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LEGACY SERIES 3

Accelerating Rural Energy Access for Agricultural Transformation:

Contribution of the CGIAR Research Program on Water, Land and Ecosystems to Transforming Food, Land and Water Systems in a Climate Crisis

Marilia Magalhaes, Claudia Ringler, Shilp Verma and Petra Schmitter

IN PARTNERSHIP WITH:

CGIAR Research Program on Water, Land and Ecosystems (WLE)

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Front cover photo: Irrigating a farm using a solar-powered water pump near Kitale, Kenya; Jeffery M Walcott / IWMI.

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Project
This synthesis summarizes research on accelerating rural energy access that took place in a series of research-for-development activities as part of or under the umbrella of the CGIAR Research Program on Water, Land and Ecosystems (WLE). The synthesis was directly supported by WLE program management.

Donors

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Contents

Abstract

With adverse impacts of climate change growing in number and intensity, there is an urgent need to reduce emissions from food systems to net zero. This can only be achieved if rural areas in low- and middle-income countries gain access to clean energy. A review of the research and capacity building contributions of the CGIAR Research Program on Water, Land and Ecosystems (WLE) over the last 10 years suggests important contributions in the areas of energy policy and energy investment planning, cost and feasibility frameworks, and business models for clean energy technology uptake. WLE has also conducted successful pilot projects on solar irrigation to provide an evidence base for scaling up innovative energy initiatives. Finally, the program also considered non-agricultural uses of energy where relevant to food systems, and implemented capacity building activities.

Going forward, CGIAR has a key role to play in providing information, supporting access and piloting innovative, scalable clean energy interventions to support the achievement of multiple impacts for the poorest and most food-insecure women and men farmers and entrepreneurs.

Introduction

Over the past two decades, the energy sector has made significant progress toward growing the share of clean energy sources in electricity generation, due to rapidly declining costs of renewables and a growing political will to address climate change challenges (Arndt et al. 2019). Investments in renewable power generation drastically increased, and public policies in many countries now include deployment of solar and wind power, and other clean technologies, as key investment priorities. This rise in clean energy sources has posed both challenges and significant opportunities for agriculture and the rural poor.

The CGIAR Research Program on Water, Land and Ecosystems (WLE) has responded to this challenge, and has dedicated a significant part of its research portfolio to supporting opportunities and reducing barriers to accessing renewable energy sources for agricultural transformation.

However, CGIAR is not a well-known actor in the rural energy space. A key question that this synthesis addresses therefore is whether, and to what extent, the world's largest global agricultural innovation network should engage in this area or not.

Following an overview of the analytical framework linking energy access with key agricultural and other development outcomes, motivating WLE's research in this space, the next section highlights selected achievements. This is followed by an identification of key gaps that should be taken forward under the 'One CGIAR' research agenda and beyond.

Methodology and framework

WLE contributions to accelerating rural energy access were assessed based on a review of journal articles, discussion papers, briefs and blog posts available on its website (https://wle.cgiar.org/), CGSpace, the repository of the International Food Policy Research Institute (IFPRI) (https://ebrary.ifpri.org/), and Google Scholar using the search words energy, CGIAR and WLE. Results included peer-reviewed journal articles, grey literature, briefs and blog pieces. These were grouped by umbrella themes and then by type of contribution. This helped develop a broader understanding of WLE's research foci. The overall themes that were identified based on WLE's research contributions are described in Table 1.

Table 1: CGIAR Research Program on Water, Land and Ecosystems (WLE) research themes and types of contribution.

Research themes	Type of contribution

• Energy policy, rural energy access – electrification, renewables
• Energy and irrigation
  ○ Energy-irrigation nexus
  ○ Energy checklist
  ○ Solar pumps
• Biomass and cooking energy
• Resource recovery and reuse (RRR)
• Capacity building
	• Energy–economic modeling
	• Frameworks and mapping
	• Policy and action research
	• Business models
	• Planning tools

Source: Authors.

An analytical framework was developed to visualize the links between clean energy access and agricultural development outcomes, and the areas where WLE's research has provided important contributions (Figure 1). The following questions guided the development of the analytical framework: 1) How can energy access transform agriculture? 2) What are the drivers and barriers to increased energy access (are there gendered challenges)? and 3) What are the factors that link agricultural outcomes to energy use?

