

POWERING
AGRICULTURE:

AN ENERGY GRAND CHALLENGE
FOR DEVELOPMENT



POWERING AGRICULTURE: SUMMATIVE EVALUATION



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ACRONYMS/ABBREVIATIONS

BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development)
DAC	Development Assistance Committee
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
IDA	Institute for Defense Analyses
LMIC	lower and middle income countries
OECD	Organisation of Economic Co-operation and Development
OPIC	Overseas Private Investment Corporation
OSTP	Office of Science and Technology Policy
PAEGC	Powering Agriculture: An Energy Grand Challenge for Development
PASTO	Powering Agriculture Support Task Order
PPP	Public-Private Partnership
PV	photovoltaic
R&D	research and development
SBA	Small Business Administration
SBIR	Small Business Innovation Research Program
Sida	Swedish International Development Cooperation Agency
STPI	Science and Technology Policy Institute
SWFF	Securing Water for Food
USAID	United States Agency for International Development
WE4F	Water and Energy for Food

Executive Summary

Purpose

Grand Challenge programs are intended to support the creation and diffusion of innovative solutions that can have transformational impacts on major international development problems. These programs assume that a wide circle of talented individuals from around the world who have not previously been engaged in international development can be tapped to invent or improve new solutions. Grand challenges provide an opportunity to test out a range of solutions as part of a cohort to determine which solutions are most effective and efficient towards driving development impact. Grand Challenges that focus on market solutions attempt to tap a large pool of entrepreneurs who can be encouraged to bring those solutions that work to market and rapidly expand sales to reach a large number of households.

The purpose of this summative evaluation is to take stock of what one Grand Challenge program, Powering Agriculture: An Energy Grand Challenge for Development (PAEGC or Powering Agriculture), has accomplished, to identify the factors that have contributed to the successes and failures of the program, and to provide recommendations for subsequent Grand Challenge programs, especially the successor program to PAEGC: Water and Energy for Food (WE4F).

This evaluation assesses the program's performance across the five criteria outlined in the Organisation of Economic Cooperation and Development (OECD) Development Assistance (DAC) evaluation framework: relevance, effectiveness, efficiency, impact, and sustainability. It distills lessons regarding the strengths and weaknesses of PAEGC. It also provides lessons learned and strategic input that the partners, the development assistance agencies that have contributed to Powering Agriculture, may use in the design of future programs. It analyzes PAEGC's current processes and procedures, including the framework for monitoring and evaluation, and suggests potential indicators or other revisions that could better enable future programs to measure the performance and impacts of technology development and commercialization efforts. The evaluation concludes with a series of recommendations pertaining to the future management of WE4F.

The program

Launched in 2012, PAEGC was a \$51.2 million multi-donor initiative that supported the deployment of clean energy technologies for agricultural value chains in lower and middle income countries (LMIC). The U.S. Agency for International Development (USAID), the government of Sweden through the Swedish International Development Cooperation Agency (Sida) and the Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (German Federal Ministry for Economic Cooperation and Development) (BMZ) through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH partnered to fund and manage PAEGC.¹ PAEGC provided support for the “development and/or adaptation of affordable technologies focused on clean energy generation, storage, and more efficient end-use within the agriculture sectors of developing countries that have potential for achieving commercial scale. This support may be for new technologies that are still in the incubation/demonstration stage, and/or existing technologies that are modified to respond to the demands of a specific target market” (USAID 2012 p. 11).

¹ The U.S. Overseas Private Investment Corporation (OPIC), also a partner, provided advice to program recipients, but did not contribute funds because it does not have that authority. Duke Energy Corporation was a founding partner and donated funds, but stopped actively participating in the program before the second cohort of innovators was funded by the program.

PAEGC set four objectives for the program:

- Enhance agricultural yields/productivity;
- Decrease post-harvest losses;
- Improve farmer and agribusiness income generating opportunities and revenues;
- Increase energy efficiency within the operations of farms and agribusinesses.

To achieve these objectives, the partners engaged in four sets of program activities: (1) technology and business model innovation, (2) commercial financing, (3) mainstreaming and acceleration, and (4) knowledge management. The program pursued these activities through the provision of grants, technical assistance, linking recipients to sources of capital, and the dissemination of knowledge through a variety of channels. Most of PAEGC's funding has gone to technology and business model innovation to support the development of new technologies or business solutions or the commercialization of technologies or other business solutions. Other funded activities have included technical and implementation assistance involving training, outreach, and entrepreneurship development, business strategy/business development assistance, and soliciting potential investment partners for awardees.

The core of PAEGC was awards made to innovators (24 funded by PAEGC and 10 that were funded separately by BMZ, but were also placed under the Powering Agriculture umbrella). For the purposes of the evaluation, we grouped all the innovators into four categories of technologies: solar-powered irrigation, cooling and heating using renewable energy, mini-grids and micro-grids, and agricultural processing equipment and other. Mini-grids using renewable energy was the largest category with 7 projects, cooling or heating and solar-powered irrigation accounted for 6 projects a piece, and agricultural processing and other accounted for 5. Of the 24 projects funded directly by PAEGC, approximately half of targeted Africa; eight, Asia and Pacific Rim countries; three, Latin America and the Caribbean; and two, the Middle East. While most projects focused on a single region, several operated in more than one country.

For this evaluation, STPI was tasked by PAEGC to assess the overall effectiveness of these activities and particularly probe the program's results in terms of four impacts:²

- Increases in agricultural output and incomes;
- Reductions in emissions of greenhouse gases;
- Reductions in poverty; and
- Improvements in gender equality.

Methodology

The core of the evaluation is an assessment of awards made to innovators. The limited number of awards made by the program made it possible for us to complete case studies of all the funded innovators. The activities of each of the innovators were judged in terms of outcomes and impacts. We defined outcomes as the progress achieved by the innovators in relation to their initial starting positions in terms of technology or product development (R&D and initial piloting), business (early adoption and commercialization), and diffusion (those primed for market growth and wide-scale adoption). We assessed the outcomes of each project in terms of the development of the technology or solution, the development of the business or demonstration of commercial promise, and diffusion or commercial scalability. Each project was coded by technology development, the development of the business or demonstration of commercial promise, and diffusion or commercial scalability. These three categories are

² Although poverty reduction was not a stated goal of the program, and gender equality was not originally given the same prominence as increases in agricultural output and reductions in emissions of greenhouse gases, current donor priorities have made them keen to develop a better understanding of these impacts, so indicators of impacts in these categories were assessed as well.

equivalent to the three Powering Agriculture Innovation Stages: initial piloting, early adoption/distribution, and market growth. Our assessments of outcomes were based on document reviews, academic and business literature about the markets and technologies targeted by the innovator, and interviews with innovators and individuals engaged in PAEGC, supplemented by site visits to selected farmers who benefited from the project (beneficiaries), equipment distributors, and similar companies within the market. Where possible, we made quantitative estimates of the current and potential impacts of the projects on increasing agricultural output or incomes and reducing emissions of greenhouse gases. We also provided qualitative assessments of their impacts on reducing poverty and improving gender equality. We evaluated PAEGC's performance in terms of technical assistance, training, and outreach; knowledge management; and the Powering Agriculture Investment Alliance, drawing on interview data and output metrics on usage. We used interview data, innovator outcomes, and previous evaluations to assess the efficacy of PAEGC processes and procedures.

What we found

Relevance

Relevance is the extent to which the aid activity is suited to the priorities and policies of the target group, recipient, and donor.

The program, as implemented, was true to the goals and policies of the partners. It supported a mix of projects involving new or existing clean energy and agricultural technologies modified for use in LMIC agricultural communities. Although some projects encountered engineering difficulties and others developed technologies that proved uneconomic, we judged all the projects as attempting to benefit LMIC agricultural communities.

The innovations were consistent with the goals of increasing agricultural output and incomes, reducing greenhouse gas emissions, and reducing poverty. All the projects were designed to increase incomes; most also involved reducing emissions of greenhouse gases. Many of the projects were designed to replace manual labor on smallholder farms with agricultural equipment powered by renewable energy, whether for irrigation or agricultural processing. Projects that substitute technologies using renewable energy for manual labor were often beneficial to women, as women are often responsible for these tasks. But most projects lacked a specific gender equality component.

Effectiveness

Effectiveness is a measure of the extent to which an aid activity attains its objectives.

Almost all Powering Agriculture awardees successfully developed their technology or business process to the pilot stage. Twenty-eight of the 32 cases (88 percent) achieved or mostly achieved technology development objectives. Five projects of the 32 have achieved or mostly achieved goals for diffusion of their products (Figure S.1).

Powering Agriculture has enjoyed its greatest success in fostering the growth of solar-powered irrigation markets in LMICs, especially in Sub-Saharan Africa. Several innovators supported by Powering Agriculture have introduced solar-powered irrigation pump catering to a variety of hydrological conditions and farm sizes. Sales are running in the thousands of units per year. The market has become sufficiently promising to induce established distributors of irrigation pumps to develop their own solar-powered pumps. Powering Agriculture has also supported a number of promising mini-grid projects.

There is a mismatch between the cost of many of the PAEGC-supported technologies and the ability of the smallholder farmer to afford them, even when the innovator provides access to financing.

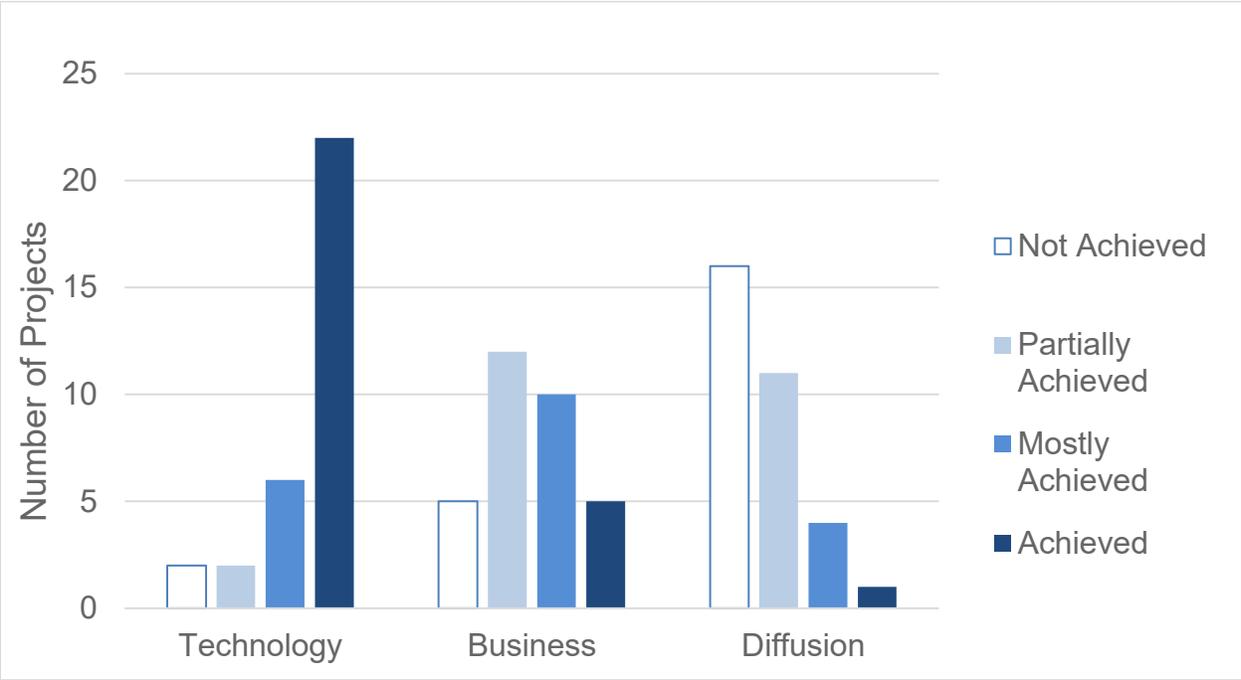


Figure S.1 Project outcomes by category

Efficiency

Efficiency measures the outputs—qualitative and quantitative—in relation to the inputs. It is an economic term that signifies that the aid uses the least costly resources possible in order to achieve the desired results.

By several measures, Powering Agriculture has been efficient in terms of resources used compared to outcomes. Nearly half of Powering Agriculture projects have attained or mostly attained business development objectives compared to approximately one half of the recipients of U.S. Small Business Innovation Research (SBIR) grants, and approximately 40 percent of recipients of Small Business Technology Transfer (STTR) grants—somewhat similar U.S. domestic technology-focused programs. The size of grants in these programs is comparable to those of Powering Agriculture in terms of size and objectives. The commercial success of SBIR and STTR recipients is positively correlated with leveraging outside investment; most PAEGC innovators have successfully mobilized additional funding in the form of additional grants or, in the case of the for-profit companies, outside investment. Additional grants and investments have been twice the amounts of the direct awards received by the innovators (\$24,471,426), and roughly equal to the total \$51.7 million funding for PAEGC.

Most of PAEGC recipients have not fully commercialized their products and therefore have not had a tangible impact on agricultural incomes. We estimated that if three innovators that have successfully diffused their technologies (Futurepump, SunCulture, and Promethean) continue to expand their sales as projected, beneficiaries’ incomes would increase by approximately \$50 million per year by 2025 (more than the total cost of Powering Agriculture).

Impact

Impact is the positive and negative changes produced by a development intervention, directly or indirectly, intended or unintended.

The solar-powered irrigation projects and the micro-grids have had the greatest impact in terms of increasing incomes and reducing emissions of greenhouse gases. The six solar-powered irrigation projects have increased crop yields and incomes and decreased costs associated with purchasing gasoline or diesel fuel for irrigation pumps or manually hauling water. The mini-grids offer beneficiaries enhanced and more consistent access to electric power, which increases their quality of life and catalyzes commercial opportunities and increases businesses' revenues. PAEGC has also funded projects that provide cool and cold storage that have increased farmer incomes by reducing spoilage. It also funded projects to mechanically process agricultural crops using renewable energy, reducing burdens on women. Figure S.2 shows increases in incomes by household associated with PAEGC funded projects. Some of these increases are large. We estimate that a large-capacity solar-powered irrigation pump increases household incomes by \$811 per year, which in Kenya would correspond to a 13 percent increase in average household incomes of \$6,318 per year, and an even higher percentage increase for the average rural household whose incomes are much less.

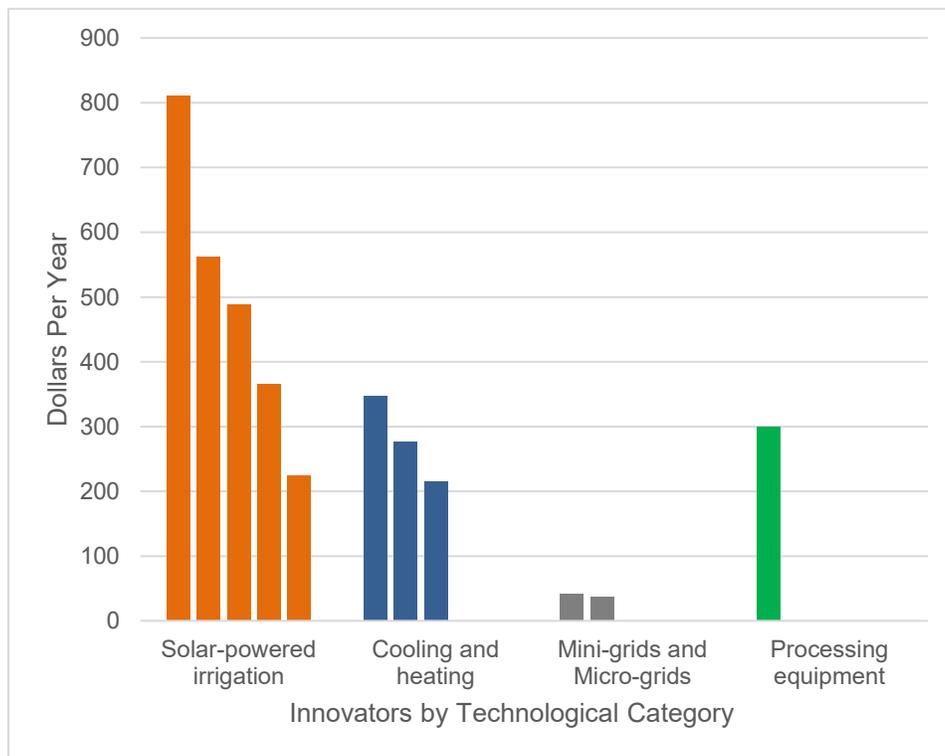


Figure S.2 Estimated Increases in annual agricultural Incomes per household stemming from PAEGC-funded projects

Figure S.3 shows our projections of reductions in greenhouse gas emissions in 2025 stemming from PAEGC projects.

PAEGC successfully stimulated the development of markets for renewable energy tied to agriculture. Powering Agriculture has led to corporate spin-outs and stimulated the entry of competitors into nascent markets such as small-scale cooling with renewable energy and solar-powered irrigation pumps.

Powering Agriculture's concrete effects on gender equality were hard to measure. Innovators were cognizant of gender equality issues and in many cases designed their products to be more ergonomic for female customers. Out of the 24 PAEGC innovators, 15 (54 percent) articulated a specific goal of

promoting gender equality, such as saving women time through the use of the innovation (PAEGC 2016e). A few of the Powering Agriculture innovators were able to point to direct impacts on gender equality from their projects. Projects that substitute technologies using renewable energy for manual labor were often beneficial to women, as women are often responsible for these tasks. Unfortunately, some of the projects that had a more direct focus on gender equality issues were unsuccessful in developing their businesses. Others never emerged from the technological development stage, so that the numbers of female beneficiaries were very small. Those innovators who were most successful at diffusing their technologies did not show evidence that their efforts to pursue gender equality had had substantial impact, as they did not have differentiated gender approaches to customers.

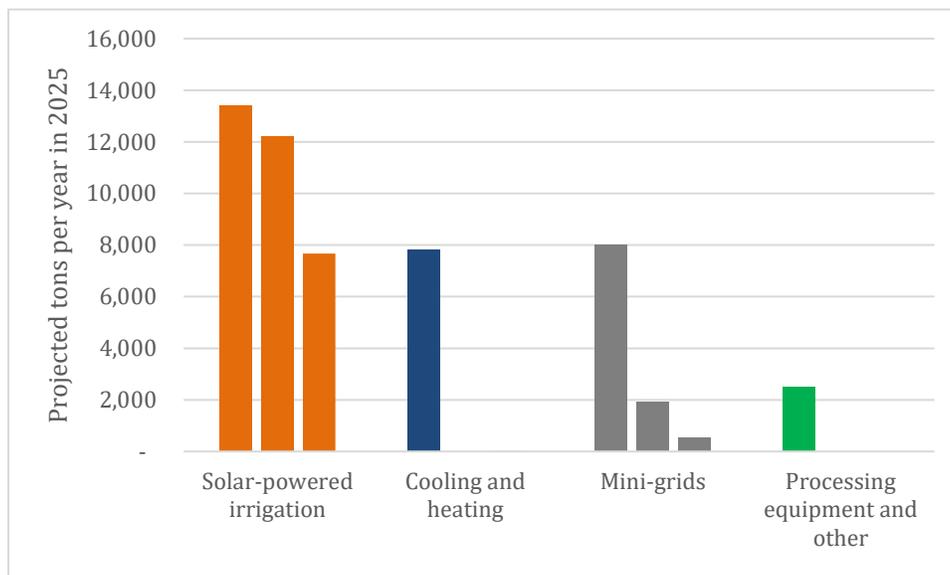


Figure S.3 Projected reductions in annual greenhouse gas emissions in 2025 stemming from PAEGC-funded projects

Sustainability

Sustainability is concerned with measuring whether the benefits of an activity are likely to continue after donor funding has been withdrawn. Projects need to be environmentally as well as financially sustainable. Fifteen for-profit and non-profit innovators among the 24 PAEGC innovators have successfully established businesses and are ramping up sales of their products. Eleven of the for-profit companies have raised substantial sums of capital, the total of which exceeds the entire amount of funds allocated to PAEGC. These organizations appear to be firmly entrenched in the market. In general, non-profits and for-profit firms that successfully attracted additional grants or investment were most likely to commercialize and diffuse their products. Projects intended solely as pilots or demonstrations and without an integral plan to transition the technology to market, especially projects by innovators at universities, were unlikely to be commercialized. None of the projects that relied on materials or components that are difficult to source in LMICs was successfully commercialized.

Our overall assessment of PAEGC's effects on environmental sustainability is highly positive. Despite some of the environmental downsides of manufacturing solar panels due to the use of toxic materials and chemicals in the manufacture of solar panels, the substitution of solar panels for diesel generators and gasoline pumps reduces emissions of greenhouse gases and conventional pollutants. Solar-powered irrigation in East Africa did not seem to threaten water tables; in India, it substitutes for heavily subsidized

diesel fuel. Only in Jordan and elsewhere in the Middle East did solar-powered irrigation potentially compound existing problems of overutilizing ground water.

Other Powering Agriculture activities

In general, innovators were complimentary concerning technical support provided by PAEGC. Tetra Tech's support through the Powering Agriculture Support Task Order (PASTO) was rated favorably by innovators. PASTO provided feedback on milestones, guidance on monitoring and evaluation (M&E), and assistance with compliance with USAID policies and procedures, including award modification.

VentureWell's provision of tailored advice through the Powering Agriculture Xcelerator program (PAX) on how to manage businesses and to attract investors was highly praised. In particular, the workshops where innovators met with each other and jointly worked on solving problems were highly rated.

Participants considered GIZ-supported knowledge products like the SPIS Toolbox and the MOOC offered on Sustainable Energy for Food highly useful. According to interviewees, the Toolbox, in particular, has contributed to the diffusion of solar-powered irrigation pumps in East Africa. GIZ's efforts to diffuse knowledge about solar-powered irrigation systems through its Toolbox on Solar-Powered Irrigation Systems (SPIS) and on renewable energy more broadly through its Massive Open Online Course (MOOC) on Sustainable Energy for Food have created a permanent cadre of individuals, especially in Africa, with the necessary knowledge to support continued diffusion of SPIS.

Among Powering Agriculture outreach activities, innovators were the most enthusiastic about support for conference attendance. The Social Capital Markets (SOCAP) conference, in particular, was praised as an excellent venue to contact potential investors.

The Powering Agriculture Investment Alliance, set up by PAEGC to enhance private sector financing for PAEGC innovators or other companies, has been tasked with catalyzing at least \$25 million in private sector finance for innovators in renewable energy and agriculture from its two partners, AlphaMundi and Factor[e], who are social impact investors. The Alliance partners had invested \$1.2 million of their own funds by December 2019 in three companies. However, few PAEGC innovators meet AlphaMundi's criteria for investment; AlphaMundi does not invest in companies that are still in the product development phase, excluding a substantial share of Powering Agriculture innovators. Factor[e] invests in companies at earlier stages of technological development than AlphaMundi, but Factor[e] also found many of the PAEGC innovators did not have well-developed plans to market their products and hence were not attractive investment prospects.

PAEGC processes

We assessed PAEGC selection, monitoring, and support processes. Outside stakeholders recommended that in future calls for proposals, applicants should be required to provide more detailed assessments of local markets and potential demand for their product, even if their project is primarily focused on developing a technology. Several promising innovations are unlikely to be commercialized because the innovator lacks incentives or the means to bring the innovation to market. In general, awardees with a track record of working in LMICs achieved better outcomes than those that had not. The large geographic spread of the innovators increased monitoring and evaluation costs, as more travel was involved. It also limited the ability of the innovators to learn from each other about how to best address the problems they encountered in their region.

Neither innovators nor beneficiaries have the ability to collect reliable information for the current impact indicators: measuring increases in agricultural output and incomes, reductions in emissions of greenhouse gases, reductions in poverty, or improvements in gender equality. Innovators resorted to asking customers for this information, an activity that added appreciably to costs, yet customers also did not have or collect this information.

Innovators complimented the PAEGC award managers for being supportive, patient, flexible, and understanding throughout the entire award process. Innovators and other stakeholders noted that the PAEGC partners are all actively involved, work well with each other, and that their roles in PAEGC are clearly assigned.

Theory of Change

The theory of change that underlies USAID's Grand Challenges states that "by engaging and mobilizing diverse, global solver communities, USAID and its Partners can source, select, incubate, test, and scale up science and technology innovations that will overcome critical barriers to development and accelerate the pace at which the world's most pressing development problems can be addressed" (Raetzell and Seidler 2016 p. 10). PAEGC is predicated on the assumption that awards ranging from \$500,000 to \$2,000,000 can catalyze the development, commercialization, and wide-scale diffusion of new renewable energy technologies coupled with new agricultural technologies.

We found many positive attributes of Powering Agriculture. As opposed to funding activities that need repeated, ongoing support, Powering Agriculture is focused on fostering the development of vibrant, sustainable markets for new technologies. It was designed to help to seed a market, generate attention, facilitate enabling environment, attract investment, and test innovations that have the potential to move to adoption through commercialization or other scaling pathways. Because funding is flexible and payments are based on milestones, recipients have more flexibility to use the funds to address emerging technological, regulatory, and business challenges. Grand Challenges are among the few, if not the only assistance programs that fund the development of new technologies by small organizations.

In many instances, however, Powering Agriculture did not validate the underlying theory of change as captured in the principles listed above:

- *Powering Agriculture was to combine solutions to provide rural households with renewable energy and increase agricultural output or incomes.* Fusing renewable energy technologies with technologies to process crops and animal products had mixed success. Several projects ended up focusing on one technology or the other.
- *PAEGC was to scale up science and technology innovations.* Few innovators reached commercial scale during the award period, only one attained wide-scale diffusion.
- *PAEGC was to engage and mobilize diverse, global solver communities.* Organizations that had previously worked in development or whose home or home market were in LMICs were more likely to be successful than innovators that had little or no previous experience with LMIC markets.
- *PAEGC was to incubate and test science and technology innovations that will overcome critical barriers to development.* Projects focused on developing new products performed more poorly than projects that focused on improving existing products or expanding sales of existing products into new markets.
- Along the same lines, addressing regulatory barriers, providing sustainable financing to poor households, or attracting investment were often more important for achieving PAEGC objectives for business development and diffusion than developing new technologies.
- Many PAEGC innovators were unable to develop products that can be sold at a price that poor smallholder farmers can afford.

Recommendations

Drawing on the evaluation, we make several recommendations that may be useful for the new Water and Energy for Food Grand Challenge, WE4F:

- WE4F should take a longer view than the initial horizon for PAEGC projects. Seven or more years is likely to be necessary to move incipient technologies to the point where they are more widely available. If WE4F wishes to disseminate solutions more quickly, it will probably need to provide incentives to existing mid-sized or larger enterprises to invest in bringing existing solutions to increasing agricultural output and reducing emissions of greenhouse gases in LMICs. Non-profits and small businesses are not able to scale as rapidly as established businesses.
- Projects should focus on commercializing or expanding sales of the product rather than developing early-stage technologies; all proposals should include a detailed, credible plan for commercializing the product.
- If WE4F wishes to continue to support the development of novel solutions, especially by universities, the partners should insist on innovators providing a realistic avenue by which their solutions will eventually come to market and be broadly disseminated. Innovations that did not have a solid path towards the market have not been broadly disseminated and do not appear likely to be so.
- Although providing funding to more than one set of technologies is important to allay risks, based on the experiences of Powering Agriculture, WE4F should focus on providing funding to help surmount technological or market barriers facing a small set of early stage technologies rather than opening up the solicitation to any novel solution. Such an approach could help open up new markets, as PAEGC has done with solar-powered irrigation, but concentrate resources on supporting innovations with better prospects for wide diffusion and broad impact.
- There is a tension between market-based solutions and entrepreneurship and short-run impacts on reducing poverty and gender equality. All, or almost all, of the innovators were focused on the survival of their organizations. To do so, they gave primary importance to solving technical and business problems that they confronted on a daily basis; issues of gender equality and poverty reduction were given lower priority. We recommend that the partners temper expectations concerning goals for improving gender equality and short-term reductions in poverty from programs like Powering Agriculture and WE4F.
- The selection process should favor innovators located in or with long experience in LMICs;
- The selection committee should include individuals familiar with the markets that prospective innovators are addressing. The members of the selection committee should be knowledgeable about competing technologies, prospective competitors, the size of the market, and key price points.
- WE4F should reduce the number and complexity of the required indicators, so the program can reduce the costs of monitoring of evaluation, including fewer in-person site visits.
- WE4F should hire third party evaluators at the beginning of selected projects to track the effects of the innovation on changes in the impact indicators over time. Because of cost considerations, probably only a few innovations will be able to be evaluated in this fashion.
- Milestones should not set arbitrary targets, like number of beneficiaries at a specific point in time, but focus on organic development of the business, like general increases in sales and progress towards profitability.
- WE4F should continue to include services from business advisors and social impact investors in its program and provide awardees with access to these services for an extended period of time.

1. Introduction

1.1 Purpose

In May 2019, the Institute for Defense Analyses (IDA) Science and Technology Policy Institute (STPI) was tasked with conducting a summative evaluation of Powering Agriculture: An Energy Grand Challenge for Development (PAEGC or Powering Agriculture).³ The purpose of this summative evaluation is to take stock of what PAEGC has accomplished, to identify the factors that have contributed to the successes and failures of the program, and to provide recommendations for subsequent Grand Challenge programs, especially the successor program to PAEGC, Water and Energy for Food (WE4F). In agreement with the PAEGC partners, STPI devoted the bulk of the effort (70 percent) to assessing the outcomes and impact of PAEGC. Consequently, fewer resources were devoted to assessing supporting activities and processes. Fortunately, PAEGC had funded two mid-term evaluations, one focused on innovators and the other more on program management, (PAEGC 2016; Raetzell and Seidler 2016) that evaluated these components of the program in more depth. We benefitted from these interim evaluations in this summative evaluation.

This summative evaluation of the performance of PAEGC assesses the extent to which technologies and other solutions have been strengthened through grant funding and technical assistance provided by Powering Agriculture, and the extent to which these strengthened technologies and other solutions demonstrate potential to accelerate the development and deployment of clean energy solutions for increasing agricultural production or value in developing countries. The evaluation assesses the program's performance across the five criteria outlined in the Organisation of Economic Cooperation and Development (OECD) Development Assistance (DAC) evaluation framework: relevance, effectiveness, efficiency, impact, and sustainability. It distills lessons regarding the strengths and weaknesses of PAEGC. It focuses on the extent to which innovators who received grants from PAEGC have achieved objectives for developing technologies and other solutions, bringing these solutions to market, and diffusing these solutions; what factors have driven achievements or lack thereof; and to what extent PAEGC helped innovators to accelerate the development and deployment of clean energy solutions for increasing agricultural production or value in developing countries. It evaluates the extent to which innovators achieved sustained impacts on PAEGC's development goals of increasing agricultural output and incomes, reducing emissions of greenhouse gases, and helping to reduce poverty and improve gender equality. It also analyzes PAEGC's current processes and procedures, including the framework for monitoring and evaluation employed, and suggests potential indicators or other revisions that could better enable future programs to measure the performance and impacts of technology development and commercialization efforts. It also provides lessons learned and strategic input that the partners may use in the design of future programs. It concludes with a series of recommendations pertaining to the future management of WE4F.

³ The IDA Science and Technology Policy Institute (STPI) is a Federally Funded Research and Development Center operated by the Institute for Defense Analyses (IDA), a nonprofit corporation. STPI was established by Congress to inform policy decisions of the Office of Science and Technology Policy (OSTP) in the Executive Office of the President. STPI does a wide range of work for its government sponsors, including evaluation of programs, identification of best practices, and analysis of policy options.

1.2 Powering Agriculture: An Energy Grand Challenge for Development

Grand Challenges for Development

Grand Challenge programs are intended to support the development and diffusion of solutions that can have transformational impacts on major development challenges. The Grand Challenge model is predicated on the assumptions that science and technology can have important transformational impacts when appropriately applied to international development challenges, and that international development will benefit from engaging a wide range of individuals and institutions in the search for solutions to these challenges (PAEGC 2019). The crux of the Grand Challenges is that science and technology can transform development, and international development agencies need to reach out to non-traditional sources for breakthrough solutions for especially challenging development problems.

Program description

Since 2011, the U.S. Agency for International Development (USAID) and its partners have launched 10 Grand Challenges for Development. Launched in 2012, Powering Agriculture: An Energy Grand Challenge for Development (PAEGC) was the third Grand Challenge. It was a \$51.7 million multi-donor initiative that supported the deployment of clean energy technologies for agricultural value chains in developing countries. It was designed to identify and support new and sustainable approaches to accelerate the development and deployment of clean energy solutions for increasing agriculture productivity and value in developing countries (PAEGC 2019).

USAID partnered with the government of Sweden through the Swedish International Development Cooperation Agency (Sida) and the Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (German Federal Ministry for Economic Cooperation and Development) (BMZ)—collectively, the “Founding Partners,” to combine resources for Powering Agriculture. BMZ has commissioned *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH* with implementing Germany’s activities under the program *Powering Agriculture - Nachhaltige Energie für Ernährung* (Powering Agriculture – Sustainable Energy for Food) (GIZ ud.). The U.S. Overseas Private Investment Corporation (OPIC) was also a partner. It has provided advice and is moving forward with loans to select program recipients, but did not provide funding because it does not have the authority to provide development grants (Interview with PAEGC donor). Duke Energy Corporation was a founding partner and initially donated funds, but stopped actively participating in the program before the second tranche of grants were issued in 2015 (Interview with PAEGC partner).

The program has four major components (PAEGC 2016b):

1. “Providing small grants (\$500,000–\$2,000,000) to entities to design, pilot and deploy clean energy solutions to different points along the agricultural production cycle—from obtaining agri-inputs, planting, irrigation and harvesting to processing, transportation and storage.”
2. “Leveraging funds for a global financing facility to provide guarantees to encourage private sector equity and debt investments within the clean energy/agriculture space.
3. “Identifying and supporting clean energy solutions that can be brought to commercial scale, and integrated within regional/national agriculture production and food security programs.
4. Hosting an online knowledge management platform to document lessons learned, promote effective technologies and business models, and foster continued engagement among stakeholders interested in exchanging ideas about the clean energy/agriculture nexus.” (PAEGC 2016b)

In alignment with these components, the partners engaged in four sets of program activities: (1) technology and business model innovation, (2) commercial financing, (3) mainstreaming and acceleration, and (4) knowledge management. It pursued these activities through the provision of grants,

technical assistance, linking recipients to sources of capital, and the dissemination of knowledge through a variety of channels (PAEGC 2019). Most of PAEGC’s funding has gone to technology and business model innovation to support the development of new technologies or other solutions, and the commercialization of these technologies or other solutions. Mainstreaming and acceleration involves linking PAEGC to public-private partnerships, training programs, and other agricultural and energy programs. For example, in 2019, PAEGC began to provide bulk procurement incentives for solar water pumps, which falls under mainstreaming and acceleration. Other funded activities have included technical and implementation assistance involving training, outreach, and entrepreneurship development; business strategy/business development assistance; and soliciting potential investment partners for awardees.

Under the Powering Agriculture Support Task Order (PASTO), USAID contracted with Tetra Tech, a firm engaged in providing support for development assistance programs, to monitor the performance of the recipients and to provide them with technical support. Through GIZ, BMZ has separately funded 10 additional small-scale technology and social innovation pilot projects similar to the PAEGC awards that it has placed under the Powering Agriculture umbrella. As part of its activities, PAEGC has also set up the Powering Agriculture Investment Alliance to catalyze private sector financing for businesses that have been recipients of PAEGC grants or that provide clean energy solutions to increase agriculture productivity or value in developing countries.

Program objectives

PAEGC provided support for the “development and/or adaptation of affordable technologies focused on clean energy generation, storage, and more efficient end-use within the agriculture sectors of developing countries that have potential for achieving commercial scale. This support may be for new technologies that are still in the incubation/demonstration stage, and/or existing technologies that are modified to respond to the demands of a specific target market” (USAID 2012 p. 11).

PAEGC set four objectives for the program (PAEGC 2016c):

- Enhance agricultural yields/productivity;
- Decrease post-harvest losses;
- Improve farmer and agribusiness income generating opportunities and revenues;
- Increase energy efficiency within the operations of farms and agribusinesses.

PAEGC asked STPI to measure PAEGC impacts on increasing agricultural output and incomes and reducing emissions of greenhouse gases. In addition, STPI examined PAEGC’s impacts on reducing poverty and improving gender equality, additional impacts on which the partners wished to focus, and which are important for informing WE4F. In particular, improving gender equality was given more prominence after the initiation of the program because of the importance attached to it by the partners (Raetzell and Seidler 2016).

Program management

The founding partners (USAID, Sida, BMZ, and Duke Energy) pooled funds into a conceptual bucket of funds that was managed by USAID.⁴ USAID has overseen the selection of grantees, provision of funding, and monitoring and evaluation. The \$51,785,100 in total funding has been allocated to all four sets of program activities, although the bulk has gone toward technology and business model innovation, commercial financing, and knowledge management activities. Of these categories, a little less than half of total funds went to direct awards received by the innovators (\$24,471,426), which fell under technology and business model innovation. technology and business model innovation also includes PAEGC funding

⁴ As of October 2019, the partners had contributed the following funds: Sweden—\$19,102,700, the U.S. Government—\$15,446,800, Germany—\$15,735,600, Duke Energy—\$1,500,000, for a total of \$51,785,100 (PAEGC 2020).

for business acceleration support and technical assistance to help innovators with advice on actions to improve gender equality. The founding partners used \$5 million to stand up the Powering Agriculture Investment Alliance, which falls under commercial financing. PAEGC does not provide commercial financing directly, but has used the Alliance to link recipients to sources of global development finance. PAEGC has also engaged in a range of knowledge management activities: websites, studies, guides, etc.

Mainstreaming and acceleration has been led by GIZ on behalf of BMZ. GIZ has also taken the lead in knowledge management, providing oversight and funding for collecting, analyzing, and disseminating knowledge that has been acquired through the implementation of the initiative's interventions and other activities related to renewable energy and agriculture. In addition to financial support, GIZ has provided in-kind support to PAEGC in the form of program activities that GIZ funds and implements itself. Several of these initiatives and projects funded solely by GIZ have been co-branded with the Powering Agriculture label. GIZ's regional hub for East Africa, located in Nairobi, Kenya, has played an important role in these activities. We review some of these initiatives and projects in the course of this evaluation.

Technology and business model innovation

To spur technology and business model innovation, PAEGC made \$24,471,426 in direct grant awards to 24 innovation projects, 11 in 2013 and 13 in 2015 (PAEGC 2020).⁵ The funding has supported technology development, initial in-country pilot testing, and early-stage commercialization. To make the awards, PAEGC issued two global calls (Broad Agency Announcements) asking for initial proposal summaries, one in December 2012 and the second in November 2014. The review process consisted of two stages: a screen of the innovation followed by a request for a full proposal for those applicants that passed the screen. Applicants submitted a short summary of their proposals for the innovation screen. Applicants that passed that screen were invited to submit full proposals that then went through a technical evaluation. Proposals were accepted from individuals at institutions, which could be universities, non-profits, or for-profit firms, located in developed and in developing countries. USAID was responsible for coordinating the review of the proposals, but worked with the other partners to make selections.

Most project winners received milestone-based grants, with funding incrementally dispersed based on achieving specified milestones, although a handful of awards were cooperative agreements under which the innovators were reimbursed for expenses incurred. As a condition of the grant, winners submitted monitoring data on a regular basis to PASTO (PAEGC 2016a).

Technical assistance, training, and outreach

In addition to the two cohorts of Powering Agriculture awards, the program partners have undertaken activities in technical assistance, training, and outreach. Both GIZ and PASTO have conducted assessments preparatory to and supporting studies focusing on technical priority areas and cross-cutting themes, with the intent of identifying high-priority topic areas for Powering Agriculture and potential best practices. They have also developed training materials, course curricula, and other documentation related to using renewable energy solutions in the context of agriculture. For example, in 2016 GIZ developed its Massive Open Online Course offered under its Sustainable Energy for Food program (part of its activities under Powering Agriculture). This 8-week course has reached more than 1,300 participants from around the world, introducing them to technical and business solutions associated with the use of sustainable energy in agriculture and other related topics. PASTO and GIZ staff have also participated in workshops and international development meetings pertaining to sustainable agriculture and the energy-agriculture nexus. Both groups also engage in outreach activities through their Internet sites, including the Energypedia portal.⁶

⁵ The initial total was 12 in 2013, but the award to Experience International was cancelled early on.

⁶ The Energypedia portal is located at https://energypedia.info/wiki/Main_Page.

Another group of activities involves supporting entrepreneurship. Both GIZ and PASTO provide technical and implementation assistance and business strategy/business development assistance to awardees. They also solicit potential partners for awardees—including through the GIZ East Africa Hub and VentureWell's activities through the Powering Agriculture Xcelerator program (PAX), a program to provide advice to PAEGC innovators on how to prepare themselves to attract investors, which falls under PASTO. VentureWell is a non-profit focused on helping companies get innovations into the market.

In 2019, Powering Agriculture provided support for the 2019 Global LEAP Awards + Results Based Financing (Global LEAP+RBF). The awards are administered by CLASP, an international resource for measuring appliance energy efficiency, supporting appliance efficiency policies, and market acceleration initiatives. This activity pre-qualifies solar water pumps through the Global LEAP Awards, which use rigorous tests to determine appliance efficiency. Distributors of solar-powered pumps that pass these tests are able to apply for bulk procurement incentives from Powering Agriculture of 25 percent of the pump price (PAEGC 2020).

Powering Agriculture Investment Alliance

As noted above, as part of its activities, PAEGC created the Powering Agriculture Investment Alliance. The Alliance was set up to catalyze private sector financing for businesses that have been recipients of PAEGC grants or that provide clean energy solutions to increase agriculture productivity or value in developing countries. Two impact investors, AlphaMundi and Factor[e], were selected to join the Alliance. They have committed to investing their own funds in companies that are pursuing PAEGC goals. The two investors received funding from PAEGC to help offset the high costs associated with identifying early-stage companies in the energy-agriculture nexus, investing in them, and assisting them in obtaining follow-on funding. The Alliance is set to continue until 2021, after the end of Powering Agriculture (PAEGC 2020).

AlphaMundi Group Ltd. is a commercial entity based in Switzerland exclusively dedicated to impact investing. It provides debt and equity financing to scalable social ventures in sustainable human development sectors. It consists of the AlphaMundi investment company, a social impact investor, and its sister organization, the AlphaMundi Foundation, a Washington, D.C.-based non-profit that provides technical assistance and impact measurement support to social enterprises and selectively sponsors other industry initiatives (AlphaMundi ud.). The investment company donates 20 percent of its annual profits to AlphaMundi Foundation,

AlphaMundi joined the Powering Agriculture Investment Alliance in April 2018 with the goal of mobilizing \$15 million in private sector financing, including investments, equity and loans, from the AlphaMundi Group through 2021. The AlphaMundi Foundation received \$3 million in PAEGC funds. The Foundation primarily provides short-term (1 year or less), small (\$40,000–\$60,000) technical assistance projects intended to support innovators to refine business structures and processes critical for young social enterprises to become investment-ready. It can also provide additional grants. AlphaMundi Foundation picks promising companies and then provides short-term assistance tailored specifically to the company. It prioritizes companies with track records of operations of over 3 years, \$500,000 or more in annual revenues, and demonstrated social or environmental impact. As of the end of 2019, AlphaMundi Foundation had provided technical assistance to 10 companies (SolarNow received two rounds of assistance) and AlphaMundi had invested in two: Coconut Holdings and Sistema.bio. Technical assistance projects were valued at \$614,280, or approximately \$56,000 on average per project, with project sizes ranging from \$18,600 to \$90,312. Six of the projects tested technologies in Kenya. In an example of support related to one of the Powering Agriculture awards, AlphaMundi assisted SunCulture to refine the credit assessment process underlying its PAYGrow financing system, helping to cut default rates and thereby increasing the SunCulture's potential to reach profitability (AlphaMundi Foundation ud.).

Factor[e] is a venture development firm headquartered in Fort Collins, Colorado. Its mission is to improve lives in the developing world through increased access to sustainable energy and related services. It supports early stage entrepreneurs through a blend of risk capital and technical resources to transform their ideas into market-based solutions (Factor[e] ud.). It is devoted to early-stage seed investments.

Factor[e] has received \$2 million in PAEGC funds with the goal of leveraging \$10 million in private investment through co-investments and follow-on funding through 2021. It utilizes its funds to make small equity investments (\$200,000–\$500,000). It supports PAEGC through the Investment Alliance by engaging and investing in very early stage technology-based companies focused on energy and materials conservation and renewable energy. As of December 2019, Factor[e] had made one investment, taking a stake in Sistema.bio. An additional investment has been approved by the investment committee and is anticipated in early 2020. Because the Investment Alliance will not end until 2021, Factor[e] will continue providing technical support and making additional investments to achieve its \$10 million goal in investments of its own funds over the remaining life of the Investment Alliance.

GIZ pilot projects

GIZ on behalf of BMZ funded 10 pilot projects from its own funds that it also branded under Powering Agriculture, which we grouped into eight case studies. The 10 pilot projects are: Analysis of the Commercial Viability of Solar Milk Cooling in Kenya, Solar-Powered Cold Rooms for Fruit and Vegetable Growers in Nigeria, Solar-Powered Milk Cooling, Energy Efficiency in Kenyan Tea Factories and Energy Auditing in Tea and Dairy Industries, Solar Bubble Dryer Optimization, Strengthening Post-Harvest Processes in Africa Using Improved Solar Drying, Solar-Powered Sesame Oil Production, Nurturing the Market Environment for Solar-Powered Irrigation Systems in India, RaSeed Solar-Powered Irrigation in Egypt, and Maximizing Use of SWP [Solar Water Pump] Technology in India. We combined the solar-powered milk cooling project that took place in Tunisia and the Kenya milk chilling into one case study and the two solar water pump projects in India into another. The GIZ pilot projects tend to be short (1–2 year) pilot efforts that focus on applying solar PV-based solutions to agricultural efforts, usually in Africa. Some projects were purely intended to refine a technology, some tested potential business models for disseminating a technology, and others involved a mix of piloting technologies and business models. Various academic departments at the University of Hohenheim received support for 5 of the 10 studies.

There are similarities and differences between the approach GIZ has adopted in supporting these 10 projects and the Powering Agriculture technology and business model innovation approach. Powering Agriculture awards are larger and most awardees are expected to move beyond initial piloting. The GIZ projects are focused on a more limited set of technologies and a recurring set of partners. While these projects therefore do not represent a formal comparison group for the Powering Agriculture 2013 and 2015 award cohorts, we have assessed them using similar methods.

1.3 Follow-on challenge: Water and Energy for Food (WE4F)

The PAEGC program was to close by the end of calendar 2019, but some projects have been extended to enable them to finish their grants. The donor partners will be funding similar projects under a new Grand Challenge, Water and Energy for Food (WE4F). WE4F will focus on the nexus of water, agriculture, and renewable energy, and will operate during the 2020s. It will capitalize on the resources and lessons from Securing Water for Food: A Grand Challenge for Development (SWFF) and PAEGC. It intends to support the most promising innovations and innovators identified and nurtured in those programs and support these innovations to grow and scale (WE4F ud.). The PAEGC partners requested this summative evaluation of PAEGC in part so that lessons from this evaluation can be used in the design and implementation of this new Grand Challenge.

1.4 Organization of this report

Following this Introduction, we discuss PAEGC's theory of change and the OECD's DAC principles. We then lay out the methodologies we employed to conduct this summative evaluation. As the case studies form the core of the assessment, the next section describes key features of the innovators: type of organization, type of innovation, location, etc. The fourth section presents our analysis of the outcomes generated by innovators. In the fifth section, we estimate the impacts of the projects on agricultural output or incomes, emissions of greenhouse gases, reductions in poverty, and improvements in gender equality. In the sixth section we assess other Powering Agriculture activities, including the Powering Agriculture Investment Alliance; technical assistance, training, and outreach; and knowledge management. In the seventh section, we provide feedback from the innovators and our own observations of the strengths and weaknesses of PAEGC processes in terms of selection of awardees, monitoring, and innovator support. We conclude with a series of recommendations pertaining to the future management of WE4F.

2. PAEGC's Theory of Change and the DAC Principles

2.1 PAEGC's Theory of Change

The concept of grand challenges for development is rooted in the belief that science and technology, when applied appropriately, can have transformational effects on international development, and that engaging the world in the quest for solutions is critical to instigating breakthroughs to solutions to hard development problems (USAID 2012c). A grand challenge is not just a problem statement, but a definable, quantifiable goal that can be achieved over a specified time frame (USAID 2012b). Grand challenges focus on surmounting key barriers to success through science and technology and by facilitating scaling. They predicate that substantial improvements in productivity, for example, are possible in developing countries through the development and wide-scale diffusion of new, cost-effective technologies or business solutions. A wide circle of talented individuals can be tapped from around the world to invent and improve on these solutions. Entrepreneurs from all parts of the world can be encouraged to set up organizations and businesses to produce and disseminate these technologies in developing countries. They are designed to make smart, small investments that help to move the needle on development programming. They bring in local partners that understand the local context. They leverage science and technology to which LMICs typically might not have access. They also leverage market dynamics. Those solutions that work well can be scaled to reach a large number of households. Grand challenges for development support the creation and development of self-perpetuating systems, rather than one-off inventions or interventions (USAID 2012c). Grand challenge solutions need to achieve scale, be sustainable, and utilize 21st century infrastructure—and beneficiaries need to be able to adopt them, if they are to be considered successful (USAID 2012c).

PAEGC has sought innovative approaches to accelerate the development and deployment of clean energy solutions to increase agricultural productivity or value in developing countries (PAEGC 2013). Historically, efforts to bolster the agriculture and energy sectors in developing countries were compartmentalized, often ignoring interdependencies between the two sectors. PAEGC was designed to identify and support solutions that would increase integration of renewable energy within each stage of agriculture supply chains: seeds, fertilizers, and feeds; irrigation; planting crops and raising livestock; storage and transport; processing; wholesaling, marketing, and retailing; and waste management. Greater use of clean energy in agriculture would also reduce emissions of greenhouse gases (PAEGC 2013). PAEGC posited that the development, commercialization, and wide-scale diffusion of new renewable energy technologies coupled with new agricultural technologies applied to agriculture or rural communities would:

- Enhance agricultural yields and productivity
- Decrease post-harvest losses
- Improve farmer and agribusiness income generating opportunities and revenues
- Increase energy efficiency within the operations of farms and agribusinesses

Implicit in PAEGC's theory of change was that innovators have not invented or commercialized these technologies in the past because of lack of knowledge of conditions in developing countries or inadequate support for research and development or commercialization of such technologies. Businesses have not scaled up promising renewable energy and other technologies in agriculture because of lack of capital or other support or the inability of potential customers to obtain financing to purchase these products. By providing funds and other support to selected innovators, PAEGC can help develop renewable energy and technologies for agriculture in developing countries, bring them to market, and encourage their rapid diffusion, resulting in increases in agricultural incomes, reductions in emissions of greenhouse gases, reductions in poverty, and improvements in gender equality.

This theory of change implies that under the PAEGC award innovators will be able to develop, test, or scale up innovations for wide-scale market adoption. Some innovators may use an award to focus on early stage technological development. Others will use funding from PAEGC plus other funding that can be leveraged during the period of the award, to take a technology through to market adoption—either during the award period itself or by cultivating a set of partners and attracting adequate capital to see the project through to commercialization post-award. This aspect of PAEGC’s theory of change focuses attention on the commercialization pathways of the innovators, mediated by the technology they are developing. It suggests that innovators intending to improve incrementally existing products already developed and being marketed pre-award or those intending to develop business models to make existing products available in new lower and middle income countries (LMIC) markets will be more likely to reach wide-scale adoption than innovators developing wholly new technologies or solutions. Sustainable results and scale will be achieved through the growth of businesses and business models that achieve commercial success. PAEGC does encourage *de novo* technology development projects that lead to valuable applications be taken forward into wide-scale adoption by others (e.g., through licensing or encouraging competitors to market a related product) even if the PAEGC-supported innovators themselves cannot bring the technology forward to wide-scale adoption. Some PAEGC funding is to support “leapfrog” or 21st Century technologies that help to solve development challenges associated with the use of renewable energy to foster increases in agricultural productivity or farmer incomes in LMICs. Many funded projects rely on newer technologies like solar photovoltaics, biogas systems and mobile services for scheduling access to the technologies and for payment to connect farmers and agricultural workers with new technologies that can increase agricultural productivity without requiring access to centralized infrastructure (energy, finance, communications) while avoiding or reducing emissions of pollutants (carbon dioxide and other pollutants from fossil fuels, wood, or charcoal). Initially, PAEGC focused on just measuring increases in incomes, reductions in greenhouse gas emissions, and diffusion of solutions as metrics of success, although the 2013 Technical Solution Evaluation Guidance stated that PAEGC would not fund projects that reinforced harmful gender norms and that projects should have measurable, gender-equitable impacts (PAEGC 2013). The 2015 Technical Evaluation Committee Guidance: Second Global Innovation Call elevated the importance of gender equality, making support for gender equality a feature that had to be included in all proposals (PAEGC 2015). In contrast, although reducing poverty is a major overall goal of all the partners, it has not been listed as an award criterion (PAEGC 2013; PAEGC 2015).

2.2 DAC Principles

Principles

In 1991, the OECD released a set of principles governing the evaluation of development assistance (OECD 1991). These criteria have since been refined to five criteria that should be followed when evaluating development assistance programs (OECD ud.). STPI developed a set of questions for this evaluation of PAEGC based on these principles. During Phase 1 of this project, the questions were refined through discussions with the PAEGC partners to the final set shown below.

1. **Relevance:** The extent to which the aid activity is suited to the priorities and policies of the target group, recipient, and donor. The following questions are useful in evaluating the relevance of a program or a project:
 - To what extent are the objectives of PAEGC still valid?
 - To what extent are the objectives of PAEGC addressing the needs and requirements of the beneficiaries, global priorities, partners’ and donors’ policies?

- Are the activities and outputs of PAEGC consistent with the overall goal and the attainment of its objectives?
 - Are the activities and outputs of PAEGC consistent with its intended impacts and effects?
- 2. Effectiveness:** A measure of the extent to which an aid activity attains its objectives. The following questions are useful in evaluating the effectiveness of a program or a project:
- To what extent were PAEGC's objectives achieved or are likely to be achieved?
 - What were the major factors influencing the achievement or non-achievement of PAEGC's objectives?
 - What is PAEGC's additionality? To what extent can results be solely attributed to PAEGC rather than PAEGC being one of several sources of support that catalyzed development and diffusion of innovations?
- 3. Efficiency:** Efficiency measures the outputs—qualitative and quantitative—in relation to the inputs. It is an economic term that signifies that the aid uses the least costly resources possible in order to achieve the desired results. This generally requires comparing alternative approaches to achieving the same outputs, to see whether the most efficient process has been adopted. The following questions are useful in evaluating the efficiency of a program or a project:
- Were the activities cost-efficient?
 - Were the objectives achieved on time?
 - Was PAEGC implemented in the most efficient way compared to alternatives with respect to the impact goals of increasing agricultural output and incomes, greenhouse gas mitigation, reducing poverty, and increasing gender equality?
- 4. Impact:** Impact is the positive and negative changes produced by a development intervention, directly or indirectly, intended or unintended. It includes the main impacts and effects resulting from the activity on the local social, economic, environmental and other development indicators. The examination should be concerned with both intended and unintended results and must also include the positive and negative impact of external factors, such as changes in terms of trade and financial conditions. The following questions are useful in evaluating the impact of a program or a project:
- What has happened as a result of the program or project?
 - What real difference has the activity made to the beneficiaries?
 - How many people have been affected?
 - Were there unintended outcomes (positive and negative) that resulted from PAEGC, and might there be future unintended consequences stemming from funded projects?
- 5. Sustainability:** Sustainability is concerned with measuring whether the benefits of an activity are likely to continue after donor funding has been withdrawn. Projects need to be environmentally as well as financially sustainable. The following questions are useful in evaluating the sustainability of a program or a project:
- To what extent did the benefits of a program or project continue after donor funding ceased?
 - What were the major factors that influenced the achievement or non-achievement of sustainability of the program or project?
 - Were the projects environmentally sustainable?
 - Did projects or the program as a whole lead to large-scale or systemic changes in participating countries that might contribute to reaching social or environmental sustainability goals?

STPI also used the OECD DAC framework components of efficiency, effectiveness, impact, and sustainability (with environmental sustainability indicators presented separately from post-award considerations and financial sustainability indicators) to develop an innovator success framework. That framework was used to assess the outcomes of PAEGC awards individually and then at the program level.

These OECD criteria do not specify a particular methodology or approach to assessing programs as long as the methods collect credible information to address these questions (OECD ud.). The OECD criteria have been used in previous USAID Grand Challenge-related evaluations, such as the SWFF impact evaluation (Hemson et al. 2018) and the PAEGC interim evaluation (Raetzell and Seidler 2016). They have also been adopted by PAEGC partners (Molund and Schill 2007).

DAC principles and the evaluation

We designed our methodology for the evaluation to conform to the DAC principles:

Relevance

The evaluation was designed to determine whether PAEGC is suited to the priorities of low-income farming communities and the innovators, and the goals of the partners. In particular, it attempted to determine the extent to which the objectives of PAEGC are still valid, and whether the innovations have been consistent with the goals of increasing agricultural output and incomes and reducing greenhouse gas emissions as well as reducing poverty and improving gender equality.

Effectiveness

The evaluation determined the extent to which the objectives were achieved or are likely to be achieved. It also determined the major factors that have influenced the achievement or non-achievement of the objectives.

Efficiency

The evaluation compared the costs of the program with the desired results. In particular, it assessed whether the activities were cost-efficient from the standpoint of the number and percentage of PAEGC projects that achieved their objectives and advanced toward commercialization, whether the objectives were achieved on time, and whether there is evidence that certain programmatic activities led to results in more cost-effective ways than others.

Impact

The evaluation focused on identifying positive and negative changes produced by PAEGC, in particular, the extent to which PAEGC-funded innovations have effected changes in agricultural output and incomes and reductions in greenhouse gases at the local level. It also identified unintended results. The evaluation took into consideration positive and negative impacts of external factors, such as reductions in the cost of solar panels and changes in local growing conditions. More specifically, the evaluation asked what has happened as a result of the innovations supported by PAEGC, and whether the innovations made a real difference to local agricultural communities, including on reducing poverty and improving gender equality.

Sustainability

The evaluation also addressed whether the innovations are environmentally as well as financially sustainable. More specifically, the evaluation determined the extent to which the benefits of PAEGC have continued or are likely to continue after the end of the program and the major factors that influenced the achievement or non-achievement of sustainability of the program or project.

3. Methodology

The core of the evaluation is an assessment of the 24 awards made to innovators, whom we divided into the 2013 and 2015 cohorts, and the ten awards funded by BMZ and managed by GIZ.⁷ The limited number of awards made by the program made it possible for STPI to complete case studies of all the funded innovators. The case studies were based on document reviews, academic and business literature about the markets and technologies targeted by the innovator, and interviews with innovators and individuals engaged in PAEGC, supplemented by site visits to some innovators, selected farmers who benefited from the project (beneficiaries), and equipment distributors. To assess these innovations, we compared them to existing technologies that farmers and other potential buyers currently use to address the needs targeted by the innovators' solutions. We also described changes in the environment in which these technologies are being offered in terms of public policy and general technological developments. In addition, eight case studies were developed from among the 10 GIZ-supported pilot projects. Two of these case studies grouped paired projects into a single case study (solar milk chilling in Tunisia and Kenya, and market development for solar-powered pumps in India through increasing utilization and developing the supply chain).

Each of the case studies was organized so as to answer the following questions:

- Who was the innovator and its partners? What was the project and what was its purpose?
- Into what market and social environment was the innovator trying to introduce its product? What are competing technologies?
- What were the performance characteristics of the technology and business model that each of the innovators intended to develop and mature?
- How far did the innovators succeed in reaching the program's intended outcomes (technology development, demonstrating commercial promise, and commercial scalability)?
- To what extent did the projects generate program impacts (increases in agricultural incomes, reductions in greenhouse gas emission, reductions in poverty, and improvements in gender equality)?
- What challenges did the project face?

The complete innovator interview protocol is provided in Appendix B below.

For the purposes of the evaluation, we organized the innovators into four groups of technologies: solar-powered irrigation, cooling and heating using renewable energy, mini-grids and micro-grids, and other. The activities of each of the innovators were judged in terms of outcomes: the progress achieved by the innovators in relation to their initial starting positions in terms of technology or product development (R&D and initial piloting), business (early adoption and commercialization), and diffusion (those primed for market growth and wide-scale adoption). We then assessed the impact of the projects on current and potential increases in agricultural output and incomes; current and potential reductions in emissions of greenhouse gases; reductions in poverty; and improvements in gender equality.

The evaluation also reviewed other programmatic activities related to training, the development of an entrepreneurial workforce, and fostering innovation in LMICs in the energy-agriculture nexus. In particular, STPI evaluated the GIZ Hub in Nairobi and other GIZ initiatives, especially knowledge management, in support of Powering Agriculture.

This evaluation concludes with an overall assessment of PAEGC, synthesizing the findings from these various sections. The figure below summarizes how the different aspects of STPI's evaluation methodology fit together.

⁷ A 25th award was given to Experience International. However, Experience International's participation in PAEGC ended after it was selected but before its project began.

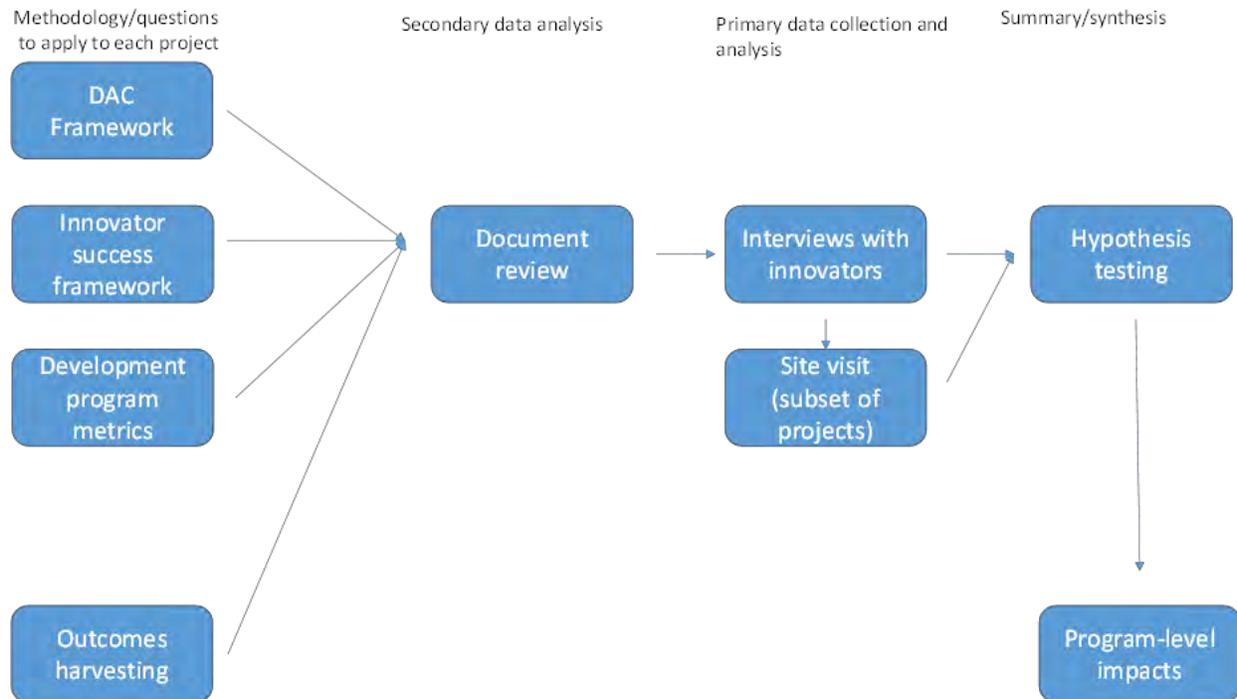


Figure 3.1 STPI methodology

3.1 Document review

STPI staff analyzed information collected by PAEGC, such as the documents and indicator data for the PAEGC awards held on the Powering Agriculture Webmo portal and fact sheets provided by GIZ for the projects it supported. The site visit reports by PASTO and the partners were particularly valuable. We drew on them heavily. The PASTO site visits included inspection of installations, interviews with beneficiaries, interviews with stakeholders, review of monitoring and evaluation, progress toward milestones, including progress towards developing the innovation, impact indicators, and investment mobilized (PAEGC 2018). The reports covered all but three of the projects funded by Powering Agriculture.⁸ We also conducted targeted literature reviews using both peer-reviewed literature and grey literature, including the innovators' Internet sites. The document reviews described each project and the context in which it operated: the team, the technology, and local conditions, such as local land tenure arrangements, primary crops, and agricultural techniques and technologies as well as observations from site visits conducted by PASTO. STPI staff used the results of the document reviews to develop a preliminary draft case study for each of the PAEGC projects. Results of the document reviews were also used to generate an individualized set of questions for each innovator team to be used during interviews with the innovators.

3.2 Interviews with innovators

STPI staff completed interviews with representatives of all 24 Powering Agriculture projects and two of the GIZ projects. Interviews with 11 of the innovators were conducted in person during the Social Capital

⁸ PASTO did not conduct site visits with Husk, the Universidad del Valle de Guatemala and Ariya, because those innovators had not constructed at least of half of their planned systems, which PAEGC had concluded is necessary to make a site visit worthwhile.

Markets conference (SOCAP 19) in San Francisco between October 22 and 25, 2019. We conducted face-to-face interviews with five innovators on our site visits to East Africa. We arranged telephone interviews or face-to-face meetings in Washington, D.C. with the rest of the innovators. In addition, STPI staff conducted interviews with participants in the Powering Agriculture Investment Alliance (AlphaMundi and Factor[e]) and with representatives of Tetra Tech and VentureWell, who provided technical and other assistance to Powering Agriculture awardees. STPI staff also completed interviews with over a dozen additional groups or beneficiaries, including farmers who purchased the innovations, to provide context related to Powering Agriculture innovator technologies. STPI also interviewed all the partners, except Duke Energy Corporation, but including OPIC.

Interviews typically lasted one hour, and were conducted by at least two members of the STPI team, with one leading the discussion and the other taking notes. STPI staff asked for (and usually received permission) to record the interviews purely for the purpose of assisting in note-taking. Once interviews were completed, STPI staff developed a set of summary notes (following the questions above) that captured the key insights from the interviews and provided those notes to the interviewees for their review and approval. Once the summary notes were approved, the interview recordings were deleted.

3.3 Site visits

Two STPI staff members conducted a set of site visits in Kenya and Uganda in November 2019. When planning the site visits, STPI made a conscious decision to avoid replicating the PASTO site visits, which were already very thorough, but instead provide complementary information. The STPI site visits were intended as a means by which the STPI team could better understand the technologies PAEGC innovators and GIZ pilot project partners had developed and the operations of innovators by meeting in country and visiting facilities. A second goal was to identify benefits from PAEGC-funded technologies and business models through interviews with beneficiaries. A third goal was to research the markets the innovators are addressing, including examining competing technologies, interviewing competitors, and discussing competing technologies with beneficiaries. A fourth goal was to provide additional context to deepen understanding of the local environment in which the PAEGC innovators operate. The final goal was to collect additional information on PAEGC impacts on agricultural and rural incomes, reducing greenhouse gas emissions, poverty alleviation, and improvements in gender equality.

The site visits began in Nairobi, where STPI staff met with 10 groups between November 4 and 10, 2019. STPI staff then went to Kisumu, Kenya, where they met with seven groups, including beneficiaries, between November 11 and 15. The site visits concluded in Kampala, Uganda, where STPI staff met with 10 groups between November 18 and 22 (Figure 2.2). Overall, STPI staff met with three government/donor groups (the GIZ Hub in Nairobi, the GIZ Green Innovation Center, and USAID mission personnel in Kenya), five Powering Agriculture innovator teams (KickStart, Ariya, SunCulture, Futurepump, and the University of Georgia), five other businesses (Sunny Irrigation, Ngere Tea Factory, Agsol, Enviu/Power Africa, and Azuri Technologies), two distributors (Davis & Shirtliff, SolarNow), and four other organizations (Millennial Legacy, Uganda Solar Energy Association, Biogas Solutions Uganda Limited, and Strathmore University). STPI staff also met with farmers who have used five Powering Agriculture technologies developed by innovators (products of Futurepump, KickStart, SunCulture, SunDanzer, and the University of Georgia).

Nearly half of the innovator interviews (9 of 20 groups) and 7 of the 11 farmer or other beneficiary interviews were associated with solar irrigation technologies.⁹ The site visits, therefore, provided direct

⁹ Note that there are “many-to-many” relationships among the number of “groups” and the number of interviewees. For example, four of the 10 meetings in the Uganda portion of the trip involved Thermogenn personnel, including a tour of the company’s R&D center, a tour of a vocational

insight into six of the 24 (25 percent) of the Powering Agriculture projects: Futurepump, KickStart, SunCulture, SunDanzer, University of Georgia, and Ariya.

Where information collected during site visits was directly relevant to a single case study, site visit findings were incorporated into that individual case study. Other site visit findings were more broadly applicable to particular outcome categories or technology sectors, and have been incorporated into the relevant outcome sections of the report.

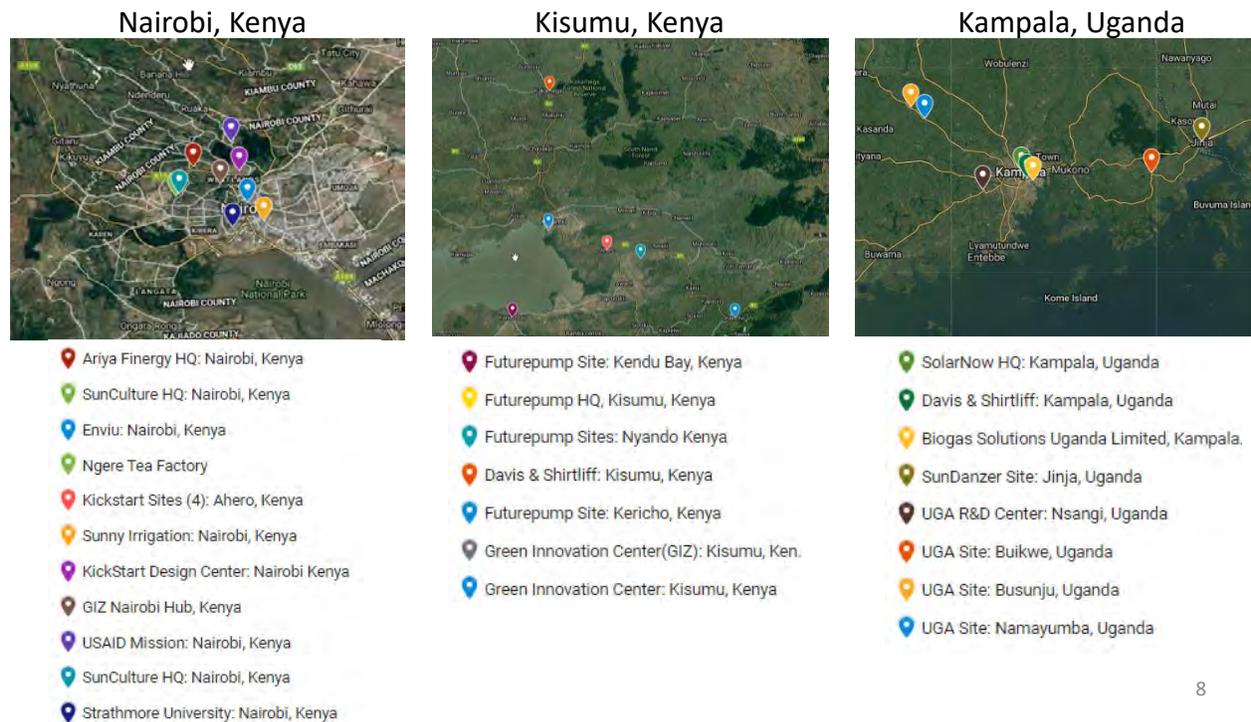


Figure 2.2 Locations of site visits

3.4 Case studies

Design

The case studies were designed to answer five sets of questions, where applicable:

1. The Technology
 - a. What did the innovator promise to achieve in terms of developing the technology?
 - b. How much progress did the innovator make in achieving the desired level of technological development?

institute that is constructing components for Thermogenn products, and two meetings among a total of three farmers. So, this set of meetings involves one "group" (Thermogenn), four meetings, and three farmers/beneficiaries.

- c. To what extent is the technology developed superior to existing technologies in terms of productivity, cost, reductions in greenhouse gas emissions, and other such factors?
2. Does the technology show commercial promise?
 - a. Have targeted beneficiaries purchased the technology? If so, how many?
 - b. What do users like and dislike about the technology?
 - c. Can the technology be manufactured at a commercial scale?
 - d. Can the technology be sold at a price competitive with existing alternatives?
 - e. Has the innovator been able to sell the product at a price that covers the costs of producing and selling it?
 - f. Has the innovator or is the innovator likely to produce and sell the product at a scale that will make the company a going concern?
3. Is the technology scalable?¹⁰
 - a. Does the innovator have access to sufficient capital to scale up production and sales?
 - b. Is demand such that either the innovator or other companies will be able to expand output to reach most potential users of the technology?
 - c. Does the innovator have a credible business plan to achieve this goal?
4. What role did PAEGC play in terms of supporting the innovator?
 - a. Was PAEGC funding used to fund the development of the technology, piloting the technology, or selling the technology?
 - b. What other sources of funding did the innovator use?
5. To what extent did the PAEGC-supported projects have the potential to, or (if projects had been commercialized) actually address program impacts (e.g., increasing incomes, reducing greenhouse gas emissions, decreasing poverty, and promoting gender equality)?

GIZ pilot projects

The 10 BMZ-supported pilot projects implemented by GIZ are similar in some ways to the PAEGC-funded projects awards. STPI staff conducted eight case studies for these awards similar to the 24 PAEGC full project awards, although the level of documentation available for the GIZ cases was less extensive. As mentioned above, STPI staff were able to conduct two interviews with GIZ-supported innovators. These cases provided insights into questions such as:

- To what extent did the two sets of awards differ with respect to developing technologies to the point of identifying whether the technologies have commercial potential? Is one approach clearly more cost-effective than the other?
- To what extent do the two sets of awards differ with respect to bringing pilot technologies to market?
- Do the two programs' differences in partnership strategies and technologies tested help to explain any differences in outcomes?

3.5 Assessment of outcomes

A key aspect of the outcomes assessment is to compute program-level summative results based on how well the projects have performed in developing promising technologies or solutions, and, where innovators have moved to commercialization, how well they have performed in terms of bringing their products to market. To generate these program-level summative results, we coded individual cases separately in terms of technology development, the development of the business or demonstration of

¹⁰ Because many of the PAEGC projects were intended to develop or pilot a technology rather than bring it to commercial scale during the award period, this third set of questions was applied only to those projects that reached or approached commercialization.

commercial promise, and diffusion or commercial scalability. These three categories are equivalent to the three Powering Agriculture Innovation Stages: initial piloting, early adoption/distribution, and market growth. In each case, we focused on what the innovators actually delivered—even if that was not the technology or business model originally proposed to Powering Agriculture. We categorized progress in each of these areas as Achieved, Mostly Achieved, Partially Achieved, and Not Achieved.

In the case of technology development (initial piloting), projects were coded as:

- “Achieved” if the innovator successfully developed the technology or business model, proved that it functioned in the field, and that it was ready to be brought to market.
- “Mostly achieved” if the technology or business model was almost fully developed, but needed additional design or manufacturing changes before it was ready to be brought to market.
- “Partially achieved” if the technology or business model needs extensive additional design work and testing before it would be considered suitable to bring to market.
- “Not achieved” if by the end of the Powering Agriculture award the innovator had yet to successfully develop the technology or business model.

We coded projects on the development of the business or demonstration of commercial progress (the early adoption/distribution stage), as follows:

- “Achieved” if the organization has made sales of the product, has revenue growth, and has shown promise of becoming cash positive or has attracted investment by an outside party.
- “Mostly achieved” if the product was successfully sold on a commercial market and the organization appears able to sell the product at a price above the cost of production and distribution.
- “Partially achieved” if the product was successfully sold on a commercial market but the organization cannot yet sell the product at a price above the cost of production and distribution and appears that it will have difficulty doing so.
- “Not achieved” if the product has not yet been sold commercially.

Diffusion (commercial scalability) was coded based upon growth in commercial sales and organizational performance. Projects were coded as:

- “Achieved” if the organization has achieved substantial product sales, sales are expanding rapidly to the point that the product is being purchased widely, and the innovator is solvent and is profitably selling the product or service.
- “Mostly achieved” if the product or service has large, growing sales, but the overall market is not yet fully developed and the company may not yet be selling the product at a profit.
- “Partially achieved” if the organization has made tangible product sales, but the market is nascent and the organization is not yet selling the product or service at a profit.
- “Not achieved” if the organization has not succeeded in selling the product or has exited the market.

Because many of the interviewees shared sensitive or proprietary information with STPI staff during the interviews, the individual case studies have not been included in the public version of this report. Instead, the outcomes and impacts sections of this report present summary findings that abstract from the case studies and interviews to track overall progress of PAEGC toward its goals.

3.6 Estimating impacts

For each case study, we attempted to provide information on four types of impacts:

1. Increases in agricultural output or incomes
2. Reductions in emissions of greenhouse gases

3. Reductions in poverty
4. Improvements in gender equality

In many instances, STPI was able to generate quantitative estimates for increases in agricultural incomes and reductions in emissions of greenhouse gases. These estimates by household or by project are designed to indicate the scale of the potential impact of the project at the product or household level. The more expansive projections are designed to identify those products that might have a more appreciable impact on incomes or reductions in emissions of greenhouse gases and those that are likely to have more modest impacts. We were only able to provide qualitative assessments of the impact of the projects on reducing poverty or improving gender equality.

Increases in agricultural output or incomes

Where information was available from previous site visits by PASTO and monitoring data provided by innovators, we reported increases in agricultural output or incomes potentially attributable to the technology provided by the PAEGC project. If the technology reduces the use of inputs, those savings are also credited to the project. In most instances, the increases in output or incomes or reductions in input use were self-reported. In these instances, we provided a detailed discussion of the extent to which the figures provided may be reliable.

Much of the information was fragmentary. Price, revenue, and income data were reported in many different currencies. We chose to report both the original information in the national currencies and that information converted into a common currency, in this case, U.S. dollars. We used average annual exchange rates for the year in question or, if no year was specified, the year 2018, to make the conversions. All exchange rates were taken from the IMF's International Financial Statistics database (IMF ud.).

Because of the fragmentary and unreliable nature of much of this self-reported information, in the case of solar-powered irrigation, we used market and financial data to calculate the likely minimum increases in annual incomes from these products. We drew on information from one of the innovators that sells its product on credit to make these calculations. The total payment by the farmer for the solar-powered pump is \$1,408 over 30 months. To make these payments, the pump would have to provide the farmer with \$563 a year in additional income. We adjusted rates of return for other solar-powered irrigation pumps based on their pumping capacities relative to this product. We assume that smaller or greater capacity leads to smaller or greater increases in agricultural output and therefore income.

Because so many of the innovators are still developing their technologies or businesses, many of the innovations are not yet at a stage where they can be evaluated in terms of their current impact on increased agricultural output or incomes. We can abstract, however, from the potential future market for these technologies as reported by the innovators. Projecting potential sales by those innovators who have entered the diffusion stage through 2025, we have estimated the associated gains in output and incomes by those innovations by that year.

Reductions in greenhouse gases

Drawing on the site visit reports by PASTO and the partners, monitoring data provided by innovators, technical information on diesel generators and other fossil-fuel driven alternatives, and standard international models for estimating greenhouse gas emissions from fossil fuels, we calculated the current achievements of the innovators in terms of reducing emissions of greenhouse gases. For projects involving solar power, biogas, and other biofuels, we estimated savings in fossil fuel use under the assumption that the electricity generated or thermal energy used had been produced by the combustion of diesel fuel, gasoline, or kerosene. We used standard estimates of greenhouse gas emissions per liter for these fossil fuels to estimate potential reductions (Natural Resources Canada ud). We did not make or

use lifecycle estimates of greenhouse gas emissions for the comparisons as we lacked the requisite data to make those computations.

STPI estimated potential future reductions in greenhouse gas emissions by using these estimates of reductions in greenhouse gas emissions for each innovator technology and the same assumptions concerning market penetration as in the assessment of potential future increases in agricultural incomes discussed above for the year 2025.

Reductions in poverty

STPI was unable to provide quantitative assessments of the actual or potential impact of the projects on reducing poverty. We did draw on site visit reports by PASTO and others, monitoring data provided by the innovators to PAEGC and anthropological, social, and economic studies of the LMIC target countries of the regions in which the projects operated, to identify which projects were more likely to have an impact on reducing poverty and to discuss the likely potential of the project to reduce poverty.

Improvements in gender equality

STPI drew on the PAEGC *Gender Integration Summary Report* (PAEGC 2016e), *Powering Agriculture: An Energy Grand Challenge for Development Final Report*, the final report for the project (PAEGC 2020), the *Powering Agriculture: An Energy Grand Challenge for Development Mid-Term Innovators' Assessment* (PAEGC 2016d), site visit reports by PASTO and others, and monitoring data on gender equality provided by the innovators to PAEGC to investigate potential improvements in gender equality stemming from the projects. Metrics included numbers and shares of women among purchasers or beneficiaries of the products and the share and number of women who are innovators or are employed by innovators. We attempted to corroborate this information during our telephone and face-to-face interviews with the innovators. STPI also utilized anthropological and sociological studies and information gathered during the site visits to assess the potential impact of the innovations on fostering gender equality.

Coding impacts

Drawing on these estimates of impacts, for each of the four impact categories STPI staff coded each project according to the following criteria:

- High impact: Demonstrated substantial impact (e.g., allowed beneficiaries to increase the number of cropping cycles, estimated annual greenhouse gas reductions in the thousands of metric tons of CO₂ equivalent per year or more than 2 metric tons per smallholder farmer per year, documented improvements in the livelihoods of poor farmers and of female farmers).
- Moderate impact: Demonstrated some impact (e.g., allows beneficiaries to shift from subsistence crops to market-valued crops, estimated annual greenhouse gas reductions of between 500 to 1,000 metric tons of CO₂ equivalent per year or 1-2 metric tons per smallholder farmer per year, strong efforts made to improve the livelihoods of poor farmers and female farmers even if no success could be documented). For gender impacts in particular, projects that focused on women in the design and implementation of the project were coded as “moderate” impact even if no lasting benefits to women were specifically identified.
- Low impact: Slight impacts within the impact categories (e.g., small reductions in farm input costs for fuel, estimated greenhouse gas reductions of less than 500 metric tons of CO₂ equivalent per year or less than 1 metric ton per farmer per year, limited efforts made to involve female farmers)
- No impact: No expectation that the project would have an impact in this category (e.g., project beneficiaries are middle-income farmers, so no poverty impact; no greenhouse gas emissions are avoided).

3.7 Assessment of other Powering Agriculture activities

Technical assistance, training, and outreach

STPI summarized available information from PAEGC annual reports, other documents from Webmo, and PAEGC partners regarding activities involving technical assistance, training, and outreach, and the impact of those activities. The summary had the purpose of describing the activities and identifying outputs (e.g., number of training activities, number of participants) where data were readily available. STPI also reviewed GIZ's Powering Agriculture supporting activities and interviewed Tetra Tech, VentureWell, and innovators concerning business and technical assistance under Powering Agriculture. We probed the extent to which innovators knew of these supporting activities, participated in them, and benefitted from them.

As part of the visit to Kenya, the STPI team visited the GIZ Hub to meet with staff and gain first-hand information regarding the GIZ Hub's activities and results to date. STPI staff also met with participants in one of the GIZ pilot projects—energy efficiency training for the Kenyan tea industry.

Knowledge management

One of the four components of PAEGC incorporates knowledge management. GIZ has led this effort. STPI drew on information provided by GIZ to describe and categorize the chief knowledge management products associated with Powering Agriculture. STPI then compared the types and sizes of the audiences that these products have reached in an effort to assess the effectiveness of this component of PAEGC.

Powering Agriculture Investment Alliance

STPI interviewed both AlphaMundi and Factor[e] about their activities under the Powering Agriculture Investment Alliance. Although it was infeasible to conduct full case studies of all of the AlphaMundi and Factor[e]-supported innovators, STPI was able, through the site visits, innovator interviews, and the interviews with the two organizations, to collect information on some of the companies in which they have invested, notably SunCulture, SolarNow, and Sistema.bio. STPI interviewed managers from these three companies and visited SolarNow offices in both Uganda and Kenya. STPI used information collected from all these sources to comment on the strengths and weaknesses of the Powering Agriculture Investment Alliance initiative.

3.8 PAEGC processes

While this summative evaluation focuses on PAEGC's outcomes, rather than its processes, through our document review, interviews, and site visits we garnered insights into the strengths and weaknesses of the program's processes. We also drew on two mid-term evaluations that were more targeted at assessing processes (Raetzell and Seidler 2016; Powering Agriculture 2016). The first of these was considered a "program focused evaluation" (Raetzell and Seidler 2016), and the other was considered an "innovator focused evaluation" (Powering Agriculture 2016). Our insights on processes are presented in terms of:

- Selection of Awardees
 - Project goals
 - Geographic distribution of awards
 - Focus on new entrants
- Monitoring
 - Monitoring processes

- Relevant indicators
 - Milestones
- Support for innovators
 - Powering Agriculture partners
 - PASTO and PAX
 - Powering Agriculture Investment Alliance

4. Description and analysis of funded projects

4.1 PAEGC projects

PAEGC initially funded a total of 25 projects in two calls, 12 in 2013 and 13 in 2015, but one project in the 2013 cohort (Experience International) was cancelled early on, so the total number of projects that proceeded was 24. Selection criteria differed somewhat between the two cohorts. As a consequence, we divide projects by these two cohorts. Table 4.1 lists each of the projects by cohort, location, and product.

Table 4.1 List of PAEGC projects by location and product

Innovator	Locations of Project	Product
2013 Cohort		
African Bamboo	Ethiopia	Flooring and biomass
Camco Advisory Services	Benin, Tanzania	Biomass-powered agricultural equipment and mini-grids
Earth Institute of Columbia University	Senegal	Micro-grid for solar irrigation
EarthSpark International	Haiti	Solar-powered mini-grids
ECO Consult	Jordan	Solar-powered hydroponic farming
iDE	Honduras, Nepal, Zambia	Solar-powered irrigation pump
Motivo Engineering	India	Solar-powered tractor
Promethean Power Systems	India	Solar-powered milk chiller
Rebound Technologies	Mozambique	Solar cooling for horticulture
SunDanzer Refrigeration	Kenya	Solar powered refrigeration
University of Georgia	Uganda	Thermized milk and evaporative cooling

Experience International ¹¹	Indonesia	Solar-powered fisheries chilling
2015 Cohort		
Ariya Finergy Limited	Kenya, Tanzania, Uganda	Solar powered mini-grids for large farms
Claro Energy	India	Solar-powered irrigation pumps
FuturePump	Kenya	Solar-powered irrigation pumps
University of Toronto	Bangladesh	Solar thermal aeration for fish farms
Horn of Africa	Ethiopia	Biogas-powered refrigeration
Husk Power Systems	Ghana, Nigeria	Hybrid biomass/solar mini-grids
ICU	Jordan, Lebanon	Solar-powered drip irrigation
iDE Bangladesh	Bangladesh	Solar-powered irrigation pumps
KickStart International	Kenya	Solar-powered irrigation pumps
SimGas	Kenya, Rwanda, Tanzania	Biogas digesters for household cooking and cooling milk for commercial sale
SunCulture	Kenya, Uganda, Benin, Senegal	Solar-powered irrigation pumps
Universidad del Valle de Guatemala	Guatemala	Solar powered mini-grids
Village Infrastructure Angels	Indonesia, Papua New Guinea, Philippines, Vanuatu	Solar powered agricultural processing equipment

Source: Data from PAEGC.

PAEGC provided \$11,588,124 for the 2013 cohort and \$12,883,302 for the 2015 cohort for a total of \$24,471,426. Disbursements for projects in the 2013 cohort ranged from \$355,000 to \$1,500,000. Nine projects in the 2015 cohort received less than \$500,000 in funds; four received more than \$1,500,000, resulting in a wider variation in funding size between the two cohorts (Table 4.2).

¹¹ Experience International's participation in PAEGC ended after it was selected but before the project began.

Table 4.2. Dollar value of PAEGC projects by cohort

Dollar Value	2013 Cohort	2015 Cohort
\$500,000 or less	1	9
\$500,000 to \$1 million	3	0
\$1 million to \$1.5 million	7	0
More than \$1.5 million	0	4
Total	11	13

Source: STPI analysis of PAEGC annual reports.

The 2013 awards generally had an expected period of performance of 3 to 4 years while the 2015 cohort's expected period of performance for individual projects was slightly shorter, between 2.5 and 3 years (Table 4.3). Most of the awards in the 2015 cohort have already received period-of-performance extensions, however, so in practice awards in both cohorts have been similar in length. Three projects in the 2013 cohort ended early: Experience International, whose project was cancelled after less than 1 year; CAMCO, whose project was cancelled more than a year early; and Rebound Technologies, whose project ended 6 months early (PAEGC 2020). Two projects in the 2013 cohort (UGA and SunDanzer) lasted more than 4 years, after period of performance extensions.

Table 4.3. PAEGC projects' periods of performance by cohort

Length of Time	2013 Cohort Initial	2013 Cohort Actual	2015 Cohort Initial	2015 Cohort Actual
2- 2.5 years	1	3	1	1
2.5 – 3 years	1	0	12	1
3 – 3.5 years	1	1	0	4
3.5 – 4 years	9	5	0	7
More than 4 years	0	2	0	0
Total	12	11	13	13

Source: STPI analysis of PAEGC annual reports.

4.2 PAEGC project characteristics

Recipients by region and country

Approximately half of the projects in each cohort targeted Africa; eight targeted Asia and Pacific Rim countries; three targeted Latin America and the Caribbean; and two targeted the Middle East (Figure 4.1). While most projects focused on a single region, several operated in more than one country: Village Infrastructure Angels works in Indonesia and Vanuatu; SunCulture operates in Kenya, Uganda, Benin, and Senegal; SimGas operated in Kenya and Tanzania; and iDE worked in Honduras, Nepal, and Zambia. Six of the projects operated in Kenya, four in Tanzania, three each in India and Uganda, and two each in Ethiopia, Zambia, Bangladesh, Indonesia, and Jordan. Innovators in for-profit companies have been most likely to work in more than one country (6 of 14). University-led innovators (5 of 6), non-profit innovators (4 of 5) and innovators headquartered in the United States or Europe (8 of 11 teams) are most likely to work in a single country.

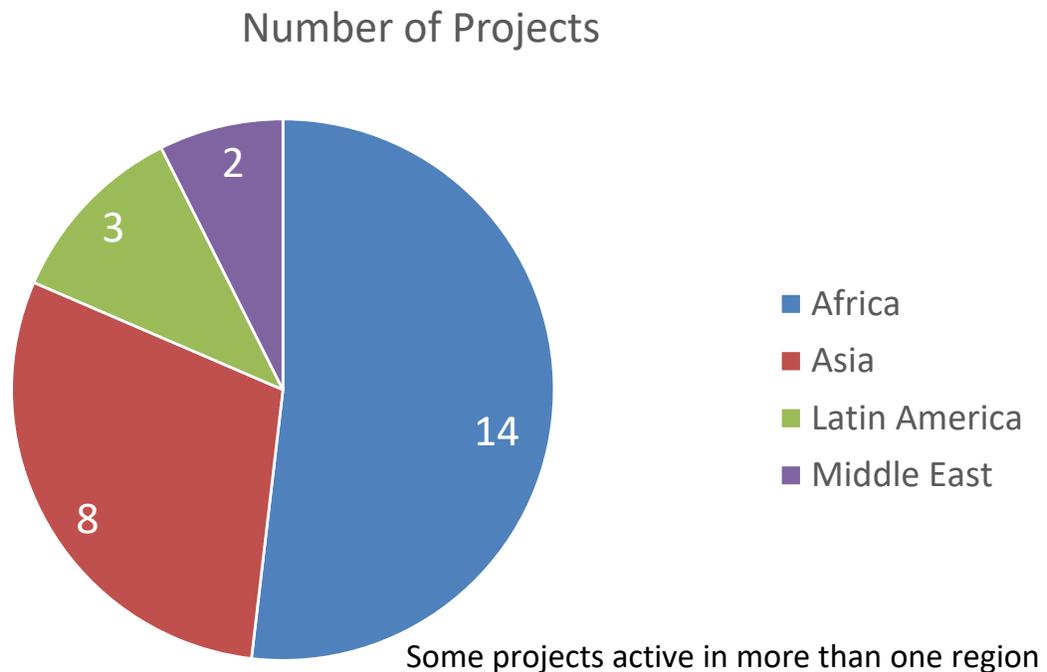


Figure 4.1 Distribution of PAEGC Projects by region

The World Bank collects statistics regarding income, employment, and fossil fuel use, among others, which serve as a baseline for understanding energy use and agricultural practices in a country (Table 4.4) (See Appendix C for this information by country). By definition, lower middle income countries have higher GDP per capita than lower income countries. They also have lower rates of absolute poverty. Their populations are more urban, less likely to be employed in agriculture, and use more liquid fuels per capita than in lower income countries. Latin America on average has much higher incomes, is more urbanized, and consumes more liquid fossil fuels per capita than does South Asia and Sub-Saharan Africa. While on average incomes and liquid fossil fuel use are greater in South Asia than in Sub-Saharan Africa, South Asia's population remains more rural than Sub-Saharan Africa's. Women in South Asia are also more likely to be involved in agriculture than women in Sub-Saharan Africa.

Table 4.4. Social conditions in PAEGC regions

	Lower Income Countries, All	Lower Middle Income Countries	Latin America and the Caribbean	South Asia	Sub-Saharan Africa
Population, (Billions, 2018)	0.71	3.02	0.64	1.81	1.08
GDP per capita (current 2018 \$'s)	\$813	\$2,219	\$9,024	\$1,906	\$1,574
% of population with incomes < \$1.90 per day (2015)	45%	14%	4%	16%*	41%
Rural population (% , 2018)	67%	59%	19%	66%	60%
Employment in agriculture (% of total)	63%	39%	14%	43%	54%
Women employed in agriculture (% of female employment)	66%	44%	7%	59%	55%
CO ₂ emissions (million metric tons, 2014)	196	4,185	1,913	2,516	823
CO ₂ emissions from liquid fuels (% , 2014)	57.1%	30.6%	58.1%	24.9%	29.9%

Source: World Bank, World Development Indicators.

Even within regions, there are substantial differences among countries with respect to the World Bank-collected social indicators. The Latin American countries in which Powering Agriculture has operated (Guatemala, Haiti, and Honduras) are poorer, more rural, and use less liquid fossil fuels per capita than the regional average; Haiti is by far the poorest of the three. There are substantial differences in the roles of women in this region as well. Less than 10 percent of employed women work in agriculture in Guatemala and Honduras, while more than one-third of employed women in Haiti do so.

In the South Asian countries in which PAEGC operated, both Bangladesh and Nepal consume much smaller amounts of liquid fossil fuels per capita than the regional average. Nepal is considerably poorer, more rural, and more likely for women to be employed in agriculture than the regional average.

Incomes, female employment in agriculture, and liquid fossil fuel use vary greatly across the countries in which Powering Agriculture operated. Average per capita income in Ghana (\$2,202) is four times that of Mozambique (\$490). In Mozambique and Uganda, the share of women employed in agriculture is 81 and 76 percent, respectively, compared with less than 30 percent in Ghana, Nigeria, and Senegal. Per capita emissions of greenhouse gases from consumption of liquid fossil fuels in Benin (0.47 metric ton) is more than five times the same emissions in Rwanda, Ethiopia, and Uganda (less than 0.1 metric ton of CO₂). Other countries in which Powering Agriculture works tend to be richer, more urbanized, consume more fossil fuels per capita, and tend to employ women in agriculture to a lesser extent, although Vanuatu is closer to the average for lower income countries in terms of the urbanization and female employment variables, despite an average per capita income comparable to the lower middle income country average.

Recipients by institutional type

More than 40 percent of the projects have been led by organizations headquartered in the United States or Europe, while nearly 40 percent have been led by organizations headquartered in LMICs (Table 4.5). Twenty percent have been led by organizations—mostly non-profits—headquartered in the United States or Europe but which have branches in the LMICs where the PAEGC projects have been implemented. The major difference between the two cohorts appears to be that a larger percentage of projects in the 2015 cohort that have been led by teams headquartered in a lower or middle income country (25 percent of the 2013 cohort; 6 of 13 or 46 percent of the 2015 cohort). Most recipients of funding have been for-profit companies.

Table 4.5. PAEGC team leadership by type of organization and location of team lead

Type of Organization	U.S./Europe	Combination of Developed and Developing Countries	Lower and Middle Income Countries	Total
For-profit	6	1	7	14
University	4	0	2	6
Other non-profit	1	4	0	5
Total	11	5	9	25

Source: STPI analysis of PAEGC annual reports.

Project focus and technologies

Nine projects, seven of which were in the 2013 cohort, focused on developing a technology. In contrast, nine projects in the 2015 cohort focused on developing a technology and a business model to commercialize the technology. Only four projects funded in the 2013 cohort attempted both of these activities. Two projects funded in the 2015 cohort focused solely on commercializing an existing

technology or solution; none of the projects funded in the 2013 cohort did so. Two projects characterized as being predominantly business model-focused (Ariya Finergy Limited and Futurepump from the 2015 cohort) received two of the three largest awards PAEGC has funded.

The majority of projects in both cohorts involved developing products around solar photovoltaic (PV) energy. Three in each cohort employed biomass/biogas and one in each cohort focused on solar thermal technologies. One 2015 innovator (Husk Power) is developing a hybrid system that combines solar PV and biomass technologies. Both solar thermal projects focused solely on technology development, as did half of the biogas projects, but 13 of the 17 solar PV projects were focused on developing their businesses as well as developing the technology. The solar thermal projects are both being developed by teams whose lead organization is in the United States or Europe while half of the biomass/biogas and 7 of the 17 solar PV projects are led by organizations headquartered in LMIC.

PAEGC characterizes the awards based upon technology application along the agricultural production chain. The most common application area is innovators developing approaches related to farm inputs (9 projects), followed by farm production and mechanization (6 projects), and residential and commercial energy production (6 projects) (Figure 4.2). Two projects are related to value-added agricultural processing and one project is related to agricultural aggregation, storage, and logistics. Among the 2013 cohort's projects, farm production and mechanization were most prevalent (4 of the 11 projects in the 2013 cohort). In contrast, 10 of the 13 projects in the 2015 cohort involved developing technologies related to farm inputs (6 of 13 projects) or energy production (4 of 13 projects).

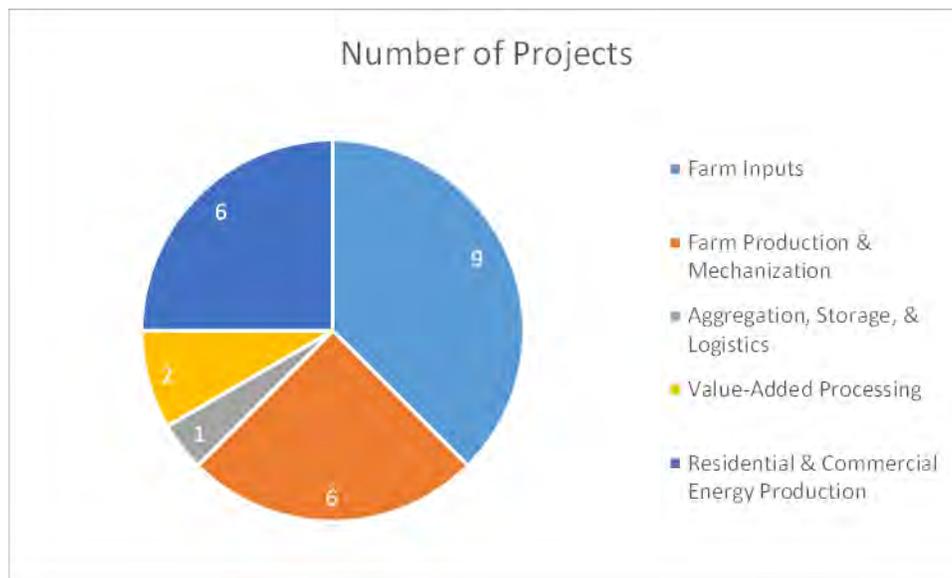


Figure 4.2 Distribution of PAEGC projects by technology

For the purposes of this evaluation, we adopted a different set of categories for the technologies: solar-powered irrigation, cooling and heating using renewable energy, mini-grids powered by renewable energy, and agricultural processing and other technologies. We found these four categories better reflect the activities of the innovators and the needs of the beneficiaries for the purposes of our analysis. Figure 4.3 shows the distribution of the projects based on these categories. As can be seen, mini-grids using renewable energy was the largest category with 7 projects, cooling or heating and solar-powered irrigation accounted for 6 projects a piece, and agricultural processing and other, which includes flooring, aeration of fish hatcheries, and solar powered agricultural equipment, accounted for 5 of the projects.

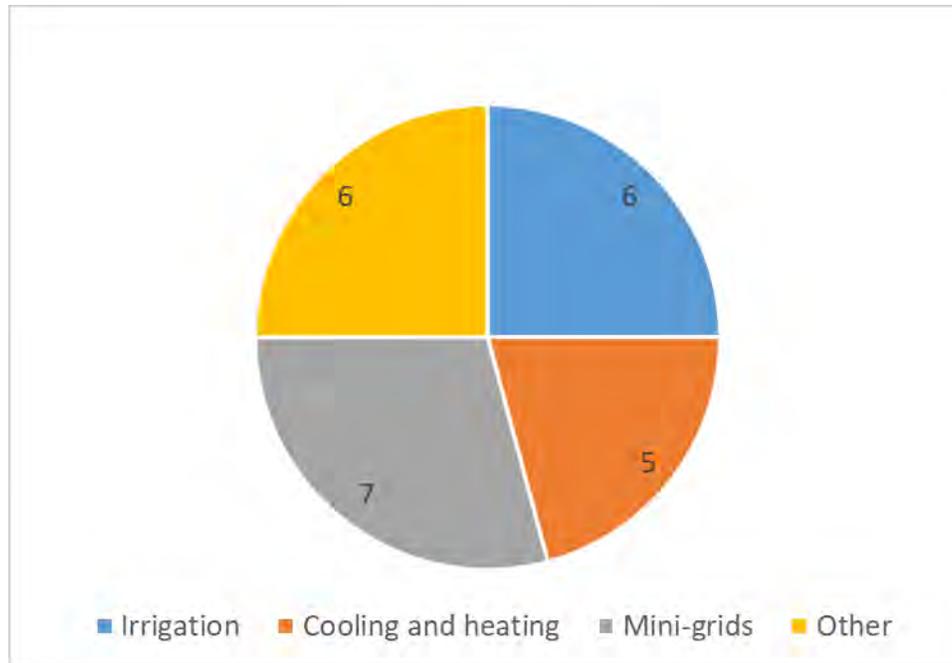


Figure 4.3 Alternative distribution of PAEGC projects by technology

Markets

Nearly half of the projects were concerned with horticulture (12 projects) followed by staple crops (6 projects) and dairy (5 projects) (Table 4.6). Other markets included aquaculture (3 projects), forestry (2 projects) and fruit cultivation (1 project). There was little difference between the two cohorts in terms of the markets targeted by recipients.

Table 4.6. PAEGC projects by market and cohort

Agricultural Market Segment	2013 Cohort	2015 Cohort
Horticulture	5	7
Staple Crops	2	4
Dairy	4	1
Other (Aquaculture, Forestry, Fruit)	3	3
Total	11	13

Source: STPI analysis of PAEGC annual reports.

Note: Experience International (2013 cohort) is not included in table due to early cancellation. Motivo (2013 cohort) is counted in all four market segment rows. ICU and Claro Energy (2015 cohort) are counted in the staple crops and horticulture rows.

4.3 GIZ pilot projects

The 10 pilot projects implemented by GIZ (grouped into 8 case studies) represent a different combination of innovators and technologies than the PAEGC awards (Table 4.7). Five of the 8 supported efforts in Sub-Saharan Africa, while two projects were conducted in Asia and two in the Middle East and North Africa.¹² Four of the 8 case studies were led by academic departments of the University of Hohenheim alongside local partners, while four were led by non-profit organizations or government organizations located in the country where the work was performed. Of the 8 case studies, 1 supported the installation of solar-powered irrigation systems, 2 fell into the cooling and heating category, while the other 5 supported other technologies—including solar-powered drying of agricultural produce, solar-powered processing of sesame seeds into sesame oil, training in conducting energy efficiency audits, and the development of business services to support the diffusion of solar-powered water pumps.

Table 4.7 List of GIZ pilot projects by location and product

Innovator	Locations of Project	Product
Indo-German Energy Programme Access to Energy in Rural Areas (IGEN-Access)	India	Ancillary services to promote solar-powered irrigation systems deployment
Kenya Tea Development Authority (KTDA)	Kenya	Energy auditing/energy efficiency
Regional Center for Renewable Energy and Energy Efficiency	Egypt	Solar-powered irrigation pump
Smallholders Foundation	Nigeria	Solar-powered refrigerated warehouse
University of Hohenheim	Philippines	Solar rice dryer
University of Hohenheim	Burkina Faso, Ghana, Kenya	Solar fruit and vegetable drying
University of Hohenheim	Kenya, Tunisia	Solar-powered milk chilling
University of Hohenheim	Burkina Faso	Solar-powered oil press

¹² The Solar Milk Chilling (SMC) in Tunisia and Kenya case is a combination of a technical pilot phase conducted in Tunisia (North Africa) and an economic assessment phase conducted in Kenya (Sub-Saharan Africa).

5. Outcomes

For the purposes of evaluating project outcomes, we have divided the projects into four categories based on technology: solar-powered irrigation, cooling and heating using renewable energy, mini-grids powered by renewable energy, and agricultural processing and other activities. The discussion for each category begins with a description of the market and social environment in which the technology is to be employed. We then assess the performance of the projects in each category in terms of technological development, business development, and diffusion. We include projects funded by both PAEGC and GIZ. We conclude with an overall assessment of outcomes from Powering Agriculture.

5.1 Solar-powered irrigation

In seven of the 32 case studies, the focus of the effort was on developing and deploying solar-powered irrigation systems.¹³ These projects had wide geographic reach, with 4 projects in Sub-Saharan Africa, 2 in the Middle East/North Africa, 2 in South Asia, and 1 in Latin America.¹⁴ The scale of the projects varied, ranging from projects installing multi-kilowatt solar arrays to power irrigation in mid-size farms through developing pumps for individual smallholder farmers to developing approaches for sharing a single solar-powered pumping system across farm communities.¹⁵

The environment for solar-powered irrigation

In most developing countries in Africa, Asia, and Latin America, farms are primarily owned by smallholders—farmers with small amounts of land, sometimes less than one-half hectare (one acre) in size. Most of these farmers employ traditional agricultural practices and rely on family labor. Farming is often their primary source of income. A second group of smallholder farmers, proportionately smaller in number, have larger land holdings, plots of over 2.25 hectares (5 acres). The primary source of income for these farmers is often a job or business in an urban area or earnings from trading, construction, or other non-agricultural activities near their farms. Their farms are a secondary source of income. These farmers often employ farmhands to cultivate their land.

In many farming regions, especially in Sub-Saharan Africa and South Asia, growing seasons are dictated by when the rains come. If crops are to be grown outside the rainy seasons, farmers need to irrigate. Irrigation makes it possible for these farmers to grow two or more additional crops per year. It also permits them to harvest crops during the dry seasons when prices are higher, boosting farm incomes.

Many countries in the Middle East and North Africa are arid, with limited, variable rainfall and abundant sunlight. These farmers have to use irrigation to grow their crops, but water is scarce and in many of these countries irrigation extracts underground water at rates that exceed replenishment by rainfall. Many of these farmers, including in countries like Egypt, Jordan and Lebanon where Powering Agriculture innovators operated, tend to use drip irrigation techniques. Even so, in these countries, the addition of solar-powered irrigation pumps can accelerate unsustainable withdrawals of underground water that is already taking place using gasoline or diesel pump technologies or pumps connected to the electrical grid. India, which receives substantially more rain than the Middle East and North Africa, has also been extracting ground water for irrigation in some regions at rates that exceed natural replenishment. However, because India already irrigates heavily, solar-powered pumps tend to substitute for gasoline or diesel pumps rather than provide new pumping capacity, so the net drain on the water table is less than if

¹³ iDE (2013), Futurepump, Claro Energy, ICU, KickStart International, SunCulture, and Solar-powered irrigation in Egypt (GIZ).

¹⁴ One PAEGC award in the 2013 cohort, iDE, operated in Honduras, Nepal, and Zambia.

¹⁵ Note that the Columbia Earth Institute case is included in the mini-grid section of the outcome's assessment, even though the power generated and shared was used for the purpose of irrigation.

the solar-powered pumps just added to overall capacity. In Africa, solar-powered pumps are usually additive: many farmers did not previously irrigate. However, water tables in western Kenya, Uganda, and elsewhere in East Africa are not as stressed as in India and the Middle East and North Africa.

The market for solar-powered irrigation

Prior to the emergence of solar-powered irrigation pumps, smallholders in Africa relied on the rains or used manually powered irrigation pumps to water their fields. Gasoline or diesel-powered pumps were confined to wealthier farmers with larger landholdings. A few fortunate farmers had access to electricity from the grid that they could use to power electric pumps. Some countries had invested in traditional, large-scale irrigation systems. These typically utilized flood irrigation techniques.

In South Asia, governments, especially India's, have subsidized the purchase and operation of irrigation pumps. In India, the electricity prices charged to farmers have been below the full cost of generation. Throughout South Asia, farmers often do not pay all of their electric power bills and are frequently delinquent, yet government-owned utilities do not cut them off, but continue to provide them with electricity. India has also heavily subsidized diesel fuel purchases by farmers.

Technological development for solar-powered irrigation

Over the course of the last decade, an expanding assortment of solar-powered pumps, many of them developed with support from Powering Agriculture, has become available to smallholders in Africa, a region where traditional irrigation systems had been less common than in other regions, and in South Asia, where irrigation has been more common. Of the seven awardees (6 PAEGC, 1 GIZ), six fully achieved the development of a solar-powered irrigation technology, mostly along the lines described in their original proposals; one mostly achieved its goal. Three new families of solar irrigation pumps were developed: Futurepump's Sunflower SF1 and SF2, initially piloted through a 2013 PAEGC award to iDE



Figure 5.1 KickStart pump used to water a farmer's greenhouse in Kisumu, Kenya

Source: Thrift and Crane 2019

and then refined through the 2015 Futurepump award; the KickStart MoneyMaker; and the SunCulture RainMaker line of pumps (RainMaker2, RainMaker2 Direct).

These three organizations target different markets. SunCulture's RainMaker2 pump is intended for smallholders with larger holdings, while its RainMaker2 Direct is intended for smaller holdings owned by the less affluent segments of the smallholder market (Jacobus and Matossian 2019). The KickStart and Futurepump solar irrigation pumps use lower-wattage solar arrays, draw water at lower flow rates and from shallower water sources, and cost less to purchase than the Rainmaker 2 (Mashnik et al. 2017). Both companies have targeted poorer smallholder farmers.

Geographically, areas in western Kenya have higher water tables that are the easier to reach than in other parts of Kenya (Holthaus et al.

2017). This is the region where Futurepump has been concentrating its efforts (USAID 2019).

Claro Energy piloted solar trolleys as part of the development of a pay-per-use irrigation service that uses a portable solar-powered pump. Two projects used commodity solar PV systems as part of pilot installations of solar irrigation systems in North Africa and the Middle East: ICU's 2015 Powering

Agriculture award supported pilot installations in Lebanon and Jordan, while a 2014-2015 GIZ pilot installed a 55-kilowatt solar array in the Egyptian desert for pumps that consume 37 kilowatts of power.

Development of the business for solar-powered irrigation

STPI judged two innovators as having completely achieved the goal of developing their businesses. Both companies are successfully selling their pumps at price points that cover their costs of production and installation, roughly \$700 per pump and \$960 to \$1,200, respectively. One innovator's financing system allows farmers to amortize the cost of their pumps over a 3-year period. The other has struggled to develop financing options its distributors could use to allow farmers to amortize the cost of its pumps.

A third innovator mostly achieved its business goals. It had planned to be able to offer its pump at a price comparable to gasoline or diesel pumps, \$150 to \$200, but has had to price it at \$420. The innovator plans to sell the pump with a 1-year warranty and has piloted financing approaches for its pumps in addition to direct cash sales. Distributors did not find its original pay-as-you-go software to be a compelling sales feature.

All three of these manufacturers are facing heightened competition from other manufacturers. Holthaus et al. reference a \$350 solar pump offered by Chloride Exide and a \$1,500 pump offered by Davis and Shirtliff (Holthaus et al 2017). Davis and Shirtliff introduced a lower-cost pump in mid-2019 under its own brand (Dayliff) that is sold at a price competitive with Futurepump and SunCulture.

STPI judged three other innovators as having mostly achieved the business development stage. In two cases, innovators attempted to sell their products in more than one country, but were unable to sell their products in all their target markets. The iDE award that served as a precursor to the Futurepump award explored the feasibility of selling its Sunflower pump in Latin American, South Asian, and Sub-Saharan African markets. In Honduras, iDE found that farmers were unwilling to pay for solar irrigation pumps because they had become accustomed to receiving services and equipment, like solar-powered irrigation pumps, for free from international donors or the government. While ICU's installation of solar-powered pumps at six demonstration sites in Lebanon showed farmers could decrease fuel costs and increase their yields over a moderate payback period, demonstrations in Jordan encountered difficulties—access to water was more limited, financing solar projects more difficult, and development aid appears to have constrained the growth of a private sector market for solar irrigation technologies because farmers expect that foreign assistance would provide these systems at no cost to them.

Claro has mostly achieved its business development effort, although the effort remained ongoing as of the end of 2019. The company has 100 solar trolleys in the field and offers customers the option to schedule irrigation service (where an operator conducts irrigation operations at a designated location and time) or to rent a trolley. Claro estimates that if its trolleys are utilized 100–120 hours per year at 3 hours per day, it will break even, but insufficient time had elapsed to establish that its pumps are being sufficiently utilized for Claro to make a profit. The Egyptian GIZ pilot only partially achieved its business case, but that project was intended purely as a technical test. While the pilot was successful, there appears to have been no additional installations nor an effort to support installations on other farms.

Diffusion for solar-powered irrigation

Two of the awardees developing solar irrigation pumps for the Sub-Saharan African smallholder market, Futurepump and SunCulture, have mostly achieved goals for diffusion, although their products address different groups of farmers and different geographical markets. Over the last few years, the overall market for solar-powered irrigation pumps has been growing and the sales of these two companies have helped drive this growth. Sales for both companies have been on the order of thousands of units per year. Both have been able to sell their products at a price that covers production and installation costs. Futurepump has expanded its operations from its initial focus on Kenya to many countries across East and West

Africa. SunCulture has sold several thousand pumps, predominantly of the RainMaker 2. Most sales have been in Kenya, but the company has expanded into Uganda and has begun to explore sales in Senegal and Ivory Coast. As of the end of 2019, KickStart had sold several hundred of its MoneyMaker pumps, primarily in Kenya.

In addition to KickStart, the ICU project and Claro were judged to have partially achieved diffusion goals. Solaris, ICU's Lebanese installation partner, has continued to install solar PV-powered irrigation systems subsequent to the completion of the award, and has expanded its staff and increased its revenues. Interviewees report that other companies have also begun to install solar irrigation systems in Lebanon as well. Claro has purchased a number of solar trolleys that it has deployed, but is still determining how profitable the technology is likely to be.

We identified two examples of market stimulation outcomes in solar-powered irrigation. The iDE 2013 Powering Agriculture award led to the spin-out of Futurepump, which has gone on to receive its own Powering Agriculture award and to develop the Sunflower line of pumps for commercialization. As noted above, Futurepump's success appears to have encouraged Davis & Shirtliff, Futurepump's first-tier distributor in Kenya, to develop its own line of solar-powered irrigation pumps.



Figure 5.2 Futurepump's Sunflower 2 pump at Davis and Shirtliff distributor

Source: Thrift and Crane 2019b

Findings for solar-powered irrigation

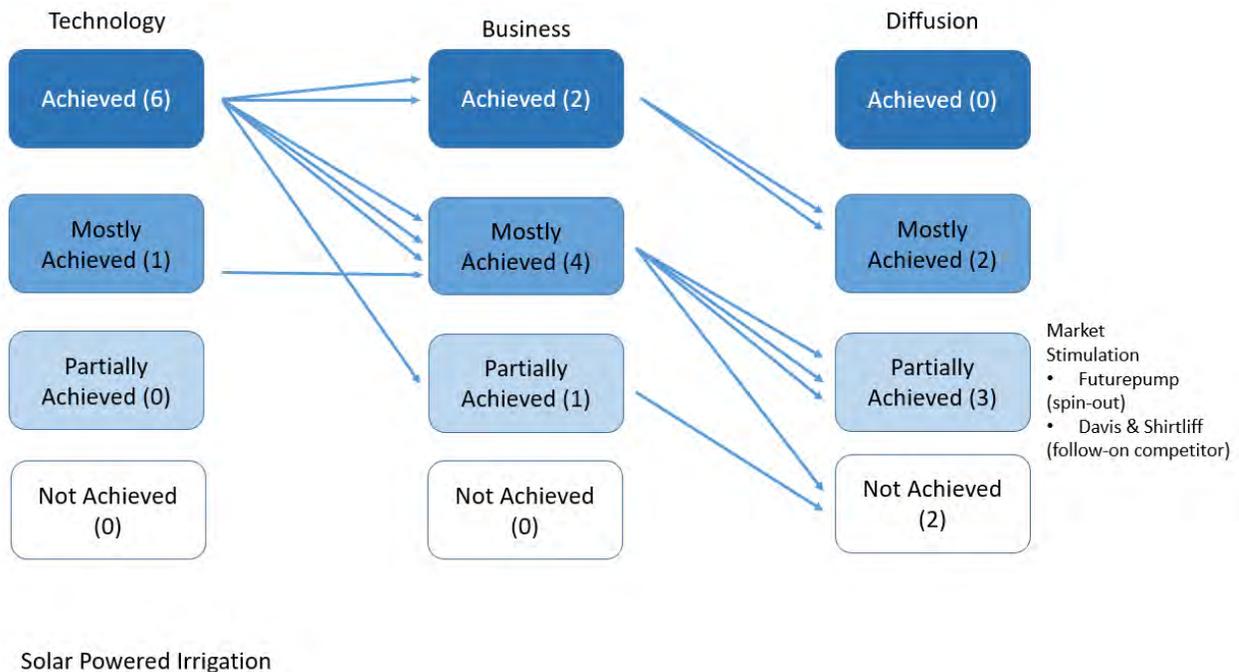


Figure 5.3 Outcomes of solar-powered irrigation cases

Powering Agriculture support has been valuable in the development of the solar-powered irrigation market in Africa and South Asia (Figure 5.3). Innovators have introduced products catering to a variety of hydrological conditions and farm sizes. For the most part, they have been selling their products and services at prices that cover costs. Some companies have enjoyed growing sales and have been selling thousands of pumps. The expanding market has attracted new entrants. Even if these new entrants come to dominate the market the Powering Agriculture-supported innovators will have helped to catalyze market development.

5.2 Cooling and heating technologies

Nine of the 32 STPI case studies fell into the cooling and heating technologies category.¹⁶ The focus of the effort was on developing and deploying cooling systems powered by renewable energy. Seven of the projects were located in Sub-Saharan Africa, one in North Africa, one in South Asia, and one in Southeast Asia.¹⁷ The scale of the projects varied, ranging from projects developing cooling solutions for individual smallholder farmers (SimGas, SunDanzer, Rebound, and University of Georgia) to systems intended for village/collective use (Promethean, Smallholders Foundation, University of Hohenheim).

The environment for cooling and heating technologies

Farmers in LMIC without access to household electricity face challenges in storing and preserving food. Every year a large share of perishable foods in LMICs is wasted because of lack of refrigeration or unreliable refrigerated supply networks, especially for dairy products, which must be cooled within hours of milking or else bacterial growth renders the milk unsafe to drink. The challenge is made more acute by the time required to transport raw milk to centers where cooling is available: without refrigeration milk and produce may not reach a chilling center in time if farmers bring their milk to centers on foot. Even where chilling technology is available—at collection centers or in urban areas with access to electricity from the grid—the need for uninterrupted chilling requires the use of diesel generators to provide power because of frequent interruptions to electricity from the grid, which add to costs and contribute to pollution.

The market for cooling and heating technologies

Smallholder dairy farmers in South Asia and Sub-Saharan Africa typically have five or fewer cows. Farmers milk the cows twice per day, in the morning and evening. Commercial dairies typically collect milk once a day in the morning because of the cost of collecting milk twice a day and because of the poor quality and lack of lighting on roads, which make driving in the evening particularly dangerous. Due to the lack of on-farm refrigeration, farmers are unable to sell evening milk to commercial dairies, which tend to pay higher prices than alternative markets for evening milk. In the absence of commercial sales, farmers sell to neighbors at lower prices, consume the milk themselves, or feed it to livestock. In urban areas and some villages, hawkers purchase some milk for evening sales; sometimes they pay as much or more than commercial dairies. However, they are often unreliable; they collect milk some days, but on other days they do not, so farmers are unable to count on income from such sales.

Many of the Powering Agriculture awards in this group targeted smallholders without access to cooling technologies. Innovators developed and deployed a range of solutions to address the cooling challenge. The GIZ pilot projects developed relatively simple solar PV-based technologies. The University of Hohenheim solar milk chiller (SMC) used a commercial freezer, paired with a solar PV power source, to freeze ice, which was placed in the outer ring of a 50-liter milk can to chill milk for collection. The

¹⁶ Promethean Power Systems, Rebound Technologies, SunDanzer Refrigeration, University of Georgia, SimGas, GIZ pilot: Solar-powered bubble dryer, GIZ pilot: Solar drying in Africa, GIZ pilot: Solar milk chilling in Tunisia and Kenya, and GIZ pilot: Solar-powered cold rooms in Nigeria.

¹⁷ The GIZ pilot solar milk chilling project conducted its pilot phase in Tunisia and its market demonstration/business development phase in Kenya.

Smallholders Foundation's 19.8-cubic meter solar-powered cold room (SPCR) can store up to 100 plastic 20-kilogram crates of fruits and vegetables. The refrigeration unit is powered by 5.5 kW of rooftop solar panels with a set of long lasting deep-cycle batteries that allow the refrigerator to operate for up to 3 days when fully charged.



Figure 5.4 Thermogenn's Evakuula at UGA's Thermogenn Research and Development Center

Source: Thrift and Crane 2019c

Two innovators developed biogas-based technologies for milk chilling. The University of Georgia developed a two-phase approach that includes a biogas-powered thermization process to reduce bacterial counts in raw milk and an evaporative cooling chamber to chill the milk and reduce the temperature until it is able to be transported to milk processing facilities. SimGas attempted a different approach that produced gas from cow manure, which was used to directly power the chiller.

The other three Powering Agriculture innovators used solar PV as the energy source for their distinct approaches. Promethean's core technology is a thermal energy storage system charged through intermittent connections to the electrical grid. The company explored using solar PV as the mechanism for charging the thermal battery. SunDanzer paired solar PV with a phase-change material to develop a refrigerator to freeze ice on the walls of a freezer that cools the refrigerator chest, thus cooling the aluminum milk cans within the chest. Rebound used solar PV as the basis for a wholly different cooling approach—freeze point suppression—where water is frozen, mixed with a freeze suppressant to create a refrigerant, the refrigerant absorbs heat and keeps products cold, and then the freeze suppressant and water are separated to begin the cycle anew.

Technological development for cooling and heating technologies

STPI assessed 6 of the 9 awardees as having achieved the development of their technologies, 2 mostly achieved development, and 1, Rebound Technologies, partially achieved development of its technology. Rebound halted the development of its SunChill™ product after installing one prototype at a pilot location. It concluded that the cost of the system was too high for its target market. Rebound did, however, go on to develop a large scale commercial refrigeration system called IcePoint™ that drew on the technology developed for SunChill™.

Of the awardees that achieved their technological goals, the University of Georgia developed a biogas-powered evaporative milk cooler called "EvaKuula," which uses biogas or other fuels to heat fresh milk, killing the bacteria. EvaKuula then uses evaporative cooling to chill and preserve the milk for market. Other cooling projects that achieved their technological goals included the University of Hohenheim pilot of a solar milk chilling technology in Tunisia, which was based on cooling units that have been tested for other devices, and the prototype Smallholders Foundation's cold room installed at a market location in Nigeria. After encountering several initial technological challenges, SunDanzer succeeded in developing a solar-powered freezer. Promethean developed solar-powered auxiliary functions for its commercial milk chillers after finding that a solar photovoltaic-powered version of its thermal battery-based chiller intended

for use in small villages was not viable due to its high cost and the large size (4 kilowatt) of the required solar array that inhibited siting.

In two cases, in which we judged the innovator as having mostly achieved the development of the technology, the innovator found that the technology was unsuitable for the target market. SimGas eventually developed a working biodigester, but its biogas-powered milk chiller never went beyond the prototype stage and appears to have continued to have problems. The University of Hohenheim's solar dryer for fruits and vegetables proved unsuitable for high value commodities like fruits and cannot be used to dry a mix of crops from different producers.



Figure 5.5. Promethean Dairy Solutions: Conventional Milk Chiller (CMC) and Rapid Milk Chiller (RMC)

Source: Mashnik 2016

Business development for cooling and heating technologies

None of the projects completely achieved the development of a business tied to the technologies. Three projects mostly achieved the development of a business: Promethean, GIZ's solar milking chilling project in Tunisia and Kenya, and its solar-powered cold rooms in Nigeria. All three of the projects sold their products at cost recovery prices or, in the case of the cold rooms, profitably leased refrigerated space. Promethean developed an option for customers to add a 1-kilowatt solar array to their core thermal battery-based system to power various subsidiary equipment such as the unit's controls, the milk tank agitator and the pumps (e.g., to transfer the milk from the collection center chiller to the tanker truck). The solar array would serve as a backup in case grid electricity was not available, replacing a diesel backup. While Promethean developed the technology and it is available for commercial sale, interviewees noted that Promethean has sold very few installations because its cost is high relative to the value that it provides. However, Promethean's core business selling milk chillers that continue to cool when the power is off remains strong. PAEGC was instrumental in assisting Promethean to expand sales of these core products into new markets, including Bangladesh.

Although the University of Hohenheim SMC has been sold commercially and has the potential to be sold profitably, the market acceptance study of the product identified complications in the business model for the chiller. Farmers needed a more modular approach rather than a one-size fits all solution. Milk yields per cow vary seasonally—with lower yields during the dry season—so that the number of farmers participating in the cooperative's efforts would also need to vary in order to fill the milk cans completely. Based on this finding, the University of Hohenheim developed a do-it-yourself (DIY) training course in which participants are trained to configure and build cooling units with materials that can be locally sourced. Moreover, installing the SMC had dynamic effects on the local milk market. Cooperatives that

installed the SMC saw farmers' incomes increase, which led to increased milk production, which led to demand for milk cooling that exceeded the capacity of the system.

In the case of the Smallholders Foundation cold room project in Nigeria, the project was able to fill the cold room to capacity while charging a market price to farmers that would result in a 3-year payback period for the cold room.

All but two of the remaining projects fell into the "partially achieved" category. In most cases, the products have not been able to be sold at a price that covers the full cost of production and distribution. In other cases, the project had made little effort to market their products. STPI considered the biogas-based systems developed by the University of Georgia and SimGas to have partially achieved goals at the business development stage. Beneficiaries considered the EvaKuula to be a useful product, but noted that the price would need to be reduced by two-thirds, before it might be commercially successful.

SimGas sold many units, but the price for its product (\$1,000) was too high for the potential market; the product could not be sold at a price that covered costs. In addition, SimGas encountered difficulties in getting paid when it sold the product on credit. Rebound completed the pilot installation of the SunChill system, but completed the award without attempting to sell the product commercially.

The solar-powered bubble dryer and the solar drying pilot projects did not appear to have made any efforts to bring the products to market themselves. The University of Hohenheim has worked, however, with a company (GrainPro), which sells a version of the bubble dryer commercially.

Diffusion for cooling and heating technologies

We assessed five of the nine innovators as partially achieving elements of diffusion: Promethean, SunDanzer, the University of Georgia, and GIZ's pilot projects on solar milk chilling technology and solar-powered cold rooms in Nigeria. In each case, the innovators have sold a number of their products on the market, but the markets for these products remain nascent.

Overall, Promethean is one of the most successful companies among all the innovators. As of 2019, it reported cumulative sales of 1,200 commercial chillers. It sells approximately 300 to 400 units per year and has enjoyed 10 to 15 percent annual sales growth. However, sales of the technology it developed under its Powering Agriculture grant, a 1-kilowatt solar array to power various subsidiary equipment, have been modest. This market has not yet materialized.

SunDanzer sold a number of its units, but found that the market for solar refrigeration in Kenya has not yet materialized. The market was not as large as expected and the potential benefits to farmers and their interest in acquiring the system had been overestimated. SunDanzer sold some of its unsold units from the project to SolarNow at a steep discount, which SolarNow has in great measure passed on to its customers. The award established that there may be a market for individual solar refrigeration in Kenya, but at a much lower price point than SunDanzer could meet.

The University of Hohenheim group licensed its solar milk chilling technology to a German company, Phaesun, which sells a "BOSS Kit Milky Way" with a 600-watt solar array and a 30-liter milk can. It is not clear how many units Phaesun has sold. Solar-powered refrigerators were not listed on its product website in 2020 (Phaesun ud.). The university also spun out a company, Solar Cooling Engineering, that sells solar milk chilling components that can be designed into systems. Solar Cooling Engineering also offers DIY trainings, where trainees learn how to use publicly available sizing tools and plans and locally sourceable materials to assemble cooling units. As these developments took place in 2019, it is premature to fully assess what has been achieved.

The Smallholders Foundation spun out a company, ColdHubs, in 2017 to commercialize the solar-powered cold rooms technology. In 2018 and in 2019 GIZ provided technical assistance to ColdHubs to scale its business model. ColdHubs also received assistance from USAID's Partnering for Innovation program to install another 20 SPCR units at 10 sites in Nigeria. As the company is still in the initial stages

of commercializing its technology, STPI assessed progress on diffusion for this project as partially achieved. A GIZ-supported business analysis suggests that a combination of operating some cooling systems directly and selling franchise rights could lead to a credible expansion plan.

In our view, the other innovators did not achieve diffusion. Rebound did not attempt to sell its technology. Neither did the innovators leading GIZ’s solar bubble dryer or the solar fruit dryer pilot projects. SimGas sold substantial numbers of its biogas refrigerator in Kenya, but went bankrupt in 2018 because of customer defaults on the loans it had advanced to sell its product.

This group is notable for its Market Stimulation outcomes. Three new companies have spun out of the nine awards: ColdHubs, Solar Cooling Engineering, and Thermogenn. Using some technological aspects and lessons learned through the creation of the SunChill™ technology, Rebound went on to develop a large-scale commercial refrigeration system called the IcePoint™ and trademarked the technology in 2014. Rebound is maturing IcePoint™ with the intention of beginning commercial sales in 2020.

SunDanzer purposely has not patented its products, and has started to see others entering the market with similar refrigeration systems. SunDanzer considers this result to be a programmatic success. As SunDanzer’s core market is refrigerated systems for medical use, if another company can develop a cheaper product for LMIC use based on SunDanzer’s design and have success distributing the product, it would not drastically affect SunDanzer as a company while providing benefits to smallholder farmers.

Innovators have also begun piloting other technologies for LMIC country use that are related to their Powering Agriculture funding. SunDanzer received follow-on grant funding to develop a smaller-scale version of its solar refrigerator as well as refrigeration systems to cool fish and for walk-in coolers.

Promethean is developing a miniaturized version of its chiller that could be used by individual villages for milk storage, but also could serve as the cooling unit for a refrigerated truck for milk transport.

Findings for cooling and heating technologies

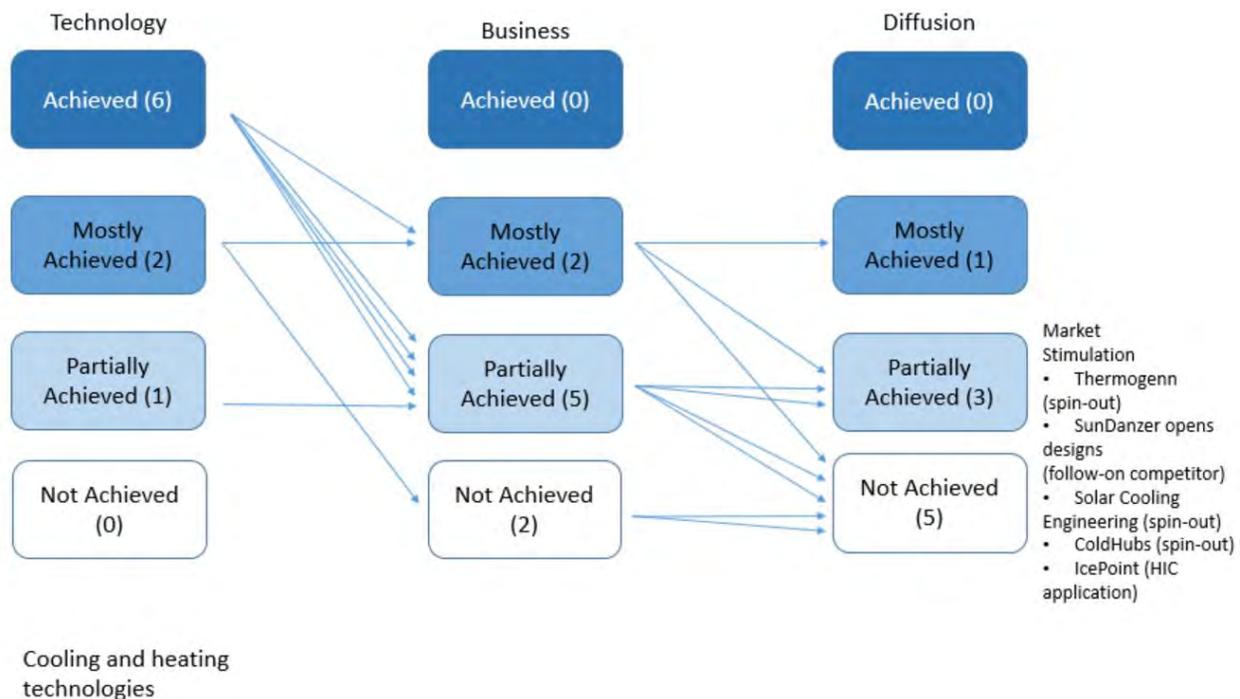


Figure 5.6 Outcomes of cooling and heating technologies

Cooling and heating is an area where innovators attempted to develop a diverse array of technologies, with variable levels of achievement (Figure 5.6). None of the technologies developed through Powering Agriculture in this category scored “fully achieved” for either business development or diffusion. However, Powering Agriculture’s support has been instrumental in assisting several innovators to advance their companies. Promethean has developed its thermal battery-based approach, and has expanded its sales beyond India to explore markets in Bangladesh and Tanzania. Powering Agriculture funding was instrumental in supporting Rebound to develop its follow-on technology, IcePoint, toward commercialization. Three companies were spun out of projects supported by Powering Agriculture and GIZ: Thermogenn (University of Georgia), Solar Cooling Engineering (University of Hohenheim), and ColdHubs, which is trying to commercialize solar-powered cold rooms in Nigeria.

5.3 Mini-grids and micro-grids

Powering Agriculture funded seven awards that attempted to harness renewable sources to provide electrical power for the purpose of processing agricultural products.¹⁸ Three of the awards funded “micro-grids” intended to power a small number of homes, farms, or businesses, including two fish hatcheries, with an installed capacity of under 10 kilowatts. Four of the awards funded “mini-grids” intending to reach entire communities and hundreds of users, with installed capacities in the tens to hundreds of kilowatts. These mini-grids were large enough to power milling and other agricultural processing machinery that have relatively high demands for power. Four of the projects operated in Sub-Saharan Africa, two in Latin America and the Caribbean region, and one in South Asia.

The environment for mini-grids and micro-grids

Most of the population of South Asia and Sub-Saharan Africa live in rural areas, as does a sizeable percentage of the population of Latin America and the Caribbean. Many, and in some regions, most of these rural communities either do not have access to the electric grid or, if they have access, service is unreliable. In Haiti, for example, 75 percent of the population lacks access to electricity. The costs of extending centralized transmission and distribution systems to these locations are high. Even in locations with connections to the grid, the quality of service is often poor or connections that reach households do not extend to farmed land. Substitute sources of electricity, primarily diesel-powered generators, are used to either provide power continuously or intermittently when the grid is down. But diesel fuel is expensive and pollutes.

The market for mini-grids and micro-grids

Electricity generation and distribution, compared with refrigeration or agricultural machinery, is relatively heavily regulated even in LMICs. Every country has developed a unique combination of regulations, ownership structures for its electricity generation, transmission, and retail distribution assets. Development of mini-grids requires an appropriate regulatory environment and alignment of the incentives of operators and users for projects to be successfully completed.

Since solar PV alone cannot provide continuous power, a variety of approaches have been developed to provide robust service. Some Powering Agriculture projects use batteries to store electricity. Others use diesel generators and some use both. Husk Power, which is developing mini-grids for communities in Sub-Saharan Africa, uses biomass gasification and batteries to provide power during non-sunlit hours. The Ariya mini-grids for large horticulture producers in Kenya and the Columbia University Earth Institute

¹⁸ Earth Institute of Columbia University, Camco Advisory Services, EarthSpark International, Ariya, Husk Power Systems, Universidad del Valle de Guatemala, and iDE Bangladesh.

micro-grids supporting agricultural irrigation in Senegal provide only part of the producers' energy needs because they do not use batteries so they only operate during daytime hours when the Sun shines.

A common technical challenge facing all mini-grid and micro-grid operations is how to charge users for electricity and prevent misappropriation or theft of power. One thread uniting three of the seven cases is the use of the SparkMeter, a low-cost, wireless-enabled metering system that measures use and handles billing and payment functions, including support for pre-payment through mobile money applications. The SparkMeter was developed by EarthSpark (a 2013 Powering Agriculture awardee) in 2012, and then spun off in 2013. The other four cases made use of different smart metering technologies.

Technological development for mini-grids and micro-grids

STPI determined that four of the seven innovators fully achieved their technological goals. As of the end of 2019, Ariya had installed five mini-grids with approximately 1.65 MW of capacity, and is in the process of installing three more. EarthSpark had installed a 100 kW mini-grid in the town of Les Anglais in Haiti and another in the nearby town of Tiburon. Husk had installed five 30-kW systems in Tanzania. Columbia University installed three small (5-7 kW each) solar PV micro-grid systems that provide power to 21 irrigation pumps for farmers affiliated with agricultural cooperatives near the town of Potou, Senegal.

Two of the projects were judged as having mostly achieved their technological goals. The Universidad del Valle de Guatemala UVG team has selected a site and created a limited liability company to operate its planned 76-kW mini-grid, but is still in the process of securing the additional funding needed to complete the installation and initiate the full pilot test. The iDE Bangladesh project installed two micro-grids—one at a fish hatchery without access to the electricity grid and one at a hatchery that does, but has found grid electricity to be unreliable. The project has experienced technical difficulties with the inverters and batteries, and has delivered less energy than was required to power the hatcheries' pumps. Moreover, in a 2018 accident, a hatchery employee was killed and another injured when they were electrocuted in an accident stemming from poor grounding of electric wires. While the systems were installed and produced power, given the difficulties encountered the pilot did not completely achieve all of its goals.



Figure 5.7 One of Earth Institute's three solar pilot sites in Gabar, Senegal

Camco partially achieved the development of its technologies. It installed one micro-grid in Tanzania, but not the second, and three sets of biomass-fueled processing equipment for palm oil in Benin. The palm oil processing equipment was to be powered by the combustion of biomass waste produced at local agricultural processing facilities. However, the systems stopped working within a few months of installation. Two of them stopped working after a few hours of operations.

Business development for mini-grids and micro-grids

STPI judged that EarthSpark International has fully achieved its business development goals. It successfully set up a mini-grid in Les Anglais and expanded it from a pilot stage with 54 connections to a town-sized, solar-powered smart grid providing power to residents and commercial

clients through a total of 452 connections, roughly 430 households and 20 businesses. It directly serves over 2,000 people with 24-hour electricity powered primarily by solar energy and battery storage. Its mini-

grid has been more reliable than the national grid. This community-scale grid is large enough to power small workshops while providing enough power to offer accessible service to every resident living within the infrastructure's footprint. Although the town and the mini-grid were badly damaged by the landfall of Category 5 Hurricane Matthew in 2016, funds were raised to repair the system and to restore it to operation. However, EarthSpark was unable to induce local businesses to purchase and operate solar-powered agricultural processing equipment.



Figure 5.8 Mini-grid in Les Anglais, Haiti

Source: Barreto 2016

We also assessed Ariya as having achieved its business development goals. As of November 2019, it had installed five systems of more than 150 kilowatts of capacity and was in the process of installing three more. Revenues have been increasing rapidly and the company's business model is focused on profitability.

Two of the projects were characterized by STPI as having mostly achieved business goals. Husk has installed five installations in Tanzania and had planned to install two or three more by the end of 2019. It had hoped to install the systems in Ghana, Nigeria, and more recently Uganda and Kenya, but regulatory issues have stalled additional installations. iDE Bangladesh completed the installation of its two micro-grids and despite its technical challenges has been delivering power to the hatchery

anchor users, as well as to households. However, the cost to individual users is much higher than electricity from the national grid. STPI calculates that without Powering Agriculture funds, given the fixed costs of solar installation this micro-grid approach is not economically viable. This said, iDE's partner in Bangladesh has built another micro-grid outside of the Powering Aquaculture project.

Two of the projects only partially achieved business objectives. Universidad del Valle de Guatemala project remains in pilot stage as of the end of 2019. As noted above, it needs additional funding to complete the pilot. The Columbia University team has been looking for a commercial partner to sell and install more systems, but had not succeeded in finding one as of the end of 2019.

Camco/VIP did not achieve business goals for its installations. In 2017, with funding from Shell Foundation and the feedback gained from the end-users during field testing, VIP developed a new prototype, the VIP 10-40. Through PAEGC, Factor[e] was introduced to VIP and has invested in this project. Three of these units are currently installed in Kenya with two under contract. An additional four units have been shipped from India for designated customers. This newer model is semi-automatic, addressing the problem of needing to feed the boiler every several minutes. STPI's analysis suggests that even if the cost of producing the VIP 10-40 were to half from the cost to build the original and the costs for collecting and processing biomass for the VIP unit were assumed to be zero, the system would have a payback period of more than 7 years, suggesting that the economics of the engine are tenuous.

Diffusion of mini-grids and micro-grids



Figure 5.9 Battery bank for mini-grid in Les Anglais, Haiti.

Source: Barreto 2016

We assessed Ariya as having mostly achieved objectives for diffusion. The company has a pipeline of additional projects, among which are agribusinesses, like other flower farms; it has also attracted investors. The market for commercial installations of solar panels is expanding in Kenya and, more slowly, elsewhere in East Africa as shown by the heightened competition that Ariya is facing.

EarthSpark International, Husk Power Systems, and iDE Bangladesh have partially achieved diffusion goals. EarthSpark has installed another mini-grid in Tiburon, a town near Les Anglais, and would like to install another 22 grids over the next 4 years on the southern peninsula of Haiti. The government of Haiti's electricity regulator *Autorite Nationale de Regulation du Secteur de L'Energie (ANARSE)* granted a 1-year provisional license to operate the Tiburon micro-grid in December 2019. Service started as of December 21, 2019. Husk Power Systems is trying to form new partnerships in Nigeria so as to construct more systems, but does not yet have a firm pipeline of new orders. iDE's partner, RREL, has installed another micro-grid outside of the Powering Aquaculture project. None of the other innovators have been able to make progress on diffusing their technologies.

SparkMeter, the spin-off company from EarthSpark, represents a successful example of Market Stimulation supported by Powering Agriculture. The company's Internet site states that as of the end of 2019 it had sold its smart meters in 22 countries. According to Crunchbase, it attracted more than \$11 million in Series A venture capital funding in 2019.

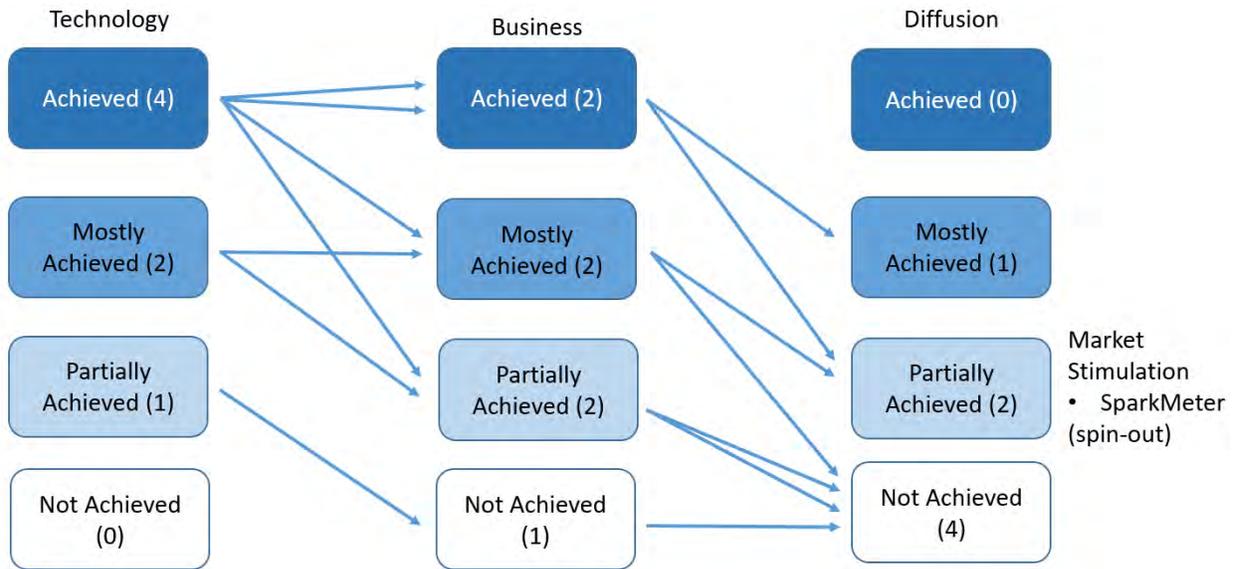
Findings for mini-grids and micro-grids

Declining costs of solar energy, improving metering, billing, and control technologies, and the financial and technological problems incumbent grid operators in LMICs have faced in expanding legacy centralized electrical grids to rural areas suggest mini-grids could be able to leapfrog centralized electricity generation and distribution, just as cellular telephones leap-frogged landlines in many LMICs. Several innovators have been able to provide reliable power at prices substantially below the cost of diesel generation and in some cases below those of the national power grid. However, these innovators have encountered substantial financial, business, and regulatory challenges in setting up their operations. In particular, the hurdles erected by existing regulatory systems and incumbent national grids have greatly slowed and hindered the establishment of mini-grids. Powering Agriculture has contributed to moving this industry forward in great part by providing funding to innovators so that they have the time and resources to surmount these regulatory challenges. PAEGC partners have also engaged with ministries and regulatory agencies to help solve regulatory issues facing mini-grid operators.

PAEGC innovators have also supported the growth and diffusion of SparkMeter, a spin off from EarthSpark, through their purchases.

The experiences of the Columbia University and iDE micro-grids (smaller than 10 kW in size) suggest that mini-grids have to be of a certain size to be sustainable. The costs of electricity generated by the micro-

grids installed by those two innovators are expensive. The capital costs associated with micro-grid (and some mini-grid) solar PV installations coupled with distribution equipment and operating costs results in costs per kWh of \$1.00. Such a price for electricity is not competitive with grid power and in many cases is more expensive than the cost of diesel generation.



Mini-grids and micro-grids

Figure 5.10 Outcomes of mini-grids and micro-grids

5.4 Agricultural processing and other technologies

While irrigation and chilling are important aspects of agricultural production, many other agricultural processes also benefit from renewable energy. Nine of the 32 Powering Agriculture cases engaged in developing technologies to make these processes more efficient or less polluting. The technologies ranged from solar-powered tractors and milling machinery to passive sources of aeration for fish ponds.¹⁹ Four of these projects were conducted in Sub-Saharan Africa, three in South Asia, one in the Middle East, and one in Southeast Asia and the Pacific.

The environment for agricultural processing and other technologies

As noted above, many small, rural villages and towns in LMICs do not have access to electricity from the national grid; for those that do, electricity is often unreliable. Many agricultural processes (e.g., harvesting, milling, grinding, and husking) are carried out using manual labor or equipment powered by gasoline or diesel fuel. Using electricity or other forms of energy to replace manual processing saves time and effort. As many agro-processing tasks are disproportionately undertaken by women, processing technologies powered by renewable energy can be especially helpful to them. The time they save in

¹⁹ African Bamboo, ECO Consult, Motivo Engineering, University of Toronto, Horn of Africa, Village Infrastructure Angels, GIZ pilot: Tea Factories, GIZ pilot: Solar-powered irrigation in India, and GIZ pilot: Solar Sesame Oil Production.

manual labor can be redirected to income-generating activities or to more time spent with children and other family members. Renewable energy can also generate cost savings from reducing consumption and expenditures on diesel fuel, and reduced time spent traveling to processing sites in other villages. Having access to processing equipment make it possible for farmers to realize higher-value from their crops, as raw agricultural commodities can be processed into products that can be sold at higher prices (e.g., processing sesame seeds into sesame oil, making uncut bamboo into flooring material, drying fruits and vegetables). These products often have longer shelf lives and can be exported.

The market for agricultural processing and other technologies

The nine cases developed technologies for a variety of markets and contexts:

- 2013 Powering Agriculture Awards
 - **African Bamboo** attempted to develop a bamboo flooring business and technology process that is more energy and material efficient than the standard Chinese bamboo processing methods for flooring and decking
 - **Eco Consult** attempted to develop a hydroponics technology powered by solar power
 - **Motivo** developed the prototype of a multifunctional solar powered electric tractor.
- 2015 Powering Agriculture Awards
 - **The University of Toronto** developed a low-cost passive method for aerating fish farms
 - **Horn of Africa** Regional Environment Center and Network (HoA-REN) of Addis Ababa University attempted to develop an apparatus for drying coffee beans with biogas
 - **Village Infrastructure Angels** installed solar-powered agricultural processing mills in villages in Indonesia and Vanuatu.
- GIZ-supported pilot projects
 - The **Kenya Tea Development Authority** developed a program on energy auditing and training staff to improve the energy efficiency of the Kenyan tea sector
 - The Self Employed Women's Association, SwitchOn/Environment Conservation Society, Vaishali Area Small Farmer's Association, and Tufanganj Anwasha Welfare Society worked with the **Indo-German Energy Programme Access to Energy in Rural Areas** to implement activities to improve the demand for solar power in agriculture
 - **The University of Hohenheim** studied the technical and economic viability of a solar-powered sesame oil production system in Burkina Faso



Figure 5.11 Worker from African Bamboo using pressing machine on bamboo at pilot site

Source: Perkinson 2016

Technological development for agricultural processing and other technologies

STPI characterized 6 of the 9 cases to have achieved their technology goals. Village Infrastructure Angels developed and installed solar-powered mills (rice hullers, rice polishers, cassava graters, coconut graters, corn shellers, flour grinders, and kava mincers), which were linked to solar panels and a lithium ion battery through a solar control box. All seven types of solar mills have been warmly received by communities, but the cassava grater was most valued. A team at the University of Toronto developed a simple, low-cost technology for passive aquaculture aeration and conducted a series of randomized

control trials to determine the effects of the technology on fish production and aquaculture operator income over several generations of fish. African Bamboo successfully developed three new technological processes to prepare and treat Ethiopian bamboo to manufacture flooring using methods that were more energy, material, and water efficient than standard Chinese bamboo product manufacturing techniques.

The initial phase of the GIZ Kenya Tea Development Authority pilot provided audits, training and recommendations for energy efficiency measures at 11 tea factories. These factories saw average reductions of 11 percent in electricity used and 10 percent in firewood consumption. The GIZ-supported Indo-German Energy Programme Access to Energy in Rural Areas project developed software tools to identify districts that are the most propitious for the application of solar irrigation pumps, developed financing products for solar-powered irrigation systems, and provided extension services to farmers in three villages with installed solar water pumping systems to help them use their pumps more productively. A third GIZ pilot project tested a solar-powered sesame oil press intended for use by an agricultural cooperative.

Motivo mostly achieved its technological development goals. It used the Powering Agriculture award to develop a prototype of a multifunctional solar powered electric tractor and tested it in a village in India. While Motivo developed the Hybrid Agriculture/Road Vehicles with Electricity Storage and Transformation (HARVEST) tractor, pilot testing revealed that the company needed to triple the size of the solar array to generate enough electricity to charge the tractor.

The EcoConsult project to pilot solar-powered hydroponic systems in Jordan did not achieve its goals for technological development. It found that the energy requirements of the hydroponic systems did not justify integrating solar PV systems, so the project substituted non-renewable energy sources for its proposed solar-powered hydroponic system.

The original goal of the 2013 Horn of Africa PAEGC project was to use biogas produced anaerobically from coffee husks to supply an infrared dryer to dry coffee beans faster than traditional air-drying methods. Horn of Africa did not achieve its technological goals, as it was unable to obtain and deploy infrared dryers or use coffee husks to generate biogas in its four biodigesters.

Business development for agricultural processing and other technologies

The Kenya energy efficiency project for the tea industry achieved its business development goals. The reductions in the consumption of electricity and firewood resulted in an energy cost savings of 60,000 euro per factory per year.

Two of the projects mostly achieved their goals for business development. Although Eco Consult did not develop its proposed technology, it did install 22 hydroponics demonstration sites; it had initially proposed to install hydroponics systems at just two sites. The sites tested both drip hydroponics and raft hydroponics approaches. They grew spices and several varieties of vegetables, including lettuce, peppers, and tomatoes.

Village Infrastructure Angels found that the solar mills were not utilized sufficiently to be commercially viable. To make the project economically viable, Village Infrastructure Angels deployed 6,500 pay-as-you-go lighting kits alongside the solar mills. It receives monthly payments from each customer to provide electric lighting and phone charging. When coupled with payments for the use of the solar mills, these revenues offset much of the revenue shortfalls from the underutilized mills. Village Infrastructure Angels sells most of these systems on credit and has managed to control the default rate to the point where its pay-as-you-go lighting kits cover costs.

The University of Toronto, African Bamboo, Motivo, and the GIZ solar-powered irrigation in India project, partially achieved business development goals. The University of Toronto's passive aeration system has been tested with 14 farmers. A local workshop was selected and manufactured the prototypes, but has had no interest in manufacturing and marketing the product on its own. A graduate student start-up at the

University of Toronto is trying to raise money to sell the product, but has not yet raise sufficient capital to do so.

African Bamboo began a bamboo seedling nursery intended to be used to establish a 2,000 hectare plantation as a source for their factory, created partnerships with state enterprises to utilize forest bamboo in the creation of pallets, and trained 2,239 small-holder farmers within 31 cooperatives on sustainable bamboo harvesting, selective harvesting, and age discrimination, and book keeping. The company has raised and spent substantial amounts of money on permit acquisition and carbon studies. However, it still has not raised the funds required to outfit the plant with the processing machinery. It discovered it would need to raise about \$20 million for equipment and tooling to manufacture bamboo flooring.

Motivo has continued to try to sell its electric-powered tractor in India, including developing applications for reserving and paying for tractor use and experimenting with leasing/rental-based business models. Nevertheless, the high capital cost of the tractor raises doubts as to whether it can be sold successfully in LMICs.

Under solar-powered irrigation in India, the National Bank for Agriculture and Rural Development has used the site selection software tool to shortlist the 100 districts with the greatest potential for the deployment of solar-powered irrigation systems (SPIS); other market participants are also interested in using the tool. Two bank loans for Joint Liability Groups have been awarded by two commercial banks in Bihar and West Bengal, respectively, to finance solar-powered irrigation pumps. However, as these are pilot projects, it remains to be seen whether they will be continued.

Horn of Africa did not achieve business development goals.

Diffusion of agricultural processing and other technologies

Of the nine cases, GIZ's tea efficiency project achieved wide-scale diffusion. KTDA, the Kenyan governmental entity under which most of Kenya's tea factories operate, has introduced the efficiency program at almost all its plants.²⁰ Village Infrastructure Angels partially achieved diffusion. It has 10,000 customers that lease or have purchased its solar lighting technologies. It has had less success with solar-powered agricultural processing equipment, the focus of its Powering Agriculture project. The market for solar-powered milling equipment remains nascent. Because the equipment is based on products designed for businesses, it is oversized, over-engineered, and too costly for use by households or even small villages. The other projects did not achieve diffusion goals.

There have been two Market Stimulation outcomes associated with this set of cases. As a result of the development of the HARVEST, Motivo spun-out a separate company, Monarch Tractor, to commercialize, sell, and manufacture its tractor. Agsol, a company that is attempting to develop and market agricultural processing equipment for Africa powered by renewable energy, emerged in part from VIA's partner, Project Support Services.

Findings for agricultural processing and other technologies

With the exception of technological development, the "Agricultural Processing and Other" category resulted in fewer achievements than the other categories. This is due in part to the diversity and complexity of many of the technologies. Six of the nine projects involved the development of new technologies or new applications: African Bamboo, Eco Consult, Motivo, Horn of Africa, Village Infrastructure Angels, and solar-powered presses for sesame oil. In the other categories, the for-profit businesses often drove commercialization and diffusion. In this category, African Bamboo and Motivo faced daunting technological challenges to developing prototypes. These difficulties disrupted moves to

²⁰ The factories themselves are owned by their members, who are eligible to own shares as long as they work in the industry, but must sell their shares when they cease growing tea.

create viable businesses to sell and diffuse the technologies. A number of these projects (Eco Consult, Earth Institute, Horn of Africa, solar-powered irrigation in India, and solar sesame oil production) lacked incentives to commercialize their products because they either were tied to universities or their business model was focused on obtaining new grants rather than spinning off businesses to sell the technologies they had developed. The lack of incentives served to slow business development and diffusion.

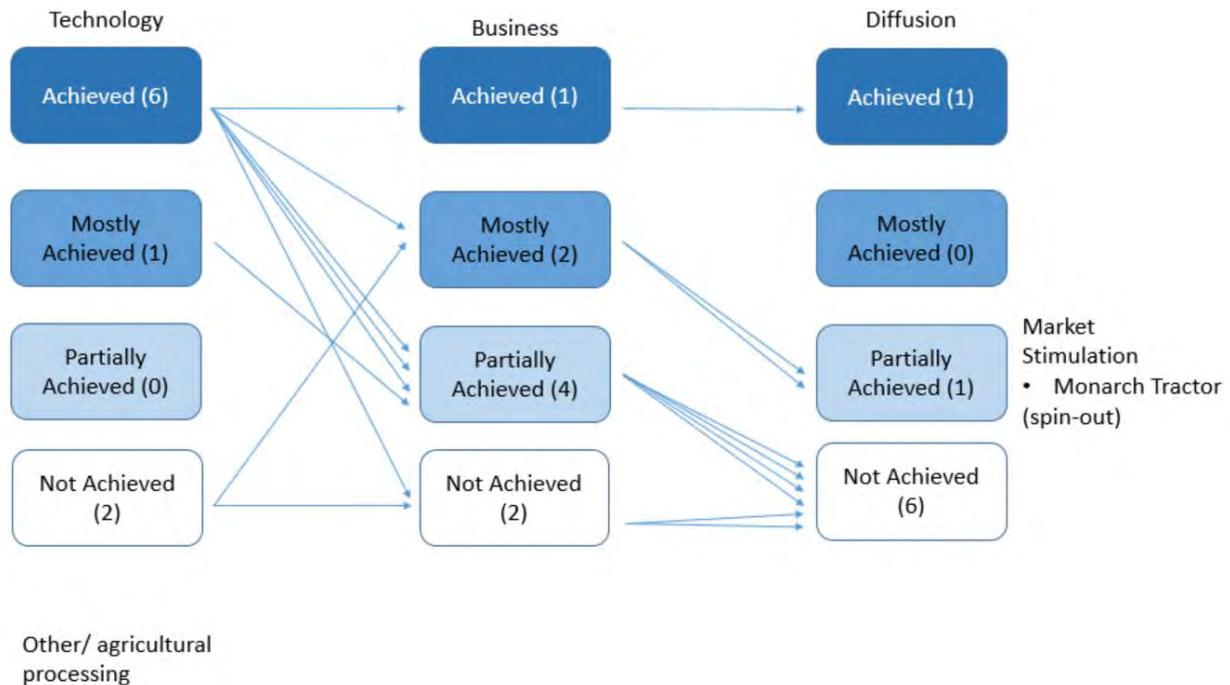


Figure 5.11 Outcomes of “other” technologies

5.5 Overall Assessment of Outcomes

Technological development

Almost all the innovators successfully developed their technologies: 22 out of 32 (68 percent) fully achieved the development of their technology; of the remainder, six mostly achieved technology development objectives. Only two innovators partially achieved and only two failed to achieve technology development objectives. These four innovators also tended not to have achieved or only partially achieved business development and diffusion objectives.

For-profit, non-profit, and universities all performed well in terms of this outcome. Innovators in the four technology categories all performed about the same in terms of the achievement of technology developments.

Business development

For-profit companies performed better than universities in terms of achieving business development objectives. Three of the five innovators that fully achieved business development objectives were for-profit businesses. All three have enjoyed solid sales of their products and have been able to attract equity investments to build their businesses. Of the 10 innovators who mostly achieved business development objectives, five were for-profit companies. The 2015 PAEGC cohort of innovators was more successful in achieving business objectives than the 2013 cohort; 9 of 13 awardees in the 2015 cohort achieved or

mostly achieved business objectives, as compared with 4 of 11 2013 awardees. Only two of the 10 GIZ pilot projects fully or mostly achieved business development objectives.

One notable finding is that non-profits (but not universities) were at least as likely to achieve or mostly achieve business development objectives (6 of 9 projects) as were the for-profit businesses (8 of 14 projects). Non-profits that either fully achieved or mostly achieved business development objectives used a variety of strategies. Several of these non-profits were business-focused. EarthSpark International's primary mission is developing mini-grid businesses in Haiti. In addition to completing and operating one mini-grid in a Haitian town, it has built another. KickStart is also a business-focused non-profit. Building on its successful handpump business, it earns revenue from commercial sales of products, including those developed under its Powering Agriculture award. Other non-profits used different strategies. ICU, for example, incorporated commercial partners into its award—installers of solar PV systems in Jordan and Lebanon. The award clearly built the capacity of its Lebanese partner, Solaris, which has subsequently expanded its revenues by installing more solar PV irrigation sites. The GIZ pilot project in the Kenyan tea industry involved a partnership among a convening non-profit (the Ethical Tea Partnership), a university that developed an energy efficiency training curriculum and conducted training efforts (Strathmore University), the smallholder-owned tea processing companies, and KTDA, that implemented the approach.

Universities lack the capacity to commercialize a product directly. Powering Agriculture projects led by universities were often launched without transition partners who could provide a clear route to commercialization. The universities hoped that partners or third parties would develop the businesses to sell the technologies. In one case, the GIZ pilot project partner University of Hohenheim did successfully spin out a company to commercialize the knowledge and technology developed through its work in Africa on solar milk chilling. The University of Toronto and the University of Georgia are also trying to create viable companies to market their products, but so far without great success.

A local presence is important for achieving business development objectives. All of the innovators that fully achieved or mostly achieved business development objectives were either headquartered in LMICs or were firmly anchored there.

Innovators engaged in solar-powered irrigation or mini-grids were more successful in achieving business development objectives than those engaged in cooling and heating or processing technologies powered by renewable energy. All of the solar-powered irrigation projects except GIZ's solar-powered irrigation project in Egypt achieved or mostly achieved business development objectives. Five of the seven mini-grid and micro-grid projects fell into these rankings; mini-grid projects were more successful in achieving business development objectives than micro-grid projects. In contrast, only two of the nine cooling and heating projects mostly achieved business development objectives; none fully achieved these objectives. In the "agricultural processing and other" category, three of the nine projects achieved or mostly achieved business development objectives, but the remaining six failed to achieve or only partially achieved those objectives. The small-scale cooling technologies powered by renewable energy and the agricultural processing equipment technologies both struggled with affordability.

When we stratified innovators by year-of-award cohort, we found that all of the innovators that fully achieved business development objectives fell into the 2015 cohort with the exception of the tea factory energy efficiency project, which was a GIZ project, and the EarthSpark project in the 2013 cohort. Only 3 of the 10 projects that mostly achieved business development objectives fell into the 2013 category even though these awardees had more time for their products and business processes to mature. Only two of the GIZ supported pilot projects fully achieved or mostly achieved business development objectives. However, the GIZ pilots intentionally focused on technology development rather than business development, so this result was not all that surprising.

Diffusion

GIZ's energy efficiency project in the Kenyan tea industry is the only project to have completely achieved diffusion objectives. Only four projects mostly achieved diffusion objectives. Two of these projects manufacture or sell solar-powered irrigation pumps; one was a mini-grid project, and one sells commercial coolers. Three of these innovators were for-profit companies. Of the 10 innovators who partially achieved diffusion objectives, three fell into cooling and heating using renewable energy, three were engaged in solar-powered irrigation, two were engaged in mini-grids, and two fell into the "agricultural processing and other" category.

Achievements in business development and diffusion reflect the relative successes of solar-powered irrigation and mini-grids in becoming commercial businesses. In these two cases, the technologies have become competitive with existing technologies, like diesel generation. In contrast, only Promethean and SunDanzer with its portable vaccine refrigerators have developed strong businesses in the renewable energy cooling and heating category. Existing refrigeration units that rely on grid electricity remain much more competitive. Potential customers have tended to focus on improving their access to grid electricity or quickly transporting milk or produce to collection sites with access to grid electricity and refrigeration rather than purchasing off-grid cooling equipment.

Projects targeting commercial clients have had more success than those targeting individual farmers. Promethean, Ariya, and the GIZ tea factory efficiency project have all mostly achieved diffusion objectives. The deeper pockets of their customers have helped them to sell their products at a profit.

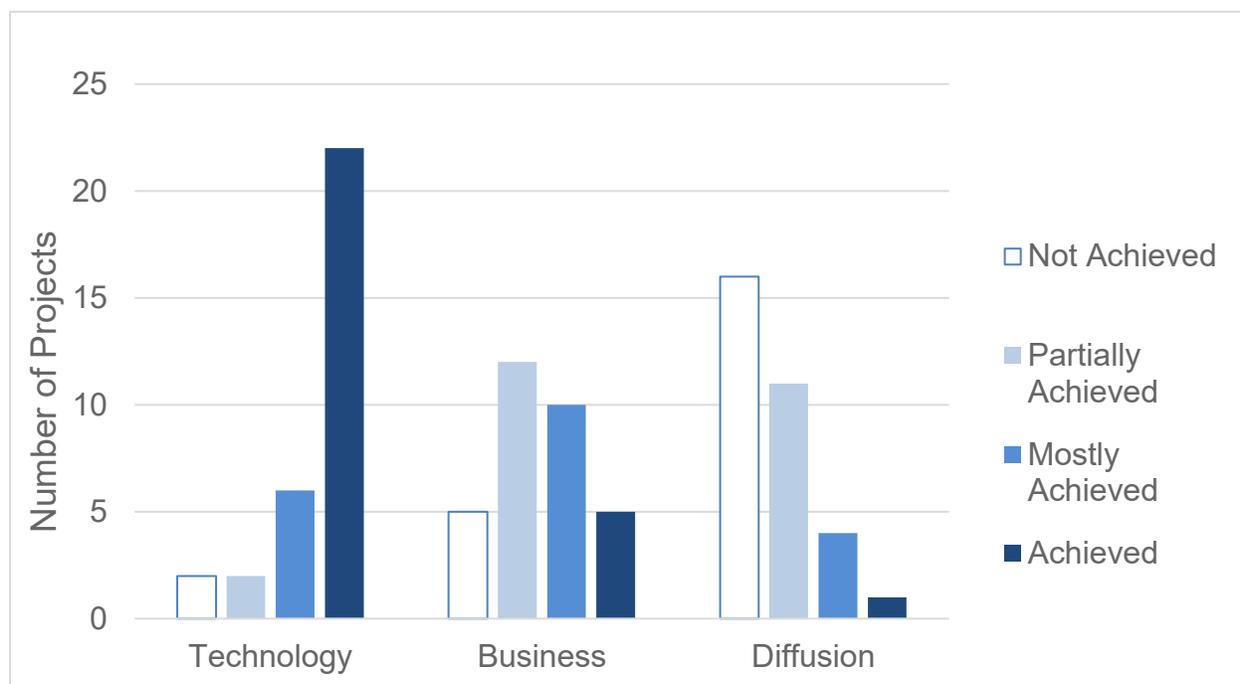


Figure 5.12 Project outcomes by category

Powering Agriculture has had several successes in terms of Market Stimulation outcomes. EarthSpark spun out a separate company, SparkMeter, which sells a smart meter that is not only used in EarthSpark's PAEGC award but also in two other PAEGC mini-grid projects. Solar Cooling Engineering was spun out of a University of Hohenheim GIZ pilot to support commercialization of the modular solar milk chilling technologies the project developed. ColdHubs spun out of a Smallholders Foundation GIZ pilot to commercialize the solar-powered cold room that the project helped to optimize.

Six of the nine Market Stimulation outcomes were associated with innovators in the 2013 cohort. These innovators have stimulated the entry of competitors into nascent markets in small-scale cooling with renewable energy and into expanding markets for solar irrigation pumps. Even if the 2013 cohort of innovators did not necessarily develop products and services that were commercialized themselves, the awards helped move technologies toward the market. In addition to SparkMeter, Solar Cooling Engineering, and ColdHubs, Powering Agriculture projects have led to the spin out of Futurepump, Monarch Tractor, and Thermogenn from the 2013 PAEGC cohort. Given a few more years, the 2015 PAEGC cohort may spin out its own set of companies.

5.6 Mobilized funds

One of the goals of Powering Agriculture is to leverage funding from other sources. The ability of innovators to mobilize investment was included in STPI's innovator success framework. Leveraged funds include awards to the innovator organization from grants or contributions from foundations and other philanthropic sources and equity or debt raised from capital markets. The ability to raise additional funding to support a PAEGC project serves to validate the project's promise and its results to date. It also provides further resources to advance the project toward commercial viability.

For the purpose of this analysis, STPI excluded from mobilized funds in-kind contributions from project partners and revenues from sales of the innovators' technology. While in-kind contributions by partners increase the pool of resources available to the innovators to develop technologies, these contributions are incorporated in the design of projects and therefore cannot be considered "leveraged." While revenues deriving from the sales of products and services during the award period are indicators of commercial success, they are not funds provided by investors or other donors.²¹ STPI did include mobilized funding for the purpose of developing follow-on technologies.

STPI's primary source for mobilized investment was the indicator data stored on the Powering Agriculture Webmo portal, although we adjusted the totals reported to exclude in-kind contributions and product sales. Below, we focus on aggregate numbers because the numbers provided by individual companies are proprietary.

The Powering Agriculture innovators have mobilized over \$50 million in funds related to their PAEGC projects, or more than twice PAEGC's initial funds.²² Eighteen of the 24 innovators (75 percent) reported at least some mobilized investment, and 10 of the 24 innovators (42 percent) reported leveraging at least the amount of funds provided by PAEGC. Even if the mobilized funding raised by the innovator that has raised the most money is excluded, the innovators leveraged 123 percent of the PAEGC funding. Stratifying by technology, mobilized funds for each area exceeded PAEGC award funds, although the mobilized funding for mini-grid development was primarily due to the funds raised by one innovator.

Stratifying the mobilized investment by cohort shows that the 2013 innovators mobilized somewhat more than their PAEGC funding (\$14.5 million leveraged versus \$11.6 million in awards). In contrast, the 2015 innovators have mobilized roughly three times their PAEGC funding (\$36.8 million leveraged versus \$12.9 million in awards). This difference appears to stem from the composition of the 2015 cohort: PAEGC selected more established for-profit companies in the 2015 cohort and fewer organizations that were focused on developing early stage, complex technologies.

Stratifying mobilized investment by innovator type shows a sharp divergence between for-profit and not-for-profit (including university) innovators. The 14 for-profit innovators mobilized \$49.1 million (or \$3.5

²¹ As the GIZ pilot projects are not included in the Webmo portal and project funding was available only for a subset of the GIZ awards, they were excluded from this portion of the analysis.

²² The Powering Agriculture 2018 annual report (USAID 2019, page 37) calculates cumulative mobilized funding of \$38.23 million. Our tabulation includes mobilized FY2019 funding – although it excludes \$3.3 million in reported in-kind contributions and sales revenue.

million per award) while the not-for-profit innovators mobilized \$2.2 million in total or \$220,000 per award. While 6 of 10 non-profits (60 percent) mobilized funds, 12 of 14 for-profit innovators (86 percent) did so. Only one non-profit leveraged more funding than was received through Powering Agriculture, as compared with 9 of the 14 for-profit innovators. These nine for-profit innovators mobilized at least some of their funding through capital markets, either through loans or by attracting equity investment from venture capital funds. Of those nine, one was primarily funded through grants from development organizations such as the World Bank and Asian Development Bank, as well as receiving funding from angel investors (interview data). It is difficult to distinguish the relative reliance of the other eight on capital markets as compared to grants as sources of leveraged funds given the information available to the evaluation. However, some innovators (e.g., Husk Power, SunCulture, Claro, Rebound) have stated publicly that they are leveraging large-scale investments (Samridhi Fund 2018; Husk Power Systems 2018; EDF 2018; Prime Coalition 2017).

The not-for-profit awardees all rely upon grants to conduct development-related activities.

5.7 Assessment of PAEGC's theory of change in light of outcomes

The theory of change that underlies USAID's Grand Challenges states that "by engaging and mobilizing diverse, global solver communities, USAID and its Partners can source, select, incubate, test, and scale up science and technology innovations that will overcome critical barriers to development and accelerate the pace at which the world's most pressing development problems can be addressed" (Raetzell and Seidler 2016 p. 10).

STPI developed a series of hypotheses to test based on PAEGC's theory of change. Below we summarize our assessment of these hypotheses in light of the project outcomes assessed above.

PAEGC innovator teams including a mix of partners (technology developers and local organizations, and for-profit and non-profit partners) will be more likely to bring agricultural technologies incorporating renewable energy to commercialization. We were not able to test this hypothesis because almost every project team included a mix of partners and local organizations.

PAEGC university-based innovator teams will be less likely to commercialize their technologies than for-profit company-based teams. Yes, the evidence supports this hypothesis. Three of the five innovators that fully achieved business development objectives were for-profit businesses and as were 5 of the 10 innovators who mostly achieved business development objectives. One of the university-led projects fully achieved or mostly achieved business development goals. It is notable, however, that teams led by non-profits were at least as likely as for-profit innovators to achieve or mostly achieve business development goals.

For-profit company-based teams with backgrounds in developing high-end products for high-income country markets using PAEGC funds to create a version of that technology for LMIC markets will be less likely to succeed than for-profit companies that have previously focused on bringing technologies to LMIC markets. Yes, the evidence supports this hypothesis. None of the high technology companies based in developed countries (Rebound, SunDanzer, Motivo) applying their expertise to an LMIC context completely or mostly achieved business development objectives through their Powering Agriculture award. Companies that fully or mostly achieved business development objectives included startups launched from developed countries that focused on developing Powering Agriculture technologies and manufacturing in LMIC countries (e.g., Solar Cooling Engineering) and companies headquartered in LMICs or in both a developed country and an LMIC (e.g., Futurepump, Village Infrastructure Angels, Promethean, SunCulture, Claro).

PAEGC innovator teams can themselves incubate, test, and scale up agricultural technologies incorporating renewable energy for wide-scale market adoption. Some PAEGC innovators have

succeeded in incubating, testing, and scaling up their innovations, but it is too early to determine whether they will be able to achieve wide-scale sales of these products. The 2013 iDE award led to the spin out of Futurepump, which received a follow-on award and commercialized the Sunflower line of pumps. SunCulture was a pre-existing small company in Kenya that used PAEGC funding to develop, test, and commercialize the RainMaker line of pumps. Solar Cooling Engineering and ColdHubs were spun out of existing organizations in an effort to bring a product to commercial scale.

It is premature to conclude that any of the technologies supported by Powering Agriculture will reach “wide-scale market adoption.” Ariya is employing existing solar panel technologies for its commercial solar systems, although it employs an innovative financing approach. Even successful companies such as Promethean, Futurepump, and SunCulture that are selling hundreds to thousands of products per year, and have revenues in the millions of dollars per year, will need to scale their operations by orders of magnitude to be said to “accelerate the pace at which the world’s most pressing development problems can be addressed.”

Smaller awards made for 2015 projects starting at early stages of development will be less likely to reach wide-scale adoption than the larger 2015 awards or 2013 awards. We found evidence that this is the case. Of the four innovators who won larger 2015 awards (Ariya, Futurepump, SunCulture, and Village Infrastructure Angels), all of them achieved or mainly achieved business development objectives and reached the commercialization stage. Of the remaining 9 companies that won smaller awards, 5 (56 percent) mainly achieved business development objectives.

Projects intending to incrementally improve existing products or to make existing products available in new LMIC markets will be more likely to reach wide-scale adoption than projects developing wholly new technologies. Yes, this hypothesis appears to be true. All the projects that mostly achieved diffusion objectives primarily employed existing technologies. Projects developing new products based on complex technologies (e.g., Motivo, Rebound, SimGas) only partially achieved or did not achieve objectives for diffusion. Most of the projects that are successfully selling products manufacture them in China or India; they do not source their products from the United States or Europe. KickStart is the notable exception—although the pumps it sources from a U.S. manufacturer have been costlier than expected.

De novo technology development projects may lead to valuable applications or may be broadly diffused by others through licensing or encouraging competitors to market a related product, even if the PAEGC-supported innovators are unable to generate wide-scale sales themselves. There is considerable support for this hypothesis. Nine of the Powering Agriculture projects have led to market stimulation outcomes, including three of the awards that developed products based on complex technologies (e.g., Motivo, Rebound, SunDanzer).

All else being equal, projects that participate actively in PAEGC technical assistance activities are more likely to receive follow-on funding and advance commercialization than those that participate less actively. Outcomes provide some support for this hypothesis. VentureWell engaged strongly with Promethean, SunCulture, the University of Toronto team, and the University of Georgia team. SunCulture and Promethean have been successful in bringing products to market, though other companies also have succeeded and the things that made their engagement with VentureWell successful (charismatic and passionate leaders who engaged with VentureWell directly) are also success factors for companies generally. The University of Georgia team has spun out a company to commercialize its technology, though sales have been limited. The University of Toronto worked with VentureWell to develop a business plan to commercialize its aerator, but as of 2019 there are no plans to bring the product to market.

PAEGC funding can support “leapfrog” technologies that help to solve development challenges associated with agriculture and renewable energy. The evidence for this hypothesis is mixed. Three of

the categories of Powering Agriculture-supported projects (irrigation, cooling/heating, other/agricultural processing) use distributed renewable energy technologies (e.g., solar PV, biogas) to power agricultural equipment, substituting for diesel generation or grid electricity. The mini-grid projects use solar PV at the facility or community level in regions that are not served or poorly served by the central grid. The Powering Agriculture projects show that these technologies can be deployed in LMIC. But they also show that the regulatory challenges faced by the mini-grid projects and the financing challenges faced by smallholder users of irrigation, cooling, and agricultural processing technologies remain barriers to widespread adoption of these technologies.

5.8 Conclusions

PAEGC was successful in selecting and supporting innovators to develop their proposed technologies and other solutions. Twenty-eight of the 32 cases (88 percent) achieved or mostly achieved their objectives for development of their technology to the pilot stage. PAEGC was relatively successful in supporting the development of organizations to the business stage. However, the 2015 cohort, which included more organizations with fairly developed products, performed better than the 2013 cohort in this regard. Due in part to the small scale of the innovators and the short time available to the 2015 cohort, PAEGC was less successful in diffusing the products that were developed.

Powering Agriculture has enjoyed its greatest success in fostering the growth of solar-powered irrigation markets in LMICs, especially in Sub-Saharan Africa. Sales of PAEGC-supported solar-powered irrigation pumps are running in the thousands of units per year and the market has become sufficiently promising to induce established distributors of irrigation pumps to develop their own. Powering Agriculture has also supported a number of promising mini-grid projects. Five projects have achieved or mostly achieved goals for diffusion of their products. There has been a mismatch between the cost of many of the PAEGC-supported technologies and the ability of the smallholder farmer to afford them, which has limited diffusion to date.

6. Impacts

6.1 Measuring impacts

Increases in agricultural output or incomes

Innovators, beneficiaries, and PASTO found it challenging to provide or gather verifiable information on changes in agricultural output and incomes that could be attributed to technologies funded by Powering Agriculture. Agricultural yields vary widely, depending on rainfall, insect infestations, and other natural phenomena. Powering Agriculture technologies are just one additional factor in changing yields. Farmers rotate crops; it is often impossible to make year-to-year comparisons of yields from the same field, as crops are shifted.

Although many of the farmers interviewed by PASTO and us keep detailed records about milk sales, we did not encounter similar records on crop yields. Market prices for agricultural products fluctuate, so increases in yields do not necessarily translate into commensurate increases in incomes. Many, if not most, farmers in LMICs generate income from a variety of economic activities, few of which are stable over the course of a year. During our site visits, one farmer had recently sold off his entire herd of cattle, enjoying a substantial lump sum addition to his income, but one that will not be repeated until he rebuilds his herd. Many men work in construction; others take seasonal jobs in urban areas. Poorer farmers frequently work for other farmers, harvesting or weeding, to generate extra income. Interviewees did not appear to keep detailed records on the sources of their annual incomes or totals. As a consequence, evidence concerning changes in agricultural output or income from technologies supported by Powering Agriculture is fragmentary and unreliable.

If the PAEGC partners consider information on increases in agricultural output or incomes highly important, they should consider funding selected detailed third-party assessments to make these measurements. Facing similar problems in determining increases in yields from interviewing farmers for a project on sweet potatoes, the GIZ Green Innovation Center in Kisumu, Kenya, conducted its own investigations, harvesting and weighing sweet potatoes from sample plots from participating farmers itself to ascertain changes in output. The Center found self-reported changes in harvests unreliable.

Reductions in greenhouse gases

Our estimates of potential reductions in greenhouse gases are more solidly based. All of our estimates of reductions in greenhouse gas emissions were based on replacing liquid fossil fuels with renewable energy. We used empirically derived information on the consumption of gasoline or diesel fuel per hour by capacity for a full range of diesel and gasoline engines and generators provided by engineering firms and manufacturers. We used standard factors for estimating how much carbon dioxide is released by the combustion of gasoline or diesel fuels from the Department of Natural Resources Canada (Natural Resources Canada [ud](#)). This information is also based on engineering or scientific measurements. We multiplied implied reductions in fossil fuel consumption by these emission factors to estimate savings in greenhouse gas emissions.

Reductions in poverty

We used economic, anthropological, and sociological studies to identify poorer social groups that might benefit from the Powering Agriculture technologies. We cross referenced current beneficiaries with these poorer social groups in an effort to determine whether the technology was likely to benefit lower income groups. We were unable to find any broad, empirical data on the impact of the technologies on lower

income groups, however. Consequently, assessments of the impact of the projects on poverty were qualitative.

Improvements in gender equality

Evidence on improvements in gender equality was anecdotal or narrowly targeted on the innovators' operations. We primarily obtained this information from the PASTO, PAEGC partner, and our own trip reports, when available. We also used anthropological and sociological studies to identify aspects of the Powering Agriculture technologies that might help improve gender equality. As a consequence, assessments of the impact of the projects on improving gender equality were also qualitative.

6.2 Solar-powered irrigation

Increases in agricultural output or incomes from solar-powered irrigation

For farmers who had previously relied on rain, solar-powered irrigation makes it possible to increase yields by ensuring that crops are adequately watered throughout the growing season and by making it possible to grow additional crops, usually vegetables or fruits, during the dry season. In the pilot testing of KickStart's solar irrigation pump, for example, farmers reported considerable increases in yields, as much as twice those when relying on rain-fed agriculture or irrigating manually using buckets. Using the solar irrigation pump reduced the time farmers spent pumping water for irrigation purposes, which allowed farmers to grow crops such as sugarcane, bananas, and sweet potatoes in addition to their staple crops (KickStart International 2019). Using the solar-powered pump also allowed farmers to grow crops outside the rainy season, increasing the number of crop cycles from 1 to 2 per year to 3 to 4 per year and to improve the quality of their products (USAID 2015). Because prices for vegetables and fruits harvested in the dry season tend to be higher than those harvested immediately following the traditional growing season, farmers not only benefit from growing an additional crop, but also from being able to sell the harvest at higher prices.

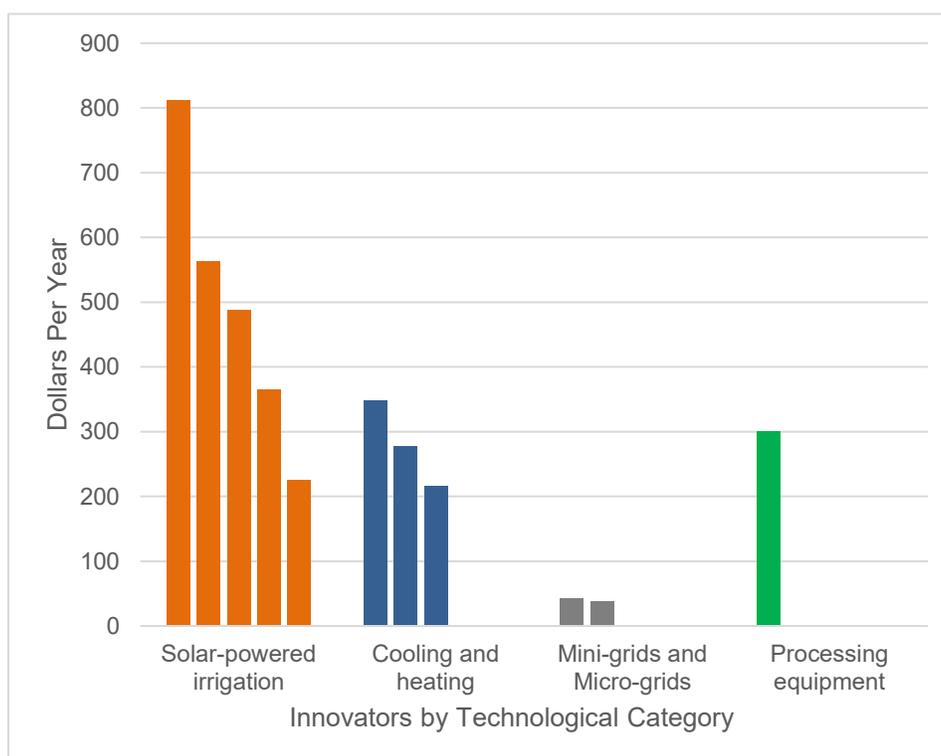
Irrigation pumps also support farmer incomes through avoided losses due to drought. During periods of drought, not surprisingly, agricultural equipment salespeople told us that sales of pumps, especially manual pumps, rise sharply. Manual pumps are labor-intensive. We were informed by farmers and sales people that it takes too much labor to use manual pumps to irrigate an additional crop during the dry season, but farmers use the pumps to save a crop threatened by drought.

Another source of higher incomes is savings from substituting renewable energy for gasoline, diesel, or grid electricity to pump water. Farmers not only use the pumps for irrigation, but also to provide water for livestock, poultry, and fish farming because they can save money on fuel or electricity for pumping water.

Despite the many anecdotes and reports provided by innovators, the information provided by beneficiaries and innovators on increases in agricultural output from solar-powered irrigation was too fragmentary to provide a basis for quantitative estimates. These same sources provided information on increases in gross incomes. The reported ranges in increases were wide: iDE provided an estimate that the Sunflower 1 pump led to increases in incomes in East Africa on the order of \$140 a year. From information provided by Claro, we calculated that Indian farmers could save \$224 a year from lower fuel costs. In contrast, Futurepump estimated that gross income increased \$4,500 per irrigated acre per year based on a customer study, although the sample was small. SunCulture reported one farmer was able to increase revenues by \$14,000 per acre per year. Both these figures seem high to us. Double or triple cropping increases revenues, but also entails increased costs for seeds, fertilizers, and often labor, as vegetables and fruit tend to be more labor-intensive and also need more care than staple crops like maize, so percentage increases in gross revenues are likely to be larger than actual increases in income. Growth in sales of solar-powered irrigation pumps has been solid, but has been driven in great part by

access to financing. Recent sales of solar pumps suggest that returns to farmers from purchases are solid, but not extraordinary.

We decided to use a market approach to estimate likely increases in gross incomes from solar-powered irrigation pumps. One of the innovators sells its pump on credit for a total payment of \$1,408 over 30 months. For a farmer to make these payments, the pump would have to provide the farmer with an additional \$563 a year in income. Because so many farmers are buying the pump, we conclude that they must be generating at least this amount in increased income annually. For competing solar pumps, we assume that differences in pumping capacity and therefore ability to irrigate leads to smaller or larger increases in agricultural output and therefore income. We adjusted our estimated increases in gross incomes by innovator on the basis of differences in pump capacity. Figure 6.1 shows our estimated increases in incomes per smallholder by innovator.



Note: To protect information provided in confidence by innovators, we have numbered innovators for each technology group, restarting from one for each new technology group.

Figure 6.1 Estimated increases in annual agricultural incomes per smallholder stemming from PAEGC-funded projects

The potential for increasing agricultural output from expanding irrigation in Sub-Saharan Africa is large. The proportion of land that is irrigated in Kenya is 25 percent, in most of the rest of Sub-Saharan Africa it is substantially less (Nakawuka et al. 2018). In contrast, irrigation is far more common in South Asia, especially India, where 40 percent of arable land is irrigated. Increasing the share of irrigated land in Sub-Saharan Africa to India’s levels would greatly increase agricultural output in the region.

However, the potential market for solar-powered pumps is more limited than these aggregate figures and some innovators suggest. Trip reports and our own interviews found that at current moment the market is smaller than claimed in some of the innovators’ proposals. Many of the farms in Sub-Saharan Africa targeted for solar-powered pumps are very small, about an acre (less than half a hectare). Because it is so difficult to make a living from such small farms, men and, to a lesser extent, women migrate to urban

areas to seek employment. In addition to farming, the wives or grandparents who stay on the farms are occupied with tending livestock and poultry, raising children, and household chores. They lack the time or energy to engage in planting additional crops during the dry season, in some cases crops with which they are unfamiliar. As noted above, crops of vegetables and fruits often are more labor-intensive than growing staple crops like corn (maize) or sorghum. Households that own these small farms also tend to be poorer than owners of larger farms and lack the funds to purchase solar pumps. Consequently, they are less likely to purchase pumps and are unlikely to benefit to the same extent from projected increases in farm output and incomes as farmers who are able to effectively utilize the pumps.

The Efficiency for Access Coalition (2019), a group that focuses on expanding access to high efficiency appliances and the use of renewable energy in developing countries (Efficiency for Access Coalition ud.). has written a study that estimates that by 2025 the market for solar-powered irrigation pumps in Sub-Saharan Africa could run 1.6 million pumps. We have used that figure to calculate the potential impact on increases in agricultural incomes of installing that number of solar-powered irrigation pumps. Using our estimate of increases in agriculture income from using one of the innovator’s pumps of \$563 a year as a proxy, if 1.6 million solar-powered irrigation pumps were to be installed in Sub-Saharan Africa in 2025, aggregate annual incomes in Sub-Saharan Africa might increase by \$900 million. It should be noted, however, that our estimates of sales by the Powering Agriculture innovators based upon their current sales trajectories total only approximately 50,000 installed pumps (or approximately 3 percent of the projected demand) as of 2025. For the Powering Agriculture innovators to reach that projected level of demand, they would need to scale their manufacturing and distribution processes by an order of magnitude in the near future—which would require these innovators to mature their businesses at a more rapid rate than was suggested by our case studies’ snapshot at the end of 2019. Alternatively, new entrants with more mature supply chains and manufacturing processes could target markets in Sub-Saharan Africa. The Davis & Shirliff example, whereby a large distributor in Sub-Saharan African markets contracted with a low-cost, high-quality manufacturer to produce a new line of solar-powered irrigation pumps, is one avenue by which 1.6 million solar-powered irrigation pumps might be sold within 5 years.

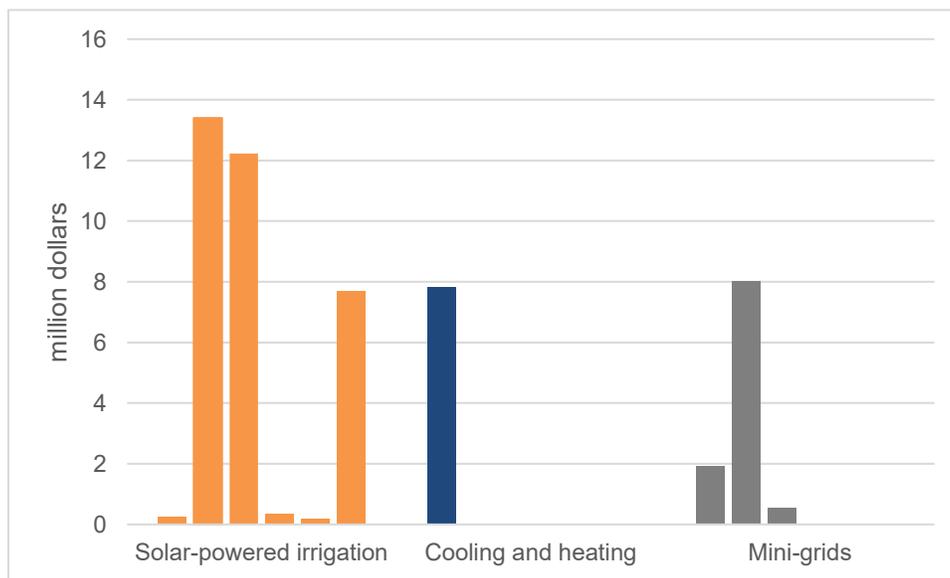


Figure 6.2 Projected gross increases in annual agricultural incomes stemming from PAEGC-funded projects

To focus more directly on the contribution of PAEGC innovators to increases in agricultural incomes, we also projected increases in agricultural incomes by innovator through 2025. To project these figures, we extrapolated from current sales data and projected sales as reported by the innovator through 2025. We then took the cumulative stock of solar-powered irrigation pumps to estimate annual increases in output stemming from the innovations. Figure 6.2 shows our projections. As can be seen, increases in agricultural incomes generated by several innovations could run \$7 million to \$14 million per year.

Reductions in greenhouse gases from solar-powered irrigation

As noted above, we based our estimates of reductions in greenhouse gases from solar-powered pumps on engineering estimates of consumption of fossil fuel-powered irrigation pumps and scientific estimates of greenhouse gas emissions per liter of fossil fuel. We assumed that each solar-powered irrigation pump either displaced or prevented the purchase of a gasoline-powered irrigation pump. For our estimates of reductions in greenhouse gas emissions stemming from solar powered irrigation, we took the pumping capacity of each solar-powered pump and compared daily flows to a representative 6.5 horsepower gasoline irrigation pump that can pump 25,000 liters of water an hour (Leo Group Pump ud.). Such an engine consumes 1.94 liters of fuel per hour (Sears ud.). We then calculated how long it would take the gasoline pump to pump the daily volume of the solar-powered pump. Based on how long the gasoline pump would need to operate, we calculated how much gasoline it would consume. We then calculated the amount of carbon dioxide that would be emitted from the combusted using 2.29 kilograms of carbon dioxide per liter of gasoline (Natural Resources Canada ud.).

The number of days that farmers use their solar pumps depends on the climate, rainfall in the particular year, the nature of the soil, the crops raised, and the number of crops the farmer plants over the course of the year. We found information on annual usage for only one innovator, Claro. Claro had assumed that the maximum utilization of its solar-powered irrigation system would be 240 days per year (20 days per month, every month), 6 hours per day (Claro 2019). Claro found that its customers used its pumps only 47 percent of that time or 113 days per year. We estimated annual savings in greenhouse gas emissions by multiplying the number of days of use (estimated at 113) times daily potential savings in greenhouse gas emissions.

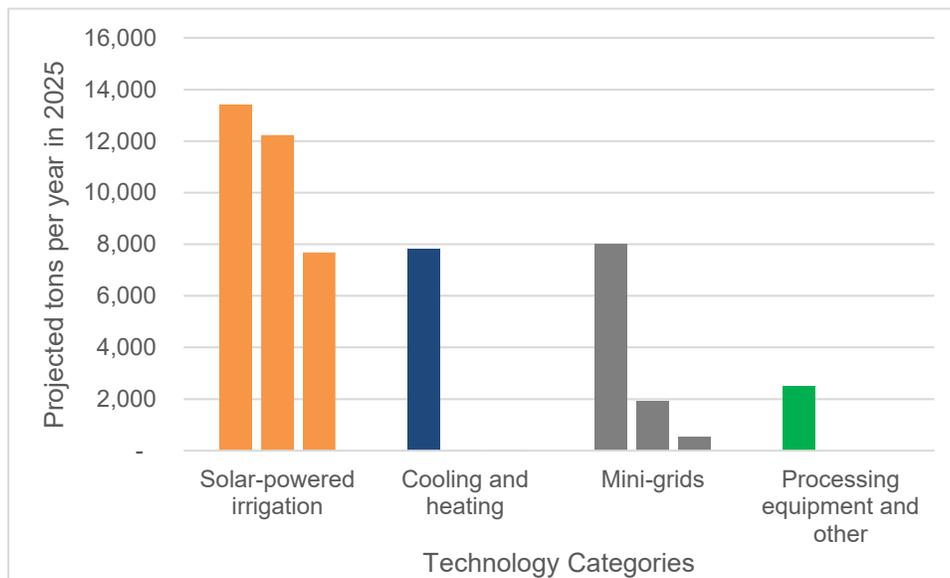


Figure 6.3 Projected reductions in annual greenhouse gas emissions in 2025 stemming from PAEGC-funded projects

The range of saved emissions of carbon dioxide by pump was 0.194 to 0.43 ton of carbon dioxide per pump per year, depending on pumping capacity. The average annual emissions of the three pumps supported by Powering Agriculture that are still on the market were Futurepump's Sunflower 2 (0.43 tons), SunCulture's Rainmaker 2 (0.3 tons), and KickStart's MoneyMaker Solar pump (0.19 tons) is 0.31 tons.

Using the same estimates of potential market size by the Efficiency for Access Coalition, we estimate that if 1.6 million households were to install solar-powered irrigation pumps in Sub-Saharan Africa and on average each pump forestalls or reduces greenhouse gas emissions by 0.31 tons per year, aggregate reductions in Sub-Saharan Africa would run 493,000 tons annually.

We also projected aggregate reductions or savings in greenhouse gas emissions by innovator in 2025 using the same methodology as we used for projecting aggregate increases in agricultural incomes.

Figure 6.3 shows those results.

Reductions in poverty from solar-powered irrigation

As noted above, there is solid evidence from reporting and sales that solar-powered irrigation pumps help boost agricultural output and farmer incomes. With the goal of increasing the incomes of poorer smallholders, most of the Powering Agriculture innovators have designed their pumps so that they would be attractive to these households. All of the pumps supported by Powering Agriculture are best suited to irrigate small fields of less than 2.5 acres (1 hectare), the size of farms that poor farmers commonly own. However, poorer smallholders have difficulty in affording the pumps. Even though some innovators have priced their pumps at less than \$700, many poor smallholders have found those prices unaffordable, even with financing. One innovator has priced its pump in the neighborhood of \$1,200 and has targeted better-off farmers. Most purchasers of solar-powered irrigation pumps to date have been farmers with larger holdings or with off-farm jobs that provide additional income that make the pumps more affordable. Claro also has targeted the poorer smallholder market in India with its pump leasing model. It, too, has struggled with smallholder affordability issues.

Improvements in gender equality from solar-powered irrigation

Innovators were attentive to gender equality issues. They designed their pumps to be light enough so that women would be better able to carry them to the field. Women often carry water to the fields in buckets, so the pumps save them time and work. In some areas women's groups share common plots of land and have bought solar-powered irrigation pumps on credit as a collective, making it possible for larger numbers of women to benefit from this technology. Usually income from these vegetable plots belongs to the women. This said, the benefits of solar-powered irrigation for gender equality tend to be indirect, as women often do not control household finances so they benefit indirectly from increased household income.

6.3 Cooling and heating with renewable energy

Increases in agricultural output or incomes from cooling and heating with renewable energy

Promethean Power Systems' chillers provide substantial benefits to milk collection centers, saving them as much as \$3,000 annually in fuel costs and reduced spoilage. For the other innovators, our estimates of increases in annual incomes for dairy farmers, primarily from selling chilled evening milk at the higher prices farmers receive from sales to commercial dairies in the morning rather than using the evening milk themselves, run from \$216 for SunDanzer to \$347 for the GIZ milk chilling project in Tunisia and Kenya.

Figure 6.1 above shows estimates of increases in agricultural incomes made possible by cooling technologies powered by renewable energy.

Promethean is a viable, growing company. Its products have been tested by the market. It has been recording solid increases in sales as it expands in markets in and outside of India. In contrast, innovators that have designed milk chillers powered by renewable energy have not yet succeeded in proving the business case for their products. Costs of production for the smaller chillers targeted at individual farmers are high relative to potential increases in incomes. Consequently, we do not see substantial increases in incomes associated with Powering Agriculture funded cooling technologies outside of Promethean's commercial applications and ColdHubs in Nigeria.

Reductions in greenhouse gases from cooling and heating with renewable energy

We estimated potential reductions in greenhouse gas emissions for each commercial cooling unit installed by Promethean at 6.7 tons per year, assuming that the cooling unit eliminates all need to use diesel powered generators for backup power. Using this estimate, if Promethean is successful in selling 500 of these units a year through 2025 (its current annual sales), the number of Promethean units installed would reach 4,200 chillers by 2025; potentially avoided greenhouse gas emissions could run 28,000 tons annually.

We estimated potential reductions in greenhouse gas emissions for both SunDanzer's FMC and the University of Georgia's Evakuula using the same methodology because the two units have almost the same capacity and tend to be powered by renewable energy. The FMC is powered by solar energy whereas Evakuula is often heated by biogas, although it can be heated by fossil fuels, like propane. We estimated potential reductions in greenhouse gas emissions by estimating emissions from a refrigerator with comparable cooling capacity powered using a diesel generator. Such a refrigerator would generate 193 kilograms of carbon dioxide per year. The solar bubble dryer for rice in the Philippines is estimated to reduce 5.5 tons of greenhouse gas emissions annually if it is used instead of a rice dryer run on fossil fuels. One of the solar dryers for fruit could reduce emissions of greenhouse gases by 0.2 tons per year. However, as of now none of these innovators has been able to sell their products at cost-recovery prices. For this reason, we have not attempted to assess the broader potential of these technologies to avoid or reduce emissions of greenhouse gases. We argue the innovators first need to show commercial viability before one can credit them with potentially having a wider impact on greenhouse gas emissions.

Reductions in poverty from cooling and heating with renewable energy

For Promethean's chillers, most of the benefits accrue to the dairies rather than the individual farmers. Therefore, the impact on reducing poverty is indirect. Smallholders and landless Indian farmers do benefit from reductions in spoilage, which would make it possible for commercial dairies to pay them higher prices for milk. Until the other technologies can be sold at cost-recovery prices, they will not have a sustainable impact on poverty.

Improvements in gender equality from cooling and heating with renewable energy

Almost all the effects of the innovations on gender equality in this category were indirect. Most of the technologies focus on chilling milk. In both Sub-Saharan Africa and South Asia, women are often heavily engaged in caring for cows and milking. Thus, these innovations have the potential for indirectly improving gender equality by raising household incomes from milking operations.

One exception was GIZ's project for a solar dryer for fruit. Gender was an integral part of that project. The University of Hohenheim designed the ergonomics of the product from a female perspective. The farm groups and small and medium-sized enterprises with which the University worked were led by women

(Schock 2019). However, the innovation has not been commercialized.

6.4 Mini-grids and micro-grids

Increases in agricultural output or incomes from mini-grids and micro-grids

Three of the projects, all mini-grids, have achieved or mostly achieved commercial viability. They benefit households through reductions in the cost of off-grid electricity and by providing more reliable power. These benefits were estimated at \$42 per year per household in the case of EarthSpark's project in Haiti and \$37 per year per household for Husk Power Systems' project in Tanzania. Ariya Finergy Limited's projects for flower farms in Kenya save an estimated \$45,100 per unit. Another project, Universidad del Valle de Guatemala's, also has the potential to benefit customers through lower cost and more reliable electricity, but the project has yet to be installed. iDE's project to provide renewable energy to fish hatcheries in Bangladesh succeeded in getting the mini-grids up and running; one follow-on installation was installed by the Bangladeshi partner.

In general, micro-grids were not successful in increasing incomes through savings in electricity costs. The capital and operating costs of the micro-grids were so high relative to the customer base that the projects could not provide electricity at competitive prices. The mini-grids also face cost challenges. Because of regulatory, organizational, and payment system challenges, if a village is connected to the grid, in general, grid electricity is cheaper than electricity from the mini-grid projects. In contrast, Ariya's commercial solar panel installations provide electricity at lower cost than the grid.

For countries that have struggled to provide grid electricity, rural household savings from mini-grids can be substantial. In Haiti 75 percent of the population, including the entire rural population, currently lacks access to grid electricity. According to EarthSpark, rural Haitians spend an average to 6.5 percent of their income on kerosene, candles, and other sources of energy, or \$42 per year. The World Bank has set up a program to install 50 mini-grids across Haiti, of which EarthSpark hopes to install 22. If each installation serves 2,000 Haitians, 50 installations would save Haitian beneficiaries \$4.16 million per year. If EarthSpark builds 22 of those installations, it would save Haitians \$1.83 million of that \$4.16 million.

Reductions in greenhouse gases from mini-grids and micro-grids

Reductions in greenhouse gases from using mini-grids powered by renewable energy rather than diesel generators are substantial on a per unit basis. Reductions range from 67 to 134 tons per installation. These estimates were calculated by estimating the number of kilowatt hours generated by the units per year and calculating the amount of diesel needed to generate these same number of kilowatt hours using a diesel generator with a similar generating capacity as the unit. Estimates for the micro-grids were calculated using the same methodology, but the reductions were much smaller, 5.2 to 7.8 tons of avoided greenhouse gas emissions per year per project.

Potential reductions in greenhouse gas emissions from EarthSpark's technology, if 22 new installations are built, would run 1,928 tons of avoided emissions per year. If Ariya successfully converts an additional 60 clients, the number of feasibility studies it has conducted for potential customers, it would potentially avoid 8,023 tons of greenhouse gas emissions annually.

Reductions in poverty from mini-grids and micro-grids

The major impact of these projects on poverty is concentrated on households in villages or towns that do not currently have electricity. Haiti and Tanzania are lower income countries. Access to lower cost electricity can have a substantial impact on disposable income. As noted above, Haitians without access to grid electricity spend 6.5 percent of their income on alternative forms of energy. In addition to cost

savings from substituting electricity from a mini-grid for kerosene for lighting or electricity from diesel generation, access to reliable supplies of electricity opens up opportunities for economic activities that would be impossible without electricity.

Those projects focused on commercial installations do not directly reduce poverty. Reductions in energy costs for flower farms do make them more competitive. As they are large employers, improvements in competitiveness should indirectly result in more employment and potentially higher wages.

Improvements in gender equality from mini-grids and micro-grids

EarthSpark made a concerted effort to hire women for its project. In addition, women entrepreneurs were some of the beneficiaries of access to electricity. The other projects did not directly address gender equality successfully, although most could have had indirect effects through the potential creation of employment for women in economic activities made possible by access to electricity.

6.5 Agricultural processing and other technologies

Increases in agricultural output or incomes from agricultural processing and other technologies

Projects in this category include agricultural processing equipment that runs on renewable energy, hydroponic systems for farms, passive aeration of fish ponds, and a solar-powered tractor, among other technologies involving renewable energy. Three of the innovators achieved or mostly achieved business development objectives: Eco Consult, Village Infrastructure Angels, and GIZ's energy efficiency pilot project for Kenya's tea industry. We were unable to obtain much information on increases in agricultural output or incomes from Eco Consult's hydroponic farm projects. However, the expansion of hydroponics installations from the proposed two to eventually 22 attests to the underlying profitability of the technology. Village Infrastructure Angels has installed over 800 processing mills in Vanuatu and Sumba Island, Indonesia. They have been warmly received. Before they were installed, people, primarily women, manually processed crops or took them to a larger town to be processed at a mill. However, we were unable to estimate a per user economic benefit for the technology because of lack of data. Energy efficiency measures in the Kenyan tea industry generated savings of \$67,000 (60,000 euros) per plant. The rest of the projects only partially achieved or did not achieve business development goals: they have not yet reached a point where they have sold products commercially or at a price that covers manufacturing and distribution costs. They have yet to have an impact on agricultural output or incomes.

Reductions in greenhouse gases from agricultural processing and other technologies

The only project for which we estimated substantial reductions in emissions of greenhouse gas emissions was the GIZ Kenyan tea efficiency pilot project. Through reductions in energy use, the project reduced emissions of carbon dioxide by 36.76 tons per plant (GIZ 2019). If all 68 Kenyan tea plants adopt these procedures, potential reductions in greenhouse gas emissions could run 2,500 tons per year. Eco Consult ended up not using solar energy, so we calculated no reductions in greenhouse gas emissions. For the Village Infrastructure Angels' project, we lacked data on annual consumption of diesel fuel for comparable mills, so we were unable to estimate potential reductions in greenhouse gases emissions. The rest of the projects had only developed prototypes or had not achieved technological development goals. We did estimate that the Motivo tractor, if rented out 365 days a year, could potentially reduce greenhouse gas emissions from displaced diesel by 2.4 metric tons annually.

Reductions in poverty from agricultural processing and other technologies

With the exception of Village Infrastructure Angels' and the Kenya tea efficiency projects, these projects either had not progressed to a point where they had a discernible impact on incomes of the rural poor or were targeted towards individuals who had more means. Village Infrastructure Angels' solar mills significantly reduce the time required to process food compared to manual processing, the method lower income households typically use to process their crops. Some of the time saved has been used to generate additional income by these poor families. Because the Kenyan tea factories that fall under the KTDA umbrella are owned by smallholders, the reductions in energy costs directly benefited smallholder shareholders in the plants.

Improvements in gender equality from agricultural processing and other technologies

Village Infrastructure Angels reported several positive impacts on gender equality from the introduction of its solar-powered mills. Women save 3 to 4 hours a day in time formerly spent manually processing food; women traditionally end up with those tasks. Manual processing is physically demanding and can be physically painful at times; solar-powered processing equipment eases the burden (Chavez 2018). Women also play a fundamental role in VIA's team from global management to local operations. Most of the other projects in this category were not designed to or directed at improving gender equality.

6.6 Overall assessment of impacts

Increases in agricultural output or incomes

Our estimates for annual increases in incomes associated with solar-powered irrigation pumps were \$563, and for mini-grids \$37 to \$42, per household. For individuals who live below the World Bank's poverty line of \$1.90 a day (\$700 a year per capita), increases in income of this size, even though at the household level, are tangible. Estimates of gross increases in incomes from off-grid household cooling technologies ranged from \$216 to \$347 per year, but because of the relatively high cost of household units, innovators have yet to show they can sell household units at a price that covers costs. SimGas went into bankruptcy because it was unable to sell its biodigester at a profit and was unable to bring its milk chiller to market. In contrast, projects involving solar-powered irrigation pumps and mini-grids have either been able to sell or operate their installations at breakeven levels or show promise of so doing. Within the "Other" category, only the GIZ tea factory efficiency pilot project had generated concrete financial savings.

Reductions in greenhouse gases

Solar-powered irrigation pumps could have a substantial impact on reducing or forestalling emissions of greenhouse gases from diesel- or gasoline-powered irrigation pumps in LMICs. According to one innovator in Africa, one-third of customers for his solar-powered irrigation pumps had previously used gasoline- or diesel-powered pumps (Futurepump 2017). In India, virtually all the farmers that use solar-powered irrigation pumps had previously used diesel-powered pumps or electric pumps working off the grid. Replacing these pumps with solar-powered pumps has the potential for a large impact: in addition to reductions in the use of diesel, as much as 70 percent of grid electricity in India is generated by fossil fuels (Penmetsa and Omohundro 2019). India's 9 million diesel irrigation pumps consume approximately 4.23 billion liters of diesel a year for irrigation and emit 11.4 million metric tons of carbon dioxide annually (GIZ 2018). Pumping water for irrigation may consume as much as 20 percent of the diesel fuel consumed in India annually (Mishra 2019). If all these pumps were replaced by solar-powered pumps, the savings in diesel and reducing greenhouse gas emissions would be large.

Solar-powered mini-grids, especially if they replace diesel generators, also have the potential to substantially reduce emissions of greenhouse gases in LMICs. Estimates of avoided emissions of greenhouse gases range from 66.5 tons per system per annum for Husk Power Systems to 133.7 tons for Ariya's solar arrays. It is notable that Ariya's installations—which focus on industrial-scale producers—reduce more greenhouse gases per installation than the mini-grids aimed at residential and small-scale commercial customers such as EarthSpark's Haiti projects or the UVG product in rural Guatemala. Because innovators in off-grid household cooling technologies have yet to show they can sell their units at cost-recovery prices, the potential for substantial reductions in emissions of greenhouse gases from these technologies is low.

The Kenyan tea industry energy efficiency pilot project led to reductions in 2,500 metric tons of greenhouse gases per year. As of 2025, Promethean's chillers and the projected annual sales of Futurepump and SunCulture's tens of thousands of irrigation pumps could lead to declines in greenhouse gas emissions of 7,820 tons, 13,400 and 7,675 tons respectively. The substantial greenhouse gas reductions associated with this small GIZ-supported pilot project suggest the potential benefits that might accrue to similar energy efficiency projects aimed at large African manufacturers and underlines the utility of some capacity building measures. To the extent to which other large industrial plants are inefficient users of fossil fuel-derived energy, a focus on increasing energy efficiency may lead to large greenhouse gas emission reductions at low cost. Outside of the tea factory efficiency project, the potential for substantial reductions in emission of greenhouse gases in the "Other" appears small.

Reductions in poverty

Most of the Powering Agriculture innovators have targeted technologies designed to help the rural poor. In practice, many of the technologies, especially renewable energy cooling and heating and agricultural processing technologies, are too expensive for poor rural households. Innovators who have targeted solar-powered irrigation pumps have also struggled with reducing costs to the point where poor rural farmers can afford these technologies. The costs of electricity from mini-grids tend to be more expensive than grid power, although less expensive than electricity from diesel generators.

Some of the projects, like Promethean's, Ariya's, and GIZ's energy efficiency project for tea factories, that have scored well on business development and diffusion, have targeted commercial clients rather than poor smallholders. However, they have indirectly benefited poor households. Promethean's products reduce milk spoilage, thereby raising the profitability of milk processing and potentially leading to higher prices for milk. The Kenyan tea factories operated by KTDA are owned by 560,000 smallholders that grow the tea that is processed. Reductions in operating costs benefit these owners.

There appears to be an inverse relationship between projects' potential for reducing greenhouse gas emissions and their focus on reducing poverty. To a certain extent, this finding is unsurprising. Poor smallholder farmers currently have little access to fossil energy-powered irrigation pumps or chillers; they rely on manual irrigation methods and farming practices that do not require access to refrigeration. Even if these farmers were using diesel-fueled pumps and chillers, the small scale of their operations requires relatively little diesel fuel, so that each farmer switching to a solar powered irrigation pump or chiller avoids tenths of a metric ton per year of CO₂ emissions. Larger producers have the capital to invest in fossil fuel-using machinery that uses hundreds or thousands of liters of diesel fuel per year—and to replace those generators, boilers, pumps, and chillers with low-emissions technology.

Improvements in gender equality

Powering Agriculture's concrete effects on gender equality were hard to measure. Innovators were cognizant of gender equality issues and in many cases designed their products to be more ergonomic for female customers. Out of the 24 PAEGC innovators, 15 (54 percent) articulated a specific goal of

promoting gender equality, such as saving women time through the use of the innovation (PAEGC 2016e). A few of the Powering Agriculture innovators were able to point to direct impacts on gender equality from their projects. Some projects, such as EarthSpark's, worked proactively to involve women at the design stage, to prioritize providing women with employment opportunities, and to involve female entrepreneurs as project stakeholders and beneficiaries. VIA is another project notable for involving women as implementers as well as beneficiaries. Projects that substitute technologies using renewable energy for manual labor were often beneficial to women, as women are often responsible for these tasks. Unfortunately, some of the projects that had a more direct focus on gender equality issues, like SimGas, were unsuccessful in developing their businesses. Others, like the University of Toronto's project, never emerged from the technological development stage, so that the numbers of female beneficiaries were very small. ICU made a deliberate effort to provide financing to female farmers, but when financing disappeared that effort was limited. Those innovators who were most successful at diffusