the mainstay of irrigation, the demand for, and interest in, solar irrigation pumps has been rapidly growing. This is evidenced by the fact that India alone has installed over 500,000 stand-alone solar pumps in the last decade, with countries in SSA seeing traction toward its adoption (Balasubramanya et al. 2024).

Globally, it has been estimated that approximately 13.2 percent of the food produced was lost from the production and harvest stages to the retail stage of the food value chain in 2021 (FAO 2023b). The studies reviewed by Agarwal et al. (2021) and Kipkirui et al. (2023) identified similar reasons for food losses in India and East Africa, respectively, such as inefficient handling and harvesting techniques, poor storage facilities, and inadequate transportation. Among these impediments, the lack of well-developed cold chains and processing infrastructure remains a challenge in developing countries, including in India, Kenya, and Uganda. These solutions need reliable electricity access, underscoring the need to better understand their role in agrifood systems.

The disparities in food loss and waste at different stages of the supply chain are also evident. Past data from the Food and Agriculture Organization of the United Nations (FAO) (Cederberg and Sonesson 2011) indicate that in developing countries, the highest food loss and wastage occurs in the production, handling, and storage stage, in contrast to developed regions, where food is primarily lost or wasted during the consumption stage. Food loss in developing countries occurs due to fragmented food systems and inefficient supply chains, which results in food loss even before it reaches the market or the end consumer. Figure 2 represents the trends in food loss percentage by region, with SSA recording the highest food loss percentage.

Pressing challenges that have attracted attention for policy integration include climate and environmental issues, food insecurity, and gender inequalities (Jordan and Lenschow 2010; Cejudo and Michel 2017; Runhaar et al. 2018; Candel 2021). Research indicates that integrative policymaking is more effective than traditional compartmentalized policymaking in achieving the desired outcomes (Candel 2021). Given how energy and food systems are deeply interconnected, it is imperative to analyze whether existing country-level policies and programs integrate the electricity needs of agrifood systems, and how policies can help transform agrifood systems by introducing sustainable and accessible electricity interventions.

About this paper

This paper aims to understand levels of policy integration to strengthen the linkages between electricity and agrifood systems. It explores the cross-geographical and cross-sectoral application of good practices in policy integration.

This study is part of WRI's Energy for Equitable Development Initiative, which focuses on improving access to reliable energy in India and SSA. The initiative adopts a multipronged approach to scaling energy solutions through access to better

Figure 2 | **Percentage of food lost in different regions after harvest (2016, 2020, and 2021)**

Source: Authors' analysis based on FAO (2021a).

data for identifying energy demand, right-sizing energy supply options to cater to demand, reforming sustainable financing instruments, mainstreaming evidence to achieve development outcomes, and lastly, building awareness and generating evidence toward enabling stakeholders to participate effectively in the clean energy transition.

Methodology

The methodology used in this working paper comprised an extensive literature review to identify and analyze existing policy documents related to agrifood systems, examining whether existing policies in the three countries mention, adopt, budget for, or integrate electricity. Hereinafter, policies, regulations, programs, schemes, strategies, guidelines, plans, and similar instruments used for administrative decision-making and implementation in the agrifood sector are referred to as "policies." Although energy could encompass other areas of agrifood systems, including cooking fuels, clean cooking, and biogas, the scope of this paper is limited to analyzing electricity as an input in agrifood policies.

This paper documents some enabling policies implemented at the national and subnational levels that effectively integrate electricity interventions. It addresses the following research questions:

- How well do national policies, programs, and regulations integrate electricity into agrifood systems?
- Based on the best practices analyzed, how can governments develop policies linking electricity and agrifood systems?

To review the various national policies, the study adopted a similar methodology to that used in Ginoya et al. (2021) to evaluate national and subnational policies in the health and education sector in India.

We categorized the level of maturity of the policies in recognizing the interlinkages between electricity and agrifood sector based on the three categories specified in Table 2.

Policies were categorized into various buckets using the levers of policy action developed by Mogelgaard et al. (2018), which identify the policy instruments designed to bridge the implementation gap by integrating nontraditional dimensions (reliable electricity access in this case) into development objectives (i.e., livelihoods). The five levers are as follows:

- **Policy frameworks** to demonstrate formalized intent regarding policy objectives. The mandated conditions and flexible provisions provide an opportunity to incorporate electricity-related priorities.
- **Coordination mechanisms** are necessary to operationalize interdepartmental requirements for incorporating electricity provisioning in agrifood systems.

Table 2 | **Categorization of policies based on integration of electricity requirements**

CATEGORY	DEFINITION	BUDGETARY ALLOCATION	EXAMPLE
Indirect	Specifies systems, roles, and processes for policy implementation but does not mention the need for electricity to operationalize them.	No direct budget for electricity within the policy.	Infrastructure development or technology-specific policies that discuss new or upgraded equipment without planning for reliable power supply.
Basic	Acknowledges electricity as a supply-side requirement and identifies institutions responsible for its provision but does not integrate its access, reliability, or affordability into sectoral planning.	General budget allocation under infrastructure development but lacks dedicated funds for implementation of electricity.	Development policies that mention electricity as a requirement but do not specify how it will be provided.
Integrative	Fully integrates electricity with clear coordination, roles, and mechanisms.	Clearly defined budgetary allocations for electricity infrastructure within sectoral policies.	Policies for technology integration such as irrigation or cold storage that incentivize clean energy supply.

Source: Authors' categorization, adapted from Ginoya et al. (2021).

- **Financial processes** support frameworks and coordination mechanisms through explicit budgetary allocations, with the finance and planning departments enabling interdepartmental coordination.
- **Information and tools** enhance cross-sectoral capacity and evidence to inform policymaking.
- **Sustained leadership** includes political leadership, bureaucrats, or financing organizations that can launch new programs or institutions to accelerate the adoption of policies.

This methodology is not entirely prescriptive, and its applicability may differ based on country-specific contexts.

Scope

This policy review focuses on India, Kenya, and Uganda—countries where WRI has active partnerships and prior experience in supporting energy for equitable development initiatives. Leveraging these relationships, this paper aims to inform policy frameworks and provide recommendations that better integrate electricity within agrifood systems.

Recent studies have highlighted the growing economic viability of PUE in agrifood systems, particularly their potential to be powered by renewable energy (EnDev and SNV 2021; CREEC et al. 2023; Jain et al. 2023; Ministry of Energy and Petroleum et al. 2023). Three PUE applications—irrigation pumps, cold storage (for horticulture and milk chilling), and agro-processing—were identified as having experienced the highest growth and maturity in terms of their adoption in the past few years—apart from bioenergy applications (IRENA and FAO 2021). Accordingly, this paper examines whether national policies in the three focus countries support electricity needs at the following value chain stages: access to water (e.g., irrigation), cooling or preservation (e.g., storage), and value addition (e.g., processing).

Table 3 presents the scope of the policy analysis.

Table 3 | **Scope of policy analysis**

COUNTRY	SECTORS	TECHNOLOGIES IN THE SECTOR	TYPES OF DOCUMENTS OR POLICIES REVIEWED	YEAR OF LAUNCH	JURISDICTION OF THE POLICY	ELECTRICITY LINKAGES
▪ India ▪ Kenya ▪ Uganda	Agri-food systems: Crops (horticulture and cereals), Livestock (dairy), and Fisheries	▪ Irrigation: water pumps ▪ Cold chain: cold rooms, freezers, etc., for dairy, horticulture crops and fisheries ▪ Agro-processing: milling, drying, grinding, pulverizers, food processing, etc.	Plans, policies, programs, schemes, frameworks, acts, regulations, rules, strategies	Launched in 2010 or after. This includes previous policies that have been amended or renewed after 2010	▪ National level ▪ State, county, or district level policies looked at only from the perspective of feeding into national policy outcomes	Provision of electricity through grid, fuel, and/or renewable energy power supply, infrastructure upgradation, electricity as an input, convergence with government stakeholders responsible for power

Source: The authors.

A total of 114 national policies were identified from the ministries of agriculture, energy, rural development, environment, finance, and planning. Based on the defined scope criteria (see Table 3), this was narrowed to 100 policies: 51 from India, 31 from Kenya, and 18 from Uganda. The higher count in India reflects the presence of multiple finance-oriented policies supplementing broader sectoral strategies. In contrast, Kenyan and Ugandan policies tend to consolidate functions such as financing, monitoring, and infrastructure under umbrella policies.

Of the 100 policies reviewed, 45 were categorized as integrative (explicitly linking electricity and agrifood systems), 28 as basic, 22 as indirect, and 5 as having no connection to electricity.

Although the review focuses on policy intent rather than on implementation, the authors acknowledge that electricity access alone does not ensure productive use. Complementary factors—such as access to technology, finance, skills, and markets—must also be addressed. The findings offer a foundation for future research on implementation effectiveness and broader system integration.

Policy review: Electricity needs in agrifood systems

Recognizing the importance of the agriculture sector in rural employment and its potential to improve social and economic conditions, governments have implemented various policy measures to foster its sustainable development.

Development policies, including agrifood system programs, have been driven by long-term vision documents that provide overarching guidance to implement various programs. Kenya's Vision 2030 aims to transition the country *into a newly industrialized, middle-income nation by providing a high quality of life to its citizens by 2030* (Government of Kenya 2007). Similarly, Uganda's Vision 2040 seeks to transform the nation from *a peasant to a modern and prosperous one within 30 years* (Government of Uganda 2007). These visions are operationalized through their respective five-year implementation plans, the medium-term plans in Kenya, and the national development plans in Uganda. Most policies developed are in line with the vision documents and aim to build upon them. These long-term plans in both countries have listed the improvement of agricultural livelihoods as a priority.

We look at the policies through the technology lens of mature PUE interventions deployed in irrigation, cold storage, and agro-processing. This section highlights the key policy drivers that some of the integrative policies have adopted in each country, and how they have shaped the integration of electricity priorities in the agrifood sector.

Irrigation

Access to water and agriculture are intrinsically linked, with the agriculture sector using water for crop cultivation, in many cases through inefficient water usage practices. Moreover, the impact of climate change has made rainfall more variable and less predictable. Thus, irrigation has become a critical input in the pre-harvest process in agriculture.

With agriculture being the primary economic activity in India, irrigation uses 78 percent of the country's total water reserves, with 60 percent of the irrigation water used by paddy and sugarcane. The reliance on these crops is also due to skewed incentive structures that include highly subsidized pricing for water and power, along with guaranteed pricing and assured markets through public procurement (Sharma et al. 2018). Coupled with the low irrigation efficiency in India, due to traditional surface irrigation methods and an overreliance on flood irrigation, there is a need to prioritize sustainable and water-efficient farming practices to improve water use efficiency on agricultural lands (Sattva Knowledge Institute and DCM Shriram Foundation 2024).

In India, the National Water Policy emphasizes management of water resources through micro-irrigation, automated irrigation operation, and alignment of cropping patterns with natural resources. It also calls for regulating electricity usage to minimize overextraction of groundwater and separating electric feeders to pump groundwater for agriculture (Ministry of Water Resources 2012). Although power-source-agnostic electrification of irrigation was initiated during the green revolution, climate change impacts have also accelerated policies to integrate renewable energy into irrigation through solar irrigation pumps (SIPs). This started with an increased push toward energy-efficient agricultural pumps, leading to various pilots across the country (PIB 2016). Then, the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan Yojana (PM-KUSUM scheme) was launched in India in 2019, with the objective of improving the energy security of farmers through three policy components: setting up decentralized solar plants (Component A); installing stand-alone SIPs or replacing existing diesel-powered irrigation pumps (Component B); and solarizing existing grid-connected pumps (Component C). Although the policy intends to support the agriculture sector, it comes under the ambit of the Ministry of New and Renewable Energy (MNRE), with most Indian states[1] designating their respective energy departments as the implementing agency.

The policy had ambitious initial targets, such as deploying 1.75 million stand-alone solar pumps as of 2022 and subsidizing capital costs through a 60 percent government subsidy consisting of central and state financial assistance, a 30 percent loan component, and a 10 percent up-front payment from farmers.

However, the scheme did not achieve its targets (295,823 stand-alone pumps were installed as of January 2024) (PIB 2024). The uptake and utilization of solar pumps depends on regional agro-climatic conditions, such as solar irradiation, groundwater availability, and crop cultivation beyond rainfed agriculture. Acknowledging some of the barriers, MNRE has revised its targets and guidelines to provide greater clarity on the procedural requirements of setting up the solar pumps and the responsibilities of the concerned stakeholders.

The PM-KUSUM scheme promotes SIPs up to 7.5 HP. Thus, although the target of the program is smallholder farmers, the beneficiary selection process is left to the implementing agencies at the subnational level. Given the large size of pumps that can be procured, the policy has achieved greater traction from medium and large farmers because they can afford solar pumps after the subsidy is applied (Bhushan et al. 2019; Yadav and Khanna 2024).

Building on the PM-KUSUM scheme, states have set up their own institutional frameworks to promote solar-powered irrigation (Box 1). Another national policy that has expanded efficient use of irrigation is the micro-irrigation component of the Pradhan Mantri Krishi Sinchai Yojana (PMKSY), which has reported a 31 percent reduction in electricity consumption costs and an average 32.3 percent reduction in irrigation costs (MoA&FW 2015).

In East Africa, the uptake of solar irrigation has mostly been led by farmers or enterprises. However, governments are addressing the need to tackle climate-change-related rainfall variation, increase productivity to meet demand, and promote sustainable production to enhance food security for a growing population. As a result, governments are embracing new approaches to irrigation development, as showcased by different policies in Kenya and Uganda.

Irrigation in Uganda remains low at 2 percent although it has the highest irrigation potential globally, with 15 percent of its surface area covered by freshwater resources (MAAIF and MWE 2017; Wanyama et al. 2024). The Micro-scale Irrigation Program is a government-led initiative supported by the World Bank through the Uganda Intergovernmental Fiscal Transfer Program (UgIFT). This program is aligned with the country's National Irrigation Policy, which aims to bring 1.5 million hectares (ha) (of the 3.03 million ha of area of mapped irrigation potential in Uganda) under irrigation by the year 2040 (NELSAP 2012). The program provides targeted subsidy support to farmers and offers funding through a combination of farmer contributions and a subsidy provided by the government that ranges between 25 and 75 percent of the total irrigation equipment cost, depending on the nature of the land and the water resources. Aiming to benefit smallholder farmers, the program limits support to 1 ha of land (MAAIF 2020). This level of targeted incentives is also due to the Ministry of Water and Environment's (MWE's) assessment that half of the irrigation potential is available as surface water and is therefore accessible through micro- and small-scale irrigation programs (World Bank 2020).

Uganda's National Irrigation Policy complements its existing policies and is codeveloped by two ministries: the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and the MWE. The policy is an elaboration of the country's National Adaptation Plan on Climate Change and is part of

Box 1 | **Subnational uptake of national policies: Examples from Indian states**

Of the three components of PM-KUSUM, Component B aims to deploy stand-alone SIPs, with smallholder farmers being the primary beneficiaries. To reach this target group, subnational governments have adopted different approaches.

The Jharkhand Opportunities for Harnessing Rural Growth (JOHAR) project is a holistic livelihoods project implemented in the state of Jharkhand, India, by the Jharkhand State Livelihood Promotion Society. The JOHAR project adopted a "community-led irrigation" model, where a water user group with 15–20 members in a command area of 6–8 hectares (ha) shared common responsibilities for the judicious use of irrigation. In addition, the introduction of 0.5 HP cycle-mounted solar pumps helped smallholder farmers irrigate up to 0.2 ha of farmland with a discharge rate of 2–3 liters per second.[a]

This model also aligned with other government initiatives. Micro-irrigation was incentivized under the "Per Crop More Drop" component of the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) implemented by the Ministry of Agriculture & Farmers Welfare (MoA&FW), and the Jharkhand Renewable Energy Development Agency further facilitated the use of solar pumps to extend irrigation coverage to deprived households.[b]

On the other hand, though the state of Chhattisgarh has not implemented PM-KUSUM, it has been implementing a subnational policy called Saur Sujala Yojana since 2016, with subsidies as high as 90 percent to its beneficiaries, that has helped significantly reduce the cost for smallholder farmers.[c]

The variety of actors involved at the subnational level—the energy, agriculture, and livelihoods departments—presents an interesting opportunity for synergy to promote the national energy ministry's technology and policy objectives.

Source: a) Newton-Lewis et al. 2020, Kishore et al. 2023. b) Newton-Lewis et al. 2020. c) Yadav and Khanna 2024.

the broader implementation of the National Climate Change Policy. It is also meant to be implemented alongside the National Water Policy. A key feature of the National Irrigation Policy is its multisectoral approach, clearly defining the roles and responsibilities of each stakeholder for implementation of the policy—ranging from the Prime Minister's office to various ministries of land, water, and planning; district governments; nongovernmental organizations (NGOs); and farmer groups (MAAIF and MWE 2017). One notable exclusion is the Ministry of Energy and Mineral Development, because it appears that the solar pumping implementation is led by the MAAIF.

Irrigation projects in Kenya, as across Africa, have been predominantly led by farmers or the market. Farmer-led irrigation development (FLID) has been driven without government support and accounts for 83 percent of the irrigation development in SSA over the past two decades (Mati 2023). These farmers have been entrepreneurial, independently developing irrigation models and investing their own resources to irrigate small plots of land through irrigation pumps (Izzi et al. 2021). The National Irrigation Policy (2017) and its corresponding instruments, including the Irrigation Act and Guidelines (2019), do not expand on the electricity needs for irrigation but mention collaborative mechanisms to develop irrigation infrastructure while promoting the use of renewable energy for irrigation. The National Irrigation Authority is the designated agency tasked with improving irrigation infrastructure and supporting county governments and other stakeholders in designing, implementing, and maintaining irrigation projects in Kenya. It also includes a Joint Irrigation Intergovernmental Stakeholder Committee, which acts as a consultative forum for cooperation among ministries—including Agriculture, Livestock and Fisheries, Environment & Forestry, Energy, and Cooperatives—and other stakeholders, including the development sector and farmer groups, on policy outcomes (Ministry of Water, Sanitation and Irrigation 2019).

The private sector in Kenya has played a role in driving the scale-up of irrigation technology. In an iterative process, private companies (manufacturers) designed products tailored to farmers' needs and launched payment systems such as pay-as-you-go options to increase affordability. Several private-sector companies dealing in SIPs have been present in the country for decades, supporting the scale-up and adoption of solar water pumps in Kenya (Michaelowa et al. 2016).

Product quality and standardization in irrigation pumps

Given that irrigation pumps are a technology-driven initiative, quality and performance standards are important to promote quality agricultural equipment to farmers. This requires balancing innovation in technology (i.e., pumps) with performance standards to ensure its wider adoption. India has developed quality standards, specifications, and cost benchmarks around pumping technology. These include detailed specifications and testing procedures to ensure that the solar pumps conform to the latest Indian and international standards (MNRE 2023). To enhance the utilization of solar pumps, the standards also promote the integration of the universal solar pump controller, so that energy can also be used for other value chain applications such as cold storage or agro-processing when the pump is not in use.

Although international quality standards for SIPs exist (IEC 2011), they are usually not applicable across different contexts and sizes (particularly small-scale SIPs). The lack of national or regional standards has been highlighted as a significant challenge for the uptake of solar water pumping in Uganda. Consumers are unable to distinguish between high- and low-quality pumping systems due to the proliferation of brands in the market, none of which are subject to standards or frameworks that assess pump quality (ACE TAF and Open Capital Advisers 2019).

Currently, in Kenya, mandatory national performance-based standards for SIPs have not been developed (Ministry of Energy and Petroleum et al. 2023). The closest quality assurance standards in place are through VeraSol, a program run by CLASP that provides testing for SIPs and other PUE appliances such as solar milling, egg incubators, and electric pressure cookers. Standardization initiatives in irrigation pumps currently focus on off-grid solar pumps with a solar capacity below 2 kW (Schatz Energy Research Center and CLASP 2021), which is paving the way for revisions to existing international standards on solar water pumps (SWPs) (VeraSol 2024). This provides the basis for developing national or regional standards, often a long and collaborative process, through local testing of solar water pumps that can address quality assurance challenges.

Postharvest interventions: Cooling

The inadequate and inefficient cold chain infrastructure causes postharvest food losses before the produce reaches the markets, saddling the food supply system with an economic burden by reducing the salable volume and value (World Bank 2022). Cooling, one of the postharvest loss management solutions, is suitable for specific perishable commodities. Losses are far higher in perishable produce such as fruits and vegetables than in cereals, especially in places with inadequate cold storage infrastructure (FAO 2019).

The postharvest losses in the agrifood sector in India amount to US$18.03 billion in monetary terms, underscoring the need to create postharvest infrastructure and introduce technological and policy changes that can reduce agrifood losses (NABCONS 2022). Several initiatives have been undertaken in India since 2010, including a comprehensive assessment by the National Centre for Cold-chain Development (NCCD to identify gaps in India's cold chain (NCCD 2015), which revealed a cold storage capacity gap of 3.2 million metric tons.

The Pradhan Mantri Kisan Sampada Yojana (SAMPADA) program by the Ministry of Food Processing Industries (MoFPI) envisioned seven components toward the creation of modern cold chain and agro-processing infrastructure for an efficient supply chain from farm gate to retail. The Integrated Cold Chain and Value Addition Infrastructure Scheme under SAMPADA facilitates the establishment of cold chain facilities for agricultural, horticultural, dairy, fish, and meat products, through various components such as farm-level infrastructure creation with an emphasis on cold chain infrastructure at the farm gate, processing centers, refrigerated vans and trucks, milk chilling, and so on (MoFPI 2022c). The scheme provides grant-in-aid of 35–50 percent of the eligible project cost of cold chain infrastructure creation. What makes this financing arrangement interesting is that although surrounding infrastructure such as approach roads, compound walls, and office buildings cannot be included in the calculation of grant-in-aids, renewable energy technologies such as solar, biomass, and wind are considered as eligible infrastructure.

Cold storage remains nascent in East Africa, especially for smallholder farmers, despite the high postharvest losses. In Kenya, nearly 40 percent of the food produced is lost between farm gate and table, driven primarily by poor postharvest practices and lack of access to markets (Efficiency for Access Coalition 2023). Although cold chains are strong in some high-value export crops and subsectors (such as fresh cut flowers in Kenya or dairy in Uganda), they are poorly developed. Sometimes, they are absent—for example, in sectors such as fresh fruits, vegetables, and livestock (Dramé et al. 2016; EEP Africa 2023). One reason for this is that over 96 percent of fruits, vegetables, and fish is locally consumed in Kenya (Efficiency for Access Coalition 2023). Thus, the lack of export opportunities has obviated the need to create regulations and standards. One of the goals under Kenya's National Agricultural Policy 2021 is to reduce postharvest losses, and the proposed interventions by the national government include ensuring reliable energy supply for postharvest processing, handling, and storage at the household and community levels (MoALD 2021a). The recently developed Post Harvest Management for Food Loss and Waste Reduction (2024-2028) strategy for Kenya recognizes the need for cooling, solar drying, and agro-processing to reduce food loss and waste in key value chains such as fruits, vegetables, fish, and dairy (see Box 2) (MoALD and FAO 2024).

In Uganda, the utilization of solar refrigeration represents a relatively newer subsector than solar water pumping (USAID 2020). Growth in this subsector has been stifled by the need for large investments and higher electricity needs for infrastructure setup. Kenya and Uganda offer a significant opportunity for cold chain infrastructure based on their large fresh produce production and export volume, which can help meet the increasing food demand while reducing food losses (EEP Africa 2023).

The need for cold chain technologies in East Africa has seen the emergence of entrepreneurs who are providing innovative cold storage solutions to rural areas (EEP Africa 2023). These include mobile cold storage facilities in rural areas based on solar technology or even large cold room space that can be rented. The business models, such as space renting or product leasing, offset the high capital cost burden.

Box 2 | **Sector-specific interventions: Dairy**

In India, the Dairy Processing and Infrastructure Development Fund (DIDF) was revised in 2021 to include renewable energy and energy efficiency infrastructure to modernize existing milk processing infrastructure and create new infrastructure. These measures would help minimize the running cost of the existing milk processing units.[a] DIFD also provides financial assistance to dairy federations, producer companies, and cooperatives through a combination of loans, interest subvention, and the end borrower's own contribution.

In Uganda, NDP III is complemented by sector-specific legislation such as the Uganda Dairy Action Plan 2022, which highlights the urgent need to strengthen cold chain infrastructure to mitigate postharvest losses and enhance dairy productivity. It outlines ambitious goals with defined targets, aiming to increase refrigerated milk transport from 20 to 50 percent by 2025. Additionally, it advocates for the adoption of sustainable solutions such as solar-powered milk chillers, particularly in areas with limited electricity access.[b]

Uganda's Dairy Development Authority Strategic Plan III (2020/21–2024/25) also highlights the critical role of cold storage in mitigating postharvest losses within the dairy sector, which currently stand at 15–20 percent for processed milk and 30 percent for raw milk. The plan sets ambitious targets to increase the prevalence of milk cooling tanks to 15 percent by 2025, pushing for investments at the farm level and the promotion of solar-powered milk chillers.[c]

Similarly, Kenya's national Dairy Master Plan (DMP) builds on the vision of Kenya's development agenda, specifically through the Agricultural Sector Development Strategy 2010–2020.[d] Kenya's dairy sector, the single largest contributor to its GDP, will use the DMP to build a globally competitive dairy value chain. The DMP includes action plans focused on productivity improvement, efficient service delivery, enabling policy and regulatory frameworks, and integration of cross-cutting concerns (gender, climate change, etc.) into the dairy value chain. It also encompasses the design of incentives for low-energy-use technologies.

Source: a) DAHD 2022. b) DDA 2022. c) Dairy Development Authority 2020. d) Ministry of Agriculture and Livestock Development 2010.

Presence of standards

A lack of technical and quality standards for components of stand-alone cold storage applications and an underdeveloped monitoring mechanism pose a challenge to the quality of the equipment used and eventually the feasibility of the deployed solutions. In India, the NCCD published engineering guidelines and minimum system standards for cold chain components, which laid a foundation for the development of various sizes of and use cases for cold storage applications for perishable produce (NCCD 2025). The document builds on the 2010 technical standards governing cold storage for fruits and vegetables (NHB 2010). MNRE has leveraged the previous guidance developed under the National Horticultural Board (NHB), the NCCD, and the Mission on Integrated Development of Horticulture (MIDH) Operational Guidelines to formulate design specifications, performance guidelines, and testing procedures for solar cold storage (MNRE 2025).

Although there are presently no quality assurance standards for irrigation or cold storage in Kenya, the Kenya National Energy Efficiency and Conservation Strategy by the Ministry of Energy (2020) outlines the need to improve energy efficiency in the agricultural value chain by promoting off-grid PUE with target projects such as solar-powered pumping water systems, cold chains, and grain milling. The strategy lists key implementation partners such as the Ministry of Agriculture, county governments, the regulatory commission, farmer producer organizations (FPOs), and project developers. The recent National Road Map on Scaling Up Productive Use of Renewable Energy (Ministry of Energy and Petroleum et al. 2023) also recommends the development and enforcement of internationally aligned mandatory standards for mature technologies, including off-grid refrigerators, to ensure quality products.

Regarding irrigation, there are voluntary quality and performance guidelines that support market uptake of dedicated cold chain solutions such as off-grid refrigeration. These include United for Efficiency's Model Quality and Performance Guidelines for Off-Grid Refrigerating Appliances and the proposed requirement that refrigerator units be certified through the VeraSol program (VeraSol 2022; UNEP 2023). The Uganda National Bureau of Standards oversees appliance standards and their enforcement. A standards and labeling program for refrigerators and freezers has been under development (De La Rue Du Can et al. 2022).

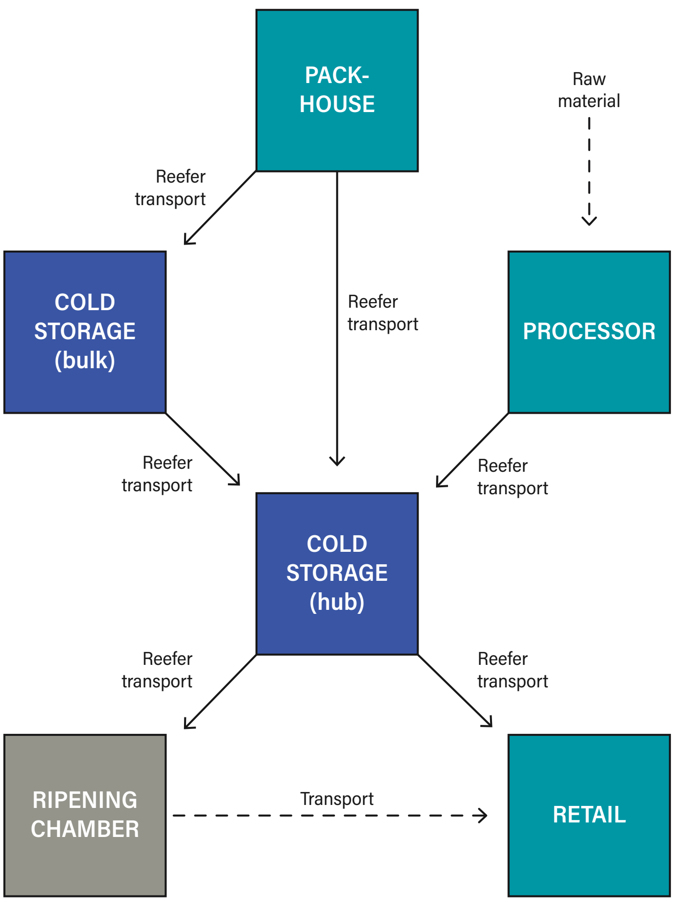
Cooling action plans

The cooling action plans in India and Kenya emphasize investments and upgrades to cold chain infrastructure such as storage facilities, refrigerated transportation, and distribution networks. They also advocate for green energy, such as solar-powered rooms in remote areas, and emphasize the importance of capacity-building initiatives for farmers in the areas of postharvest handling and cold storage usage.

The India Cooling Action Plan (ICAP), launched in 2019 by the Ministry of Environment, Forest and Climate Change (MoEFCC), projects India's cooling demand growth across sectors for 20 years—that is, up to 2037–38 (MoEFCC 2019). The MoEFCC followed a multi-stakeholder development framework with representation from ministries such as agriculture and power, industry associations, think tanks, and research organizations. One of the identified thematic areas was cold chain and refrigeration, which deals with the development of cold chain components (see Figure 3) for perishable produce (MoEFCC 2019). It also provides details on renewable-energy-powered cold chain development initiatives supported by the Ministry of Agriculture & Farmers Welfare (MoA&FW).

Kenya's National Cooling Action Plan for Kenya 2022 outlines its strategy to address the challenges of cooling demand while minimizing environmental impact and maximizing energy efficiency (Ministry of Environment Climate Change and Forestry 2023). Agricultural cold chain is a key sector,

Figure 3 | **Flow of perishable produce in a cold chain**



Source: MoEFCC 2019..

requiring climate-smart solutions to improve access to cold chains in order to build resilience by reducing postharvest losses. This includes creating a conducive regulatory environment to prioritize energy-efficient cold storage units and also pilot solar-powered cold storage.

Uganda does not currently have a national cooling action plan; however, the development of cold chain infrastructure is supported by various policies in the country. Other policies supporting cold chain infrastructure include the Third National Development Plan (NDP III) 2020/21 – 2024/25, which articulates the need for adopting cold storage to mitigate postharvest losses (NPA 2020a).

Postharvest interventions: Agro-processing

Agro-processing refers to the ability of agrifood systems to enhance value, improve livelihoods, and minimize postharvest losses for farming communities. Without mechanized processing equipment, community members have to rely on labor-intensive or manual processing methods, or they are compelled to sell unprocessed produce, missing out on opportunities to add value independently (IRENA and FAO 2021).

MNRE's DRE policy has the potential to boost the development of renewable-energy-powered livelihood applications in agriculture, agro-processing, dairy, poultry, and so on (MNRE 2022). The policy encourages ministries of agriculture, rural development, MSME, and food processing to integrate decentralized renewables under their respective policies to strengthen postharvest management. MNRE has proposed forming a committee that will meet every six months to monitor the progress of DRE projects. Apart from cold chain infrastructure, the SAMPADA program in India has two other sub-schemes: one on the creation of infrastructure for agro-processing clusters and another on the expansion of food processing and preservation capacities. These grant-in-aid schemes could fund two components: basic enabling infrastructure and core infrastructure. The basic enabling infrastructure of the scheme includes development of the site through water supply, electricity supply including power backup, roads, drainage, and other infrastructure needs. Up to 40 percent of the basic infrastructure cost is eligible for financial assistance (MoFPI 2022a, 2022b). Such segregation of financial assistance ensures that electricity infrastructure is not neglected in PUE interventions.

Agro-processing in Kenya remains low, with only 16 percent of all agricultural produce being processed within the country (Ministry of Agriculture, Livestock, Fisheries and Irrigation 2019). In contrast, Uganda's agro-processing sector dominates its manufacturing output, contributing approximately 60 percent of its total output, with food processing alone accounting for 40 percent (Fowler and Rauschendorfer 2019).

In India, both agro-processing and cold storage policies are driven by the MoFPI. Neither Kenya nor Uganda has a dedicated government department for food or agriculture processing; instead, such processing is integrated within their industrial policy frameworks. The absence of dedicated agro-processing policies means that the sector's growth, and manufacturing in general, is being driven by long-term development plans in each country.

Industrial policies in both Kenya and Uganda play significant roles in promoting agro-processing, though without emphasizing electricity needs. Kenya's Industrial Policy (Government of Kenya 2012) aligns with Vision 2030, incentivizing investment in high-value agricultural processing, promoting industry clusters around specific agricultural resources, and reviving struggling agro-mills. Long-term plans complement these initiatives. Kenya's Third Medium Term Plan (MTP III), 2018–2022, prioritized increasing agro-processing to at least 50 percent of the total agricultural production (National Treasury and Economic Planning 2018) by establishing special economic zones and industrial parks, creating 1,000 manufacturing enterprises, providing affordable capital and training, and ensuring market access in all counties. A review of MTP III indicates that the performance of the agriculture sector fell short of the targets from 2019 to 2022, and achieved the target in 2018. This underperformance was due to the slow implementation of irrigation projects, along with unpredictable weather patterns such as erratic rainfall and prolonged droughts. This plan was followed up with the Fourth MTP, 2023–2027, which built on the lessons learned from the preceding plan. It incorporated the creation of value chain suitability maps and recognized the need for a collaborative framework involving the national government, subnational governments, and other stakeholders to enhance the profitability and productivity of commodities. The plan also recommended carrying forward the ongoing programs, such as the Agricultural Mechanization Programme, Livestock Production Programme, and Agro-food Processing and Value Chain Support Programme, to the next phase (National Treasury and Economic Planning 2024).

For mechanization of agriculture equipment, Kenya's National Agriculture Mechanization Policy 2021 promotes the use of equipment to intensify production, enhance value addition, and reduce costs and drudgery. Although the policy does not explicitly mention how the equipment should be powered, the policy implementation framework highlights that the national and county governments are responsible for promoting the use of renewable energy sources for agriculture mechanization (MoALD 2021b).

Similarly, Uganda's National Agriculture Policy highlights agro-processing and value addition to various commodities as an export priority. The National Industrial Policy 2020 (Ministry of Trade, Industry and Cooperatives 2020) prioritizes 14 commodities for agro-processing, supported by interventions to increase public financing and deploy appropriate technologies. The agro-industrialization program of the Third National Development Plan 2020/21–2024/25 (NPA 2020a) has six objectives: increasing agricultural production and productivity, improving agro-processing and value addition, improving postharvest handling and storage, increasing market access, ensuring equitable access to agricultural finance, and strengthening institutional coordination. The program provides detailed implementation action plans that list the activities and outputs under each objective and the agencies to lead the interventions, along with the financial outlay in the five-year plan. Notably, coupled with a monitoring and evaluation (M&E) framework, such an exercise ensures accountability and clarity in the execution of the national development plan and clarifies the roles of each department in ensuring the delivery of the outputs. The activities listed under its objectives include the construction of small-scale solar-powered irrigation systems and the extension of medium- to high-voltage electricity grids to the agro-industrial parks (NPA 2020b).

Summary

Enhancing measures for the integration of electricity, which is a critical infrastructure requirement, can improve the effectiveness of agrifood system policies. The following recommendations can facilitate this integration.

Cross-sectoral collaboration

- **Policy ownership and accountability:** In all three countries, policy ownership reflects the cross-cutting nature of electricity needs in agrifood systems, spanning energy, water, and agriculture. In India, solar irrigation is primarily led by MNRE, with implementation support from state-level agriculture departments. Uganda's micro-scale irrigation efforts are anchored in MAAIF, and Kenya's agriculture mechanization and growth strategies come under the Ministry of Agriculture and Livestock Development. These variations highlight how similar programs are anchored by different ministries based on their specific context. India's energy-led model has enabled scale but may have unintended consequences for groundwater extraction or crop choices for cultivation. In contrast, Uganda and Kenya integrate energy needs within agriculture-led policies, which may support alignment with rural development priorities but risks underemphasizing energy-specific considerations. Effective policy implementation depends not just on clear ownership but also on mechanisms that facilitate interministerial collaboration. This could include formal joint responsibilities, interministerial working groups, or shared accountability structures. Exploring collaborative institutional arrangements, particularly for interventions such as solar irrigation that sit at the nexus of water, food, land, and energy, can improve their potential to scale.

- **Multisectoral coordination:** Given the interlinkages of agrifood systems with water, land resources, energy, and industries across the value chain, it is imperative that interdepartmental coordination drive policymaking. This prevents duplication of efforts, reduces ambiguity among end users, and at the same time synchronizes achievement toward larger goals on improving livelihoods. Uganda's National Irrigation Policy, which is codeveloped by the ministries of agriculture and water, is a promising example of cross-ministerial collaboration and aligns with the country's National Adaptation Plan and broader National Climate Change Policy, but its implementation has been hindered by limited institutional capacity and financing constraints. Coordination mechanisms can also include engagement with the private sector and industry associations to hear different viewpoints on policy effectiveness and implementation. Kenya has established a more inclusive coordination platform through its National Technical Working Group on Food Systems, which brings together ministries, civil society, farmer groups, and county governments. Although such coordination facilitates stakeholder engagements, its effectiveness varies across countries, and its influence on actual policy uptake and investment is still evolving.

  In contrast, India's approach has been more siloed, with ministries such as MNRE, the MoA&FW, and state departments working largely within their domains. Although some coordination occurs at the state level, a lack of formal convergence mechanisms often limits the integration of energy needs across agrifood value chains.

- **Local implementation and adoption:** Policies must be cognizant of the conditions on the ground. National policies are often adopted and adapted by subnational governments to fit local contexts. At the local level, Kenya's constitutional reforms and the Energy Act of 2019 provide a strong enabling framework for bottom-up planning. Counties are empowered to develop their own energy plans aligned with local priorities, as seen in Makueni County's focus on energy access for seven specific value chains (Government of Makueni County 2024; Ireri et al. 2024). The absence of such local energy-planning structures may constrain local adaptation of national policies in different countries.

Financial support and incentives

- **Budgetary allocations:** The sustainability of policies depends heavily on adequate budgetary allocations. India has several policies (Table A-1, Appendix A) that incorporate financial incentives, such as low-interest loans, subsidies, grants, and tax incentives, and various combinations of these are offered by both national and subnational governments to end users. In contrast, Kenya and Uganda have focused on overarching vision documents and plans without dedicated public budgets, relying more on multilateral development programs and private investments such as the World-Bank-funded National Agricultural Value Chain Development Project (NAVCDP) in Kenya or the Micro-scale Irrigation Program in Uganda. International financial assistance provided to governments should incentivize collaboration between ministries, local financial institutions, and technology providers. This will facilitate the entry of private and development capital, complementing public investments and avoiding siloed operation.

- **Financial mechanisms to support technology integration:** A range of financial instruments can be used to promote the integration of energy, particularly renewables, in agrifood systems. These include public capital investments, funding for research and development, and fiscal incentives to lower market barriers. For instance, Kenya's green fiscal policy has zero-rated value-added tax (VAT) on raw materials used to manufacture solar equipment and batteries, lowering the cost of renewable technologies in the supply chain (National Treasury and Economic Planning 2022). Similarly, public investments in awareness programs and technical capacity-building are critical to enable adoption, especially in rural contexts.
- **Subsidies and grants for end users:** Targeted subsidies and grants remain essential to improve the accessibility and affordability of PUE technologies for smallholder farmers. India's PM-KUSUM scheme offers uniform capital subsidies for solar pumps, and Uganda's Micro-scale Irrigation Program provides need-based support to smallholder farmers for irrigation equipment. These demand-side subsidies, when combined with awareness and capacity-building measures, can significantly improve uptake and ensure equitable access to clean energy solutions.

M&E

- **Policy monitoring:** A sustained policy ecosystem requires ongoing M&E to assess progress and inform future policies. Uganda's National Development Plan III includes a detailed M&E framework with specified outputs, time frames, and lead departments for each activity. The National Planning Authority oversees this process, working with line ministries and local governments, and reports progress through annual performance reviews. One notable best practice is the integration of geospatial tools and digital dashboards to track the implementation of irrigation schemes in real time. Such mechanisms help ensure accountability and provide feedback loops for adaptive policymaking. However, many policies still lack clarity on data collection roles, coordination processes, and independent evaluation criteria, highlighting the need for stronger institutional ownership of M&E functions. Similarly, Kenya's Climate Smart Agriculture Implementation Framework (2018–2027) outlines M&E strategies for integrating renewable energy into agriculture. The framework is a collaborative effort involving the Ministry of Agriculture, Livestock, Fisheries and Cooperatives and other stakeholders.
- **Learning and adaptation:** Continuous policy review and adaptation based on monitoring outcomes ensure that policies remain effective and relevant. This iterative process helps identify and address implementation challenges, fostering a dynamic and responsive policy environment. Moreover, there is a need for coherence across policies, to ensure that policies developed by one ministry (e.g., energy) complement and align with other sectoral policies (e.g., agriculture and food processing). Such coherence can ensure that different ministries are aligned in meeting multiple cross-sectoral targets.

Integration of electricity and agriculture

- **Climate change mitigation and adaptation:** National policies in India, Kenya, and Uganda recognize the agriculture sector's role in addressing climate change issues, especially the adoption of efficient irrigation and water conservation to address the challenges of rainfed agriculture, groundwater depletion, and climate vulnerability. This includes integrating water–energy management practices, regulating electricity and water usage, offering incentives for micro-irrigation adoption, and promoting community-based solar irrigation models. Additionally, integrated agrifood system policies must consider both environmental and social benefits, ensuring that interventions support equitable access to resources, enhance livelihoods, and contribute to long-term food security while maintaining the ecological balance.
- **Electricity adoption via renewable energy:** Although policies identify postharvest losses and value addition as challenges, most policies do not prescribe specific electricity interventions; rather, they view the development of electricity infrastructure as a broad objective. Guidelines and technology standards such as India's engineering guidelines for cold chain infrastructure focus on the design and deployment of solar and biomass-based systems to complement grid-based electricity for stand-alone cold storage facilities. Similarly, Kenya's Climate Smart Agriculture Strategy and Uganda's Green Growth Development Strategy promote renewable energy in PUE interventions.

Technology standards and innovation

- **Standards for PUE technologies:** A gap that emerged in all three countries is the absence of defined standards for different PUE technologies, which are essential to ensure the quality, performance, and acceptability of the solutions. Standards also facilitate the adoption of energy-efficient solutions. Although India has established technology and cost standards for SIPs and engineering guidelines and minimum standards for cold chain infrastructure, Kenya and Uganda need to formulate similar standards for all three technologies to ensure greater technology adoption.
- **Promoting innovation:** Research and development funding is essential to support innovation and the adoption of new solutions in existing markets. This could be achieved through tax reforms that promote innovation or through global South–South cooperation to foster joint research and investment by multiple countries. Balancing innovation with performance standards is equally important for the dissemination of agricultural mechanization and adoption of PUE technologies. Although performance standards will make technologies more expensive, financial incentives should be aligned to keep the price of high-quality, efficient agricultural equipment competitive with lower-quality alternatives.

The way forward

The three countries analyzed in the study have put enabling policy frameworks in place to reduce food loss and improve crop productivity. With technology playing a significant role in improving agrifood systems, a continued emphasis on electricity infrastructure is required within policies across sectors to realize their potential. This will involve setting technology-specific targets, revising guidelines to include decentralized renewables, creating awareness, and building the capacity of stakeholders.

Policies are designed to offer guidance and directions by outlining expectations, defining targets, and assigning responsibilities, with the goal of achieving joint key performance indicators. Understanding the political economy of agrifood systems and electricity supply, including the underlying interests of various stakeholders, is essential. Therefore, we should not overlook the political dynamics and socioeconomic realities of the contexts in which policies are applied.

The scope of this working paper is limited to the analysis of policy directives, but it does not examine whether integrative policies lead to impacts on the ground. However, having policies in place is a critical building block for the successful adoption of electricity in agrifood systems. They facilitate improved stakeholder coordination, clarify financing mechanisms, and provide sustained leadership for accelerated implementation. Future studies should evaluate performance of past policies (especially those classified as integrative) against their targets and outcomes, including the role of effective implementation and supportive institutional frameworks.

Policymakers need to proactively assess where renewable energy interventions can support existing development priorities and realign policies accordingly. Stronger policy signals can provide an impetus for clean energy integration into upcoming programs and investments in the agriculture and allied sectors. This will contribute to the growth of the renewable energy market and associated livelihood opportunities.

The analysis of national policies in the three countries highlights that there is room for cross-geography learning in how policies are designed, developed, and deployed to integrate electricity infrastructure priorities in agrifood systems. Providing such knowledge exchange opportunities on policy development can help design more effective and integrated policies—not only within the agrifood sector but also across other key development sectors.

Appendix A: Policies reviewed

Table A1 | **Policies reviewed in this study**

	POLICY	YEAR OF COMMENCEMENT OR UPDATE	IMPLEMENTING MINISTRY
	INDIA		
1	Agriculture Infrastructure Fund (AIF)	2020	Ministry of Agriculture and Farmers Welfare (MoA&FW)
2	Mission for Integrated Development of Horticulture (MIDH)	2014–15	MoA&FW
3	National Mission for Sustainable Agriculture (NMSA)	2014	MoA&FW
4	Mission Organic Value Chain Development for North East Region (sub-mission under NMSA)	2015	MoA&FW
5	National Mission on Agricultural Extension and Technology (NMAET)	2014	MoA&FW
6	Sub-Mission on Agriculture Mechanization (SMAM)	2014 (revised guidelines 2018–19)	Department of Agriculture, Cooperation & Farmers Welfare
7	Sub-Mission on Agricultural Extension (same)	2013	Department of Agriculture, Cooperation and Farmers Welfare (Extension Division)
8	Agri Clinics and Agri Business Centres Scheme (ACABC)	2010	MoA&FW
9	Sub-Mission on Seed and Planting Material (SMSP)	2014	Department of Agriculture, Cooperation and Farmers Welfare
10	Sub Mission on Plant Protection and Plant Quarantine (SMPP)	2014	Department of Agriculture, Cooperation and Farmers Welfare
11	National Innovation on Climate Resilient Agriculture	2011	Indian Council of Agricultural Research (ICAR)
12	Integrated Scheme on Agriculture Cooperation (ISAC)	2012 (now discontinued)	Ministry of Cooperation
13	Digitalization of Primary Agriculture Cooperative Societies	2022	Ministry of Cooperation
14	Pradhan Mantri Matsya Sampada Yojana (PMMSY)	2020	Ministry of Fisheries, Animal Husbandry and Dairying; Department of Fisheries
15	Fisheries and Aquaculture Infrastructure Development Fund (FIDF)	2018–19	Ministry of Fisheries, Animal Husbandry and Dairying; Department of Fisheries
16	Dairy Processing & Infrastructure Development Fund (DIDF)	2017	Department of Animal Husbandry and Dairying
17	National Programme for Dairy Development (NPDD)	2021-22	Ministry of Fisheries, Animal Husbandry and Dairying
18	National Livestock Mission	2014	Ministry of Fisheries, Animal Husbandry and Dairying
19	Pradhan Mantri Kisan Sampada Yojana	2016	Ministry of Food Processing Industries (MoFPI)
20	Scheme for Integrated Cold Chain & Value Addition Infrastructure	2022 (latest guidelines)	MoFPI
21	Scheme for Creation of infrastructure for Agro Processing Clusters (APC)	2017	MoFPI
22	Scheme for Creation/Expansion of Food Processing and Preservation Capacities (CEFPPC)	2022	MoFPI
23	Prime Minister Formalisation of Micro Food Processing Enterprises Scheme (PMFMPE)	2020	MoFPI
24	Production-Linked Incentive Scheme for Food Processing Industry (PLISFPI)	2021-22	MoFPI
25	Pradhan Mantri Krishi Sinchayi Yojana (PMKSY)	2015	MoA&FW

	POLICY	YEAR OF COMMENCEMENT OR UPDATE	IMPLEMENTING MINISTRY
26	Har Khet Ko Pani	2015-16	Ministry of Jal Shakti
27	Per Drop More Crop (Micro Irrigation) Component of PMKSY	2017	MoA&FW
28	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM)	2019	Ministry of New and Renewable Energy (MNRE)
29	Specification and Testing procedure for the Solar Photovoltaic Water Pumping System and USPC	2023	MNRE
30	Benchmark costs for Off-grid Solar PV Systems and Solarisation of Grid Connected Agricultural Pumps for the Year 2019-20	2019	MNRE
31	National Bio Energy Programme	2022	MNRE
32	Framework for promotion of Decentralised Renewable Energy Livelihood applications	2022	MNRE
33	Guidelines of Design Specifications, Performance Guidelines, and Testing Procedure for Solar Cold Storage with Thermal Energy Storage	2025	Ministry of Rural Development (MoRD)
34	Deendayal Antyodaya Yojana - National Rural Livelihoods Mission (DAY-NRLM)	2016	MoRD
35	Shyama Prasad Mukherjee Rurban Mission	2016	MoRD
36	National Handloom Development Programme (NHDP)	2021	Ministry of Textiles
37	Pradhan Mantri Jan Jatiya Vikas Mission (PMJVM)	2022	Ministry of Tribal Affairs
38	Development of Particularly Vulnerable Tribal Groups(PVTGs)	2015	Ministry of Tribal Affairs
39	Pradhan Mantri Aadi Adarsh Gram Yojana (PMAAGY)	2022	Ministry of Tribal Affairs
40	Integrated Scheme for Agricultural Marketing (ISAM)	2014	MoA&FW
41	Agriculture Marketing Infrastructure (AMI)	2018	MoA&FW
42	Special Long Term Refinance Schemes: 1. Transformation of PACSs as Multi Service Centres (MSCs) 2. Promoting Micro Food Processing Activities	2021	National Bank for Agriculture and Rural Development (NABARD)
43	Agriculture Infrastructure Fund (National Agriculture Infra Financing Facility)	2020	Department of Agriculture and Farmers Welfare
44	Rural Infrastructure Development Fund (RIDF)	Created in 1995-96, but ongoing	NABARD
45	Tribal Development Fund (TDF)	Started in 2003-04, corpus continues to be updated	Farm Sector Development Department
46	Producers Organization Development Fund (PODF)	2011	Farm Sector Development Department
47	Farm Sector Promotion Fund (FSPF)	2014	Farm Sector Development Department
48	India Cooling Action Plan	2019	Ministry of Environment, Forest and Climate Change (MoEFCC)
49	National Energy Efficient Agriculture Pumps Programme	2016	Ministry of Power
50	National Water Policy	2012	Ministry of Water Resources
51	Engineering Guidelines & Minimum System Standards for Implementation in Cold Chain Components	2025	National Centre for Cold-chain Development (NCCD)
		KENYA	
52	Kenya Vision 2030	2008	Government of Kenya
53	Agricultural Sector Development Strategy 2010–2020	2010	Government of Kenya

	POLICY	YEAR OF COMMENCEMENT OR UPDATE	IMPLEMENTING MINISTRY
54	National Dairy Master Plan	2010	Ministry of Agriculture and Livestock Development (MoALD)
55	Fourth Medium Term Plan (2023-2027)	2024	National Treasury and Economic Planning (NTEP)
56	National Cooling Action Plan 2022	2023	Ministry of Environment, Climate Change and Forestry
57	National Roadmap on Scaling Productive Use of Energy (PURE) in Kenya	2023	Ministry of Energy and Petroleum (MoEP)
58	Agricultural Sector Transformation and Growth Strategy 2019-2029 (AGTGS)	2019	Ministry of Agriculture, Livestock, Fisheries and Irrigation (MoALFI)
59	Agriculture Marketing Strategy 2023-2032	2023	MoALD
60	National Agriculture Investment Plan (NAIP) 2019-24	2019	MoALFI
61	National Climate Change Action Plan 2018-2022	2018	Ministry of Environment, Climate Change and Forestry
62	Agricultural Policy 2021	2022	Ministry of Agriculture, Livestock, Fisheries and Cooperatives
63	National Agriculture Mechanization Policy 2023	2024	MoALD
64	Kenya Agricultural Sector Extension Policy 2023	2023	MoALD
65	Kenya National Energy Efficiency and Conservation Strategy	2020	MoEP
66	Kenya National Electrification Strategy	2018	MoEP
67	Bioenergy Strategy (2020-2027)	2020	MoEP
68	National Energy Policy	2018	MoEP
69	Kenya Climate Smart Agriculture Strategy 2017-2026	2017	Ministry of Agriculture, Livestock and Fisheries
70	Kenya Climate Smart Agriculture Implementation Framework	2018	Ministry of Agriculture, Livestock and Fisheries
71	Kenya Youth Agribusiness Strategy 2018-22	2018	MoALFI
72	National Irrigation Policy 2017	2017	Ministry of Water, Sanitation and Irrigation (MoWSI)
73	Irrigation Guidelines	2019	MoWSI
74	National Irrigation Authority Strategic Plan 2023-2027	2024	National Irrigation Authority
75	Resource Mobilization Strategy	2022	National Irrigation Authority
76	Irrigation Act 2012	2012	MoALFI
77	Dairy Industry Regulations 2021	2021	Ministry of Agriculture, Livestock, Fisheries and Cooperatives
78	Fisheries Management and Development Act_No 35 of 2016	2016	MoALFI
79	Kenya Micro and Small Enterprises Policy (Sessional Paper No. 05 of 2020)	2020	Ministry of Investments, Trade, and Industry
80	National Green Fiscal Incentives Policy Framework	2022	NTEP
81	Kenya Dairy Board Strategic Plan 2023-2027	2024	Kenya Dairy Board
82	Post Harvest Management for Food Loss and Waste Reduction 2024-2028	2024	MoALD
		UGANDA	
83	Uganda Vision 2040	2007	National Planning Authority (NPA), Uganda
84	National Development Plan III	2020	NPA, Uganda

	POLICY	YEAR OF COMMENCEMENT OR UPDATE	IMPLEMENTING MINISTRY
85	Energy Policy for Uganda 2023	2023	Ministry of Energy and Mineral Development (MEMD)
86	Rural Electrification Strategy and Plan	2013	MEMD
87	The Electricity Connections Policy	2018	MEMD
88	Uganda Green Growth Development Strategy 2017	2017	NPA, Uganda
89	National Climate Change Policy 2015	2015	Ministry of Water and Environment (MWE)
90	National Agriculture Policy	2013	Ministry of Water and Environment (MAAIF)
91	National Irrigation Policy	2017	MAAIF and MWE
92	National Organic Agriculture Policy	2019	MAAIF
93	National Agricultural Extension Strategy 2016/17–2020/21	2016	MAAIF
94	National Fisheries and Aquaculture Policy	2017	MAAIF
95	Micro, Small and Medium Enterprise Policy 2015	2015	Ministry of Trade Industry and Cooperatives (MTIC)
96	Uganda Dairy Policy Action Plan 2022	2022	Dairy Development Authority
97	Dairy Development Authority Strategic Plan III, 2020/21-2024/25	2021	Dairy Development Authority
98	Agriculture Sector Strategic Plan 2015/16-2019/20	2016	MAAIF
99	Agriculture Cluster Development Project	2017	MAAIF
100	Micro-scale Irrigation Program	2020	MAAIF

Source: The authors.

Abbreviations

DRE	decentralized renewable energy
FAO	Food and Agriculture Organization of the United Nations
FSSD	Farm Sector Development Department
INR	Indian rupee
kW	kilowatt
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries, Uganda
MALD	Ministry of Agriculture and Livestock Development, Kenya
MEMD	Ministry of Energy and Mineral Development, Uganda
MNRE	Ministry of New and Renewable Energy, India
MIDH	Mission on Integrated Development of Horticulture, India
MoA&FW	Ministry of Agriculture and Farmers' Welfare, India
MoALD	Ministry of Agriculture and Livestock Development, Kenya
MoEFCC	Ministry of Environment, Forest and Climate Change, India
MoEP	Ministry of Energy and Petroleum, Kenya
MoFPI	Ministry of Food Processing Industries, India
MoRD	Ministry of Rural Development, India
MoWSI	Ministry of Water, Sanitation and Irrigation, Kenya
MSME	Micro, Small and Medium Enterprises, India
MWE	Ministry of Water and Environment, Uganda
NABARD	National Bank for Agriculture and Rural Development, India
NDP	National Development Plan, Uganda
NPA	National Planning Authority, Uganda
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan Yojana (India)
PUE	productive use of electricity
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana (India)
SAMPADA	Pradhan Mantri Kisan Sampada Yojana (India)
UgIFT	Uganda Intergovernmental Fiscal Transfer Program

Endnotes

1. States in India are self-governing administrative divisions, each having its own elected state government. There are 28 states in India. Similarly, Kenya is divided into 47 counties (as of 2022), and Uganda is divided into 135 subdivisions or districts (as of 2020). For the purpose of this paper, we use the counties in Kenya as the equivalent of subdivisions and districts in Uganda and states in India. Although the administrative divisions across the three countries are not comparable in terms of population, demographics, or area, the foregoing convention has been used in order to gauge the devolvement of authority and responsibility in implementing policy decisions.

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About the authors

Beryl Ajwang is a Food Loss and Waste Associate within the Food Program at WRI Africa.

Lanvin Concessao is a Program Manager in the Energy Program at WRI India.

Preeti Kumari is a Senior Program Associate in the Energy Program at WRI India.

Namrata Ginoya is a former Senior Program Manager with the Energy Program at WRI India.

Vandita Sahay is a former Senior Research Specialist with the Energy Program at WRI India.

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