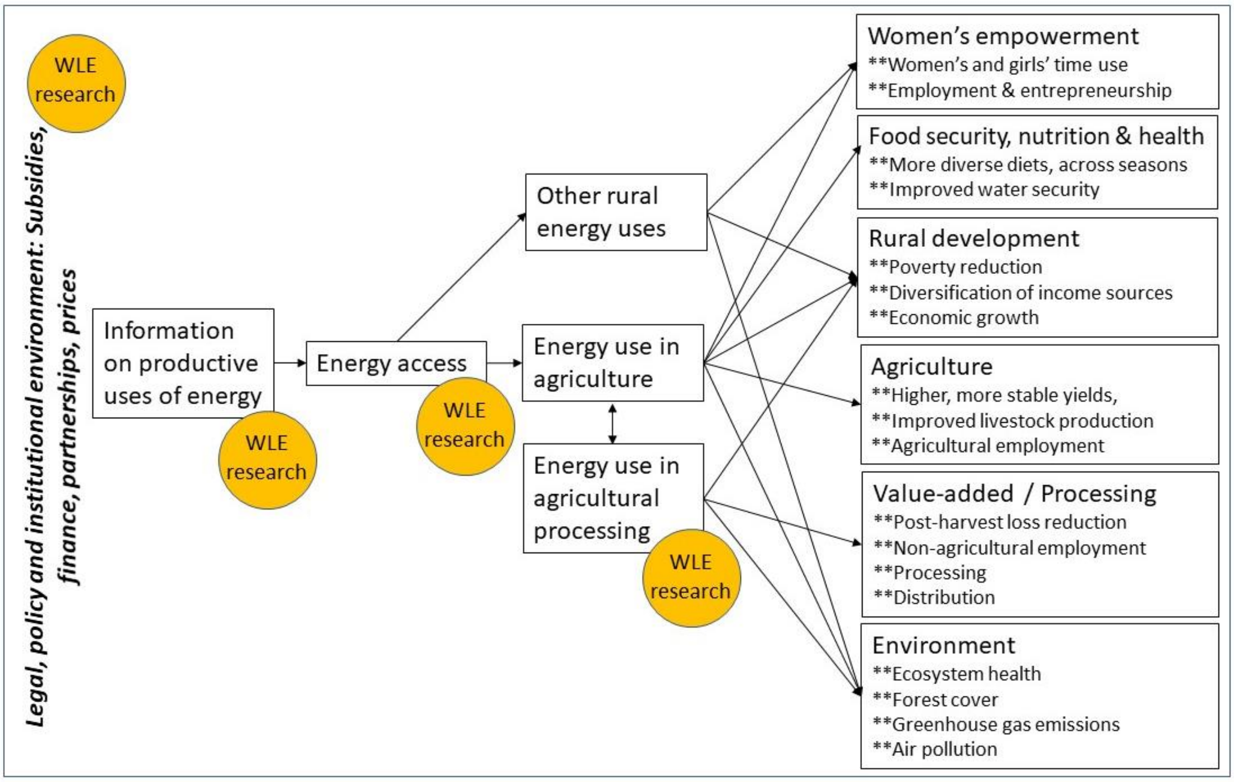

Figure 1: Framework linking rural energy access with agriculture and related outcomes.

Note: Other CGIAR research is also exploring the contribution of energy to peace (https://climatesecurity.cgiar.org/).
Source: Authors.

Legal, policy and institutional environments

The legal, policy and institutional environments determine the speed, quality, equity and environmental outcomes of reaching rural areas with clean energy. These environments shape policy frameworks, subsidy and financing ecosystems, partnerships with the private sector, and the availability and pricing of energy sources.

Information on productive uses of energy

Accelerating rural energy access requires information on which energy sources and mixes are suitable for which context. Moreover, energy investors are seeking information on the locations of productive uses and users of energy, as other uses, such as lighting or cooking, often do not generate enough income for poor rural households to pay for energy access. On the other hand, using energy for irrigation, cooling poultry pens or for agro-processing can increase rural incomes and support the expansion of rural energy access. WLE has developed substantial research on identifying productive use locations.

Energy access

Even if clean energy sources are available, many farmers cannot access the resource, for economic or social reasons, or due to social norms and traditions. They suffer from energy poverty, a lack of choice to access adequate, affordable, reliable, high quality, safe and environmentally benign energy services (Reddy 2000). For example, in much of South Asia and sub-Saharan Africa, men farmers traditionally purchase and take decisions over solar-powered irrigation pumps, potentially widening the gender gap. WLE has focused on strengthening access to clean energy sources for the poor.

Energy use in agriculture

Energy use in agriculture refers to the use of agricultural inputs, such as chemical fertilizers and pesticides, and also agricultural machinery, such as irrigation pumps or tractors, as well as the energy to heat or cool animal stables, or to aerate fishponds. These uses of energy are typically geared toward improving agricultural production levels. In a wider sense, human and animal labor in food production, processing, etc., are also energy uses. These are not considered in this review. Some of the energy work of CGIAR has focused on RRR of fecal sludge to develop fertilizers, and to also generate income opportunities for women and young people.

Energy use in agricultural processing

Energy use in agricultural processing refers to storage, drying, ventilation and transportation, as well as processing and packaging of agricultural produce until it reaches the retail sector. Processing can add considerable value to primary production, enhance the shelf life of nutrient-dense foods, and reduce food loss and waste. Improved food safety and nutrition and rural income generation directly supports One CGIAR's mandate to end hunger by 2030. This could be an important focus of CGIAR's energy research, in collaboration with other partners.

Other rural energy uses

Other rural energy use refers to all non-agricultural uses, such as lighting and cooking, that can also affect important well-being outcomes, including an improvement in women's time burden and health through accessing more fuel-efficient cookstoves and improved nutrition and health. The reduction of fuelwood and other resource use can also directly improve agricultural productivity (Mekonnen et al. 2017).

Development outcomes

Accelerated rural energy access can have multiple benefits for human well-being outcomes and the environment. They include changes in women's empowerment, food security, nutrition and health, agriculture and rural development, value addition and the environment. Different energy uses have differential impacts on these well-being outcomes, many of which have yet to be fully explored. Moreover, more research is needed to understand gendered pathways from rural energy access to agricultural transformation, rural development and the environment.

Highlights of WLE's contributions to accelerating rural energy access for agricultural transformation

Based on the review of documents, WLE has worked on energy policies and provided investment recommendations; developed cost and feasibility frameworks; created businesses models; conducted pilot projects to provide an evidence base for scaling up innovative energy initiatives; considered non-agricultural uses of energy where relevant to food systems; and implemented capacity-building activities. Some of these activities are described in more detail below.

Energy policies and investment recommendations

Energy–economic modeling tools can support investment in clean energy technologies. WLE undertook an analysis to understand the impacts of a carbon tax on fossil fuels, and water and food security. The analysis found that a fossil-fuel tax would not substantially adversely affect food security and could be a boon to global food security if resulting emission reductions lower the climate change impacts on food production systems (Ringler et al. 2016).

A further analysis at the global level supported by WLE assessed the irrigation water security impacts from hydropower development across major river basins (Zeng et al. 2017). The analysis found that globally 54% of installed hydropower capacity competes with irrigation, including in the central United States, northern Europe, India, central Asia and Oceania. On the other hand, globally 8% of installed hydropower capacity complements irrigation, particularly in the Yellow and Yangtze river basins of China, on the east and west coasts of the United States, and in most river basins of Southeast Asia, Canada and Russia. No significant relationship was found for the rest of the world.

At the regional level, both water and energy scarcities have been driving tension and conflicts between governments. Joint water–energy–food security analyses can help identify pathways for collaboration. Several such analyses were carried out under the umbrella of WLE for the Aral Sea Basin, the Eastern Nile Basin and the Niger Basin using hydro-economic modeling tools. Scenario analyses in the Aral Sea Basin found that cooperation to maximize basin-wide benefits between upstream Tajikistan and downstream Uzbekistan would increase upstream hydropower production with small reductions in downstream irrigation benefits, while unilateral maximization of energy production would substantially reduce overall benefits (Bekchanov et al. 2015). In the Eastern Nile Basin, a regional TIMES (energy systems) modeling framework for the electricity sector covering Egypt, Ethiopia and Sudan assessed the potential of energy trading for cross-border collaboration in this rapidly growing region. The study found that electricity-trading scenarios outperformed a reference scenario that assumed no energy trading, lowering the energy systems cost by 4.5-7.2%. Costs were lower with trading, even when transmission costs associated with trading were considered (Mondal and Ringler 2020). Finally, an analysis in the Niger River Basin found that dam development can increase the sustainability of water availability for basin-wide hydropower generation and ecosystem health (Yang et al. 2018).

Energy policy assessments are particularly important at the national level to support governments in their design of energy development strategies based on their own development goals, as well as on major drivers of change (i.e., population growth, climate change, economic development). As with many other low- and middle-income countries, Ethiopia was lacking this type of assessment. Research conducted under WLE, through financial support by the African Development Bank, has filled some of these gaps.

The research assisted the Government of Ethiopia in developing alternative energy investment pathways based on national priority goals, which include universal electricity access and clean energy generation from renewable resources. The research identified the economic feasibility of investing in solar photovoltaic (PV) and wind power for electricity generation to meet projected demand (2014-2050). In doing so, WLE developed the first-ever homegrown Ethiopia TIMES energy systems model for Ethiopian energy stakeholders to identify least-cost solutions to meet the country's rising electricity demand while improving energy security, promoting access to modern energy sources and mitigating greenhouse gas emissions. To ensure local ownership, an Ethiopian energy modeling group was formed and trained through a series of face-to-face and online workshops.

A separate set of investment recommendations was linked to the assessment of the development of a decentralized rural energy system comprising solar PV arrays, wind turbines, a diesel generator and batteries to electrify a remote rural village in Ethiopia (Gebrehiwot et al. 2019).

A further Ethiopian policy analysis focused on the potential energy savings from expanding efficient lighting and improved cookstoves (using the Long-range Energy Alternatives Planning [LEAP] model) (Mondal et al. 2018).

Energy investment and policy analysis is important not only for overall energy planning and reducing tradeoffs between energy, irrigation and food security goals, but also to support accelerated development of agro-processing and to fuel rural economic growth. In the case of Ethiopia, Borgstein et al. (2020) identify six agricultural production and processing opportunities – horticulture, grain milling, injera baking, milk cooling, bread baking and coffee washing – with a joint potential to generate USD 4 billion annually following electricity rollout by 2025. The acquisition of energy appliances is a further economic development opportunity, as would be the income generated for the energy supplier (Borgstein et al. 2020).

Frameworks to support rural energy access

Agricultural research centers around the world have carried out extensive research on the linkages between labor, fertilizer and agricultural productivity. A much less studied area relates to energy use in irrigation. Realizing the irrigation potential of poor countries is an important step toward improving agricultural production, food security, nutrition and climate resilience. WLE research has stepped in to fill important research gaps in this area.

In partnership with the Asian Development Bank, WLE developed an energy checklist for irrigation systems (ADB 2017) to support irrigation development and rehabilitation specialists to jointly improve water and energy productivities, and to avoid tradeoffs that would result in increased energy use in irrigation investments that strive to reduce irrigation water use. This research directly supported the Government of Vietnam's plans to increase the adoption of high efficiency irrigation systems (HEIS). If there is a medium or high risk that energy could affect irrigation outcomes, the study recommends the development of a screening report and the monitoring of energy–irrigation indicators during the project cycle. Also, as part of this research, elements of a business model for the introduction of HEIS were developed and tested in two sites in Vietnam (Box 1).

WLE also developed an integrated framework for off-grid solar irrigation (Lefore et al. 2021), noting the need for multisectoral alignment and coordination in policy and regulation that is often absent but crucial for the sustainable and inclusive scaling of solar irrigation. The framework combines social equity with energy, water and food security (Figure 2). It is intended to support policy, regulation and monitoring for environmentally sustainable and socioeconomically inclusive solar irrigation investment. An additional framework by Pavelic et al. (2021) focuses on managing groundwater depletion risks associated with solar water pumping.

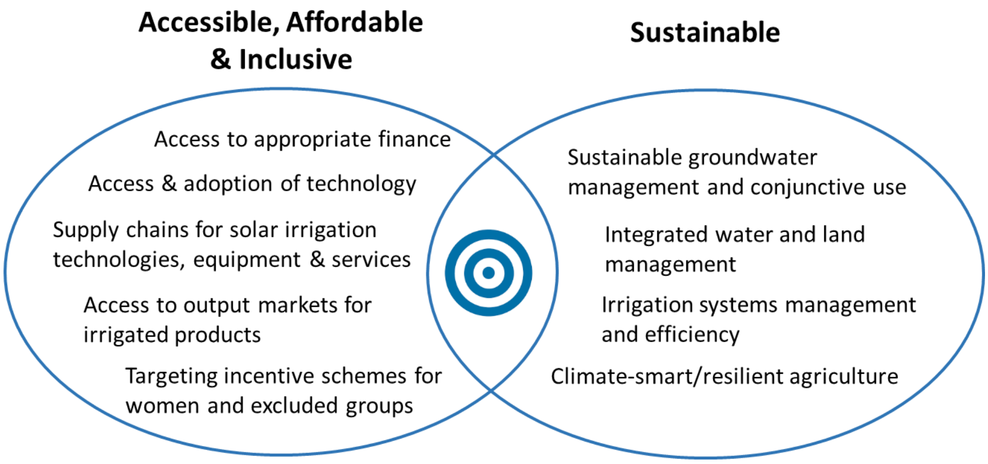

Figure 2: Components for feasible and sustainable scaling of solar irrigation for smallholder agriculture.

Source: Adapted from Lefore et al. (2021).

Another framework was developed, together with the Niger River Basin Authority and its nine member states, to increase understanding of water–energy–food–environment (WEFE) synergies and tradeoffs across the 350 investment projects of the authority as part of its 2016-2024 operational plan. The framework and checklist include information on the locations of proposed Niger Basin investments, as well as an assessment of their contribution to various nexus objectives, such as energy, water and food security, and environmental sustainability. Importantly, investments are not discouraged if they reduce the achievement of certain sectoral objectives, such as environmental sustainability. Instead, proponents are asked to identify mitigation actions or additional activities that would need to be advanced for negative linkages to be reduced or eliminated (Seidou et al. 2021). The framework has supported the agency in strengthening cross-sectoral synergies of the operational plan.

Mapping of productive uses

Rural energy access can be accelerated through the identification of appropriate productive uses in the agri-food and water sectors. Various efforts have now started to co-locate energy and productive users – generally irrigation operations or agro-processing centers. As the price of solar PV panels has decreased and solar water pumps have become more affordable and can offer a climate-smart solution for small-scale farmers across Africa, Asia and beyond, the identification of suitable locations for solar pump-based irrigation has become increasingly relevant to support small-scale irrigation development led by governments, donors and private-sector initiatives.

A key investment under WLE was the development of an online solar suitability tool (IWMI n.d.) using a geographic information system (GIS)-based Multi-Criteria Evaluation (MCE) technique, which includes solar irradiation, slope, groundwater levels, aquifer productivity, groundwater storage, groundwater sustainability, population, roads and travel time to markets. WLE also developed national-level solar suitability maps to help public and private investors choose the right locations to unlock the full potential of solar-based PV pumping for irrigation. This framework has been applied in Ethiopia, Ghana and Mali, where scenarios accounting for availability of groundwater and surface water were established to assess the suitability of solar water-lifting devices (IWMI 2018, 2021) (see Figure 3 for suitability maps for Ethiopia). The Ethiopia study identified that 9% of irrigated land and 18% of rain-fed land would be suitable for solar PV pump irrigation (Schmitter et al. 2018). In Mali, the total area suitable for solar-based irrigation varied between 11% and 69% of the country's croplands (IWMI 2019). Currently, the tool is being adapted to the needs of private-sector companies.[1]

Another study mapped the economic feasibility of solar-based irrigation versus diesel-based irrigation based on cropping patterns, and technology costs of solar and diesel pumps, as well as a series of biophysical factors using life cycle analysis across sub-Saharan Africa. Groundwater-fed solar irrigation was found to be cost-effective in southern and central Africa but less so in countries that subsidize diesel fuel (Angola, Nigeria and Sudan), and economic feasibility was higher where more water-intensive crops were irrigated (Xie et al. 2021). An important takeaway of this study is that results vary across location and scenarios, and they depend on factors such as sunlight, cropping systems, and fossil-fuel subsidies.

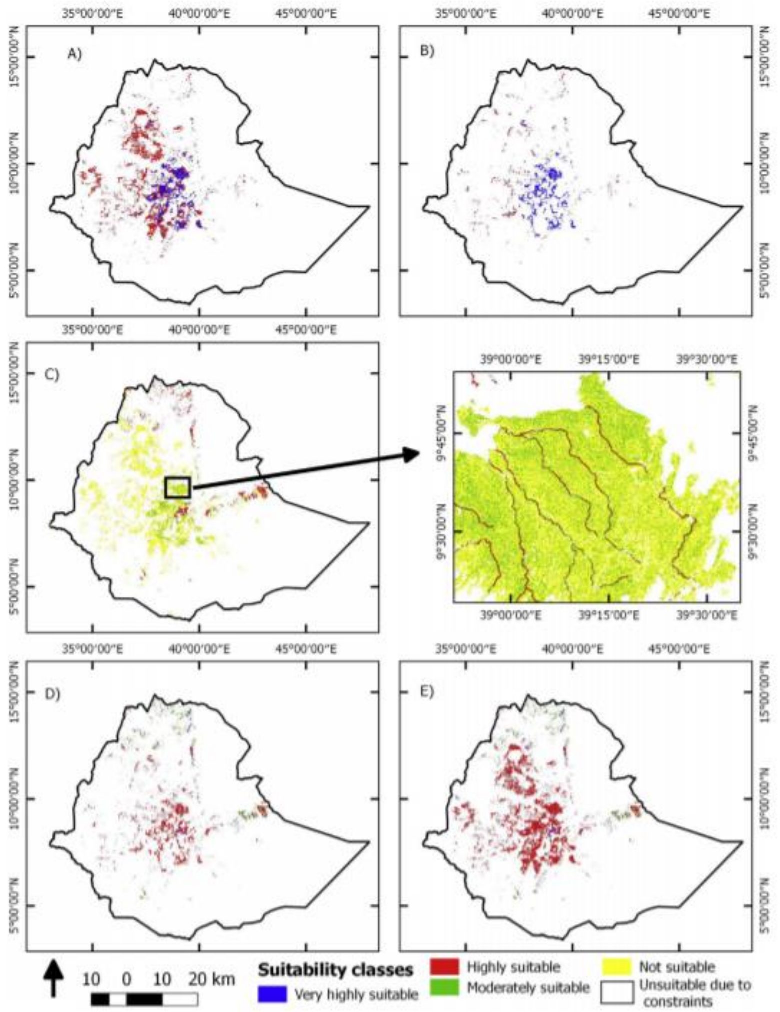

Figure 3. Suitability maps for Ethiopia: A) Scenario 1; B) Scenario 2; C) Scenario 3; D) Scenario 4a; and E) Scenario 4b with groundwater depth up to 25 meters. Only the first three suitability classes are shown (i.e., very highly suitable, highly suitable and moderately suitable).[2]

Source: Adapted from Schmitter et al. (2018) (CC BY 4.0).

[1] https://wle.cgiar.org/thrive/2021/06/23/mapping-tool-helps-private-sector-identify-high-potential-locations-solar

[2] Scenario 1 included groundwater depths up to 25 m divided into two classes (0–7 m, 7.1–25 m); Scenario 2 considered very shallow groundwater (0–7 m) levels only; Scenario 3 covered only surface water: the proximity to rivers and the potential of small reservoirs; and Scenario 4 combined both water resources with scenario 4a including groundwater depth up to 7 m and scenario 4b including groundwater depth up to 25 m.

Business models for accelerating energy access

Research suggests that richer, male farmers are more likely to be able to access irrigation technologies, including solar technologies (Lefore et al. 2019; Kafle et al. 2020). In response to this challenge, WLE embarked on the development of various business and finance models to help identify how sellers and buyers of energy technologies can benefit from the exchange of such technologies while lowering barriers to entry. Box 1 describes a series of business models focused on advanced, energy-intensive irrigation technologies, and also the circular economy or RRR.

Box 1: Making the case for business models.

Elements of a HEIS business model in Vietnam: Research under WLE in two areas of Vietnam showed that there was limited understanding of the full benefits and full costs of HEIS, and farmers generally lacked incentives for the adoption of HEIS. Seven different characteristics for a HEIS business model were suggested, related to prioritization of areas with water scarcity, credit, technology, extension services, holistic water management and governance (ADB 2017).

Smallholder solar pump irrigation business model: WLE developed a business model approach for encouraging investments in smallholder solar pump irrigation. Ethiopia was used as a case study for the development of three business models that presented opportunities for investing in smallholder solar pump-based irrigation. The scenarios were based on the value proposition to supply water to smallholder farmers for irrigated agricultural production (Otoo et al. 2018). See also Gebrezgabher et al. (2021) for business models on solar irrigation for Ghana.

Solar Power as a Remunerative Crop (SPaRC): In collaboration with the Tata Trusts and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), WLE developed an innovative model of grid-connected solar irrigation systems that offer farmers the option to 'grow' solar energy as an additional crop, adding a new source of income. This SPaRC model was piloted in three locations in western India and has become an inspiration for provincial and national solar irrigation expansion programs and policies (Shah et al. 2017).

Pro-poor solar irrigation entrepreneurs: The floodplains of the Ganga–Brahmaputra–Meghna (GBM) basin – covering Nepal *Terai*, eastern India and Bangladesh – are home to a quarter of the world's rural poor. The basin's excellent aquifers are underutilized due to a lack of affordable and reliable energy access. WLE, CCAFS and the Tata Trusts have developed an enterprise-based business model that can deliver reliable and affordable irrigation to small farmers through equitable and competitive irrigation service markets (Shah et al. 2019).

Business models for energy, nutrient and water reuse: RRR business models were developed based on a large number of empirical case study examples, including: 1) the value proposition and value chain of the business; 2) the institutional setup; 3) risks in terms of viability and safety; and 4) overall performance data. The business models proposed include methods for transforming human waste into fertilizer, food waste into biogas and wastewater into irrigation sources (Otoo and Drechsel 2018).

Pilot projects to test energy technologies

Solar irrigation pilots in Africa

WLE, through the Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) and Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES) projects, piloted eight solar pumps for smallholder irrigation in selected farm households in Oromia and the Southern Nations, Nationalities, and People's Region (SNNPR) in Ethiopia (Gebregziabher et al. 2019). The goal of the project was to test whether solar pumps could provide smallholder farmers with affordable and sustainable irrigation through water pumping and, as such, be a less costly and more environmentally friendly alternative to diesel pumps.

Results showed that investment in solar pumps was profitable, depending on crop type and water delivery systems. The use of solar pumps was combined with three water application methods (drip, furrow and overhead), with benefit streams largest under the drip system.

Key lessons and challenges identified by the project on the use of solar pumps are listed below:

- Cost sharing can be a solution to the high initial investment cost, especially if additional investment is made for drip systems which allow the irrigated area to grow to around 0.5 hectare (ha) for these smaller pumps.
- Partnerships between key actors, including rural financial institutions, are essential to lower barriers to entry for poorer farmers.
- Targeted subsidies are needed at an early stage until solar pump prices become competitive.

Ongoing work addresses bottlenecks for solar irrigation in sub-Saharan Africa, directly working with private-sector solar pump providers, using a market-based approach to scale solar pumps in Ghana and elsewhere.

Solar irrigation pilots in South Asia

In the past decade, WLE researched a series of solutions to the complex energy–irrigation crisis that has affected parts of the South Asia region, threatening water resources and agricultural sustainability, and generating an enormous financial burden to the energy utilities (Verma et al. 2018). The research built on foundational analysis of the impacts of subsidies on groundwater depletion, the impacts of subsidy removal and the reasons why alternative policy approaches were needed (Box 2).

Box 2: The Water–Energy–Food Nexus in India: some findings and lessons learned (*sources:* Meenakshi et al. 2012; Mukherji and Das 2012; Mukherji and Shah 2012; Mukherji et al. 2012; Shah et al. 2012).

India is the world's largest user of groundwater, mostly for irrigation but also for industrial and domestic use. While this 'groundwater boom' has helped India sustain national food security, it has also imposed a huge socioeconomic cost.

- ✓ More than 72% of India's roughly 20-21 million groundwater irrigation structures run on highly subsidized electricity. The annual subsidy burden exceeds USD 15 billion, affecting the financial health of the country's energy utilities, and has contributed to severe groundwater depletion.
- ✓ Heavy subsidies have also been linked to low energy efficiency and crop productivity in the country (Rajan and Ghosh 2019).
- ✓ Subsidized electricity for groundwater irrigation has fuelled groundwater depletion. This, in turn, required farmers to install higher capacity pumps, increasing electricity use. To address financial losses, electricity utilities have started to ration supply hours; in response, farmers have resorted to illegal hook-ups to the grid and oversized pumps, further reducing energy efficiency and crop productivity.
- ✓ The complete withdrawal of these perverse subsidies would come at a high political cost.
- ✓ A solution pre-dating WLE was the separation of agricultural and non-agricultural electric grids in Gujarat (Shah et al. 2004); this was later replicated in several other Indian states (Shah and Verma 2008).
- ✓ Farmers without electricity subsidies or access in India continue to rely on highly polluting diesel, mostly in eastern India and central India's tribal heartlands.
- ✓ A 2009 study noted that farmers in India's water scarce regions that benefited from access to subsidized electricity faced little or no economic water scarcity while India's water rich regions were net virtual water importers in the form of agricultural commodities (Verma et al. 2009).

Together with policy research, WLE tested innovative approaches to reduce farmers' dependence on energy subsidies through the adoption of solar pumps. Experiments have shown that solar pumps can save money and require less maintenance compared to diesel pumps. However, results are context-specific and solar pumps are not a panacea. Instead, they could worsen the groundwater depletion crisis in northwestern and peninsular India, for example (Durga et al. 2016). Specifically, the Tata Trusts, WLE and CCAFS piloted a Solar Pump Irrigators' Cooperative Enterprise (SPICE) located in the village of Dhundi in central Gujarat, India (Shah et al. 2017). The idea of the cooperative was to promote SPaRC; that is, rather than using all the solar energy for pumping groundwater, farmers augment their income through the sale of surplus energy to the local electricity utility. The cooperative established a mini-grid connected to the local power utility grid for the sale of surplus energy under a 25-year power purchase agreement. To kick off the program, tariffs received by farmers were topped up with a green energy and water conservation bonus. This small pilot inspired the Government of Gujarat's 'Suryashakti Kisan Yojana' initiative, under which more than 4,500 farmers participate in this business model. The SPaRC model also forms part of the Government of India's ambitious Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) campaign with the goal of reaching two million farmers (Verma 2021).

In eastern India – where groundwater is abundant, but energy access is expensive and unreliable – the Tata Trusts, WLE and CCAFS piloted 'Solar Irrigation Service Providers' (SISP) with a view to catalyzing pro-poor, competitive irrigation service markets – replacing the prevalent oligopolistic and highly polluting diesel irrigation regime (Shah et al. 2019). In Bihar, studies have shown that government programs that offer very high capital subsidies for solar irrigation pumps are highly inefficient and poorly targeted (Durga et al. 2016). A better approach towards ensuring delivery of affordable and reliable energy for irrigation to the maximum number of small farmers would be to set up efficient and equitable solar irrigation enterprises. Each of the solar irrigation entrepreneurs set up in the pilot in Chakhaji village of north Bihar services 80-100 small farmers at prices that are less than half of diesel-based irrigation services (Durga et al. 2020; Durga and Rai 2018).

Overall, researchers emphasize that solar irrigation pumps need to be promoted through models that fully understand the local context, particularly with respect to the availability of water resources, the potential negative impacts, and the agricultural system within which the water–energy–food–climate operates (Verma et al. 2018).

The India experience is currently being transferred to Bangladesh, Nepal and Pakistan where solar programs are piloted and South-to-South learning is promoted with African countries (Verma 2021).

Non-agricultural uses of energy

Although the United Nations Sustainable Development Goals (SDGs) envision a world with "access to affordable, reliable, sustainable and modern energy for all," in sub-Saharan Africa, around 75% of households continue to rely on biomass for cooking (Mekonnen et al. 2017). Furthermore, electricity in many places is used only for lighting while biomass continues to be used for cooking, as electricity access is either unreliable or no electrical cooking appliances are available. The use of biomass for cooking can adversely affect women's available time for agricultural activities, in addition to negative health impacts from related air pollution. Moreover, biomass removal from agricultural fields can adversely affect agricultural productivity, and the clearance of forests has broader biodiversity, climate and agro-ecosystem impacts. Lessons from WLE's research on biomass energy are shown below.

- In Malawi, biomass sources are the main cooking energy source in rural and urban areas and will continue to be so due to high population growth, despite policy measures aimed at increasing energy efficiency. Simulations of alternative scenarios have shown that agro-forestry interventions are an essential tool to ensure sustainable supply of fuelwood and food security in Malawi (Schuenemann et al. 2018).
- In rural Ethiopia, many households collect firewood and cow dung to be used as fuel for cooking. The removal of cow dung from crop fields was associated with lower agricultural productivity, while on-farm production of fuelwood was associated with higher crop productivity and labor savings, by making fuelwood collection easier and more convenient for households (Mekonnen et al. 2017).
- Initiatives encouraging farmers to grow additional trees on their farmland are a way of improving the availability of firewood stocks and decreasing the amount of time needed for collecting natural energy resources by women (Scheurlen 2015).

Resource recovery and reuse (RRR) for income generation

WLE research also investigated innovative approaches for the reuse of available waste materials. As noted earlier, the burden of the collection of biomass for energy and other uses often falls on women and children. Through the development of business models and capacity building, the WLE RRR subprogram has helped women and young people to transform local waste into business opportunities (see Box 3 for advantages of RRR approaches).

Specifically, business models have focused on the conversion of crop and forestry residues, animal and human manure, or market waste into fuel pellets, briquettes or biogas, with a focus on involving women in such small enterprises. Waste-based bioenergy sources have advantages over coal and wood because they are cleaner, virtually free from incombustibles, easy to handle and cost-effective, and have lower ash and moisture contents.

Case studies described in Njenga and Mendum (2018) showed that recovering energy from organic waste had multiple positive impacts, in particular, for women and young people. RRR approaches required little investment capital, and were a simple and adaptable technology with cheap input materials. Through different partnerships, RRR initiatives have improved energy access, reduced waste, and empowered women in Kenya, Uganda and Ghana, among other countries. These measures were supported by capacity building in the form of development and expansion of university curriculums.

Box 3: Advantages of RRR approaches.

- Reusing waste materials from urban markets and highly populated neighborhoods, with limited sanitation services, can help to keep streets and public spaces clean while providing raw materials for briquette production.
- In extreme cases, such as refugee camps in arid locations, human waste that would otherwise be a threat to drinking water and human well-being can be directed toward fuel production.
- Providing indoor urine-diverting dry toilets for recovery of human excrement can prevent refugees, especially women and children, from having to go outside at night to use pit latrines and can also supply fecal sludge for briquette production.
- RRR for energy contributes to providing cheap, accessible cooking and heating energy that burns cleaner than firewood and charcoal.
- Bioslurry from biogas production has been shown to increase yields of coffee cherries, and can also be used as feed for pigs and poultry.
- Burning biomass in gasifier stoves produces biomass gas for cooking and also charcoal as a by-product, which can be used as biochar to improve soil quality in gardens or used again as fuel for cooking.
- The RRR-to-energy innovations reduce pressure on trees that would otherwise be cut down for charcoal or firewood.

Source: Njenga and Mendum (2018).

Research gaps and suggestions for 'One CGIAR'

First, while WLE developed a broad set of research activities in the energy space, the research did not consider the multiple impacts of accelerated rural energy access – for example, on nutrition, health, women's empowerment and environmental sustainability.

Given One CGIAR's focus on making a difference in five impact areas – 1) nutrition, health and food security; 2) climate adaptation and mitigation; 3) environmental health and biodiversity; 4) gender equality, youth and social inclusion; and 5) poverty reduction, livelihoods and jobs – research on accelerating rural energy access should more proactively assess these contributions. Similarly, a cost of inaction study should be considered, given the significant climate and environmental health costs of continued slow expansion of energy access and energy technologies in rural areas. Both such analyses could also further strengthen the business case for rural energy investment.

Second, while research suggested that small-scale, poorer and women farmers were less likely to directly benefit from accelerated energy access – for example, from owning and making decisions over a solar irrigation pump – there was little research focused on how to remove gendered barriers to energy technologies.[3] Under One CGIAR, in-depth assessments are needed on the suitability for, and distribution of benefits to, women farmers, including possible financial models that reach women and contribute to transforming gender relations.

Third, while WLE had a substantial energy research program, this was not integrated with other research on energy-related topics, such as work on the expansion of tractors in sub-Saharan Africa under the CGIAR Research Program on Policies, Institutions, and Markets (PIM), or work on crop protection in some of the research programs focused on agro-food systems, or with early work on low emission development strategies under CCAFS. It is important to pursue synergies across different, but related, strands of research under One CGIAR.

Several One CGIAR programs are considering advancing rural energy security with a focus on accelerating agricultural transformation, improving food and nutrition security, and reducing conflicts and civil strife. Key among these are the NEXUS Gains Initiative with an explicit focus on accelerating rural energy access, the Mitigation and Transformation Initiative for Greenhouse Gas (GHG) Reductions of Agrifood Systems Related Emissions (MITIGATE+) with a focus on low-carbon agricultural futures, and the Rethinking Food Markets and Value Chains for Inclusion and Sustainability Initiative that aims to strengthen energy use in the post-harvest sector. Several proposed regional initiatives also consider energy as a key factor for rural well-being and environmental sustainability. To ensure synergies in CGIAR's energy work and to increase impacts across these and other initiatives, a cross-initiative working group could be established.

The urgency of accelerating rural energy access for agricultural transformation is acute, as evidenced by intensifying climate change, growing food insecurity and malnutrition, and severe environmental degradation, including groundwater depletion. There is much to do and CGIAR has a key role to play in providing information, supporting access and piloting scalable energy interventions to support the achievement of multiple impacts for the poorest and most food-insecure women and men farmers and entrepreneurs.

[3] See, for example: Innovating for financial inclusion: Strengthening asset-based financing for women farmers - Innovation Lab For Small Scale Irrigation (tamu.edu); https://ilssi.tamu.edu/2021/06/18/supporting-solar-irrigation-companies-to-break-down-markets-and-lift-up-smallholder-farmers-in-ghana/–

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RESEARCH PROGRAM ON Water, Land and Ecosystems

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CGIAR Research Program on Water, Land and Ecosystems (WLE)

The **CGIAR Research Program on Water, Land and Ecosystems (WLE)** is a global research-for-development program connecting partners to deliver sustainable agriculture solutions that enhance our natural resources – and the lives of people that rely on them. WLE brings together 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO), the RUAF Global Partnership and national, regional and international partners to deliver solutions that change agriculture from a driver of environmental degradation to part of the solution. WLE is led by the International Water Management Institute (IWMI) and partners as part of CGIAR, a global research partnership for a food-secure future.

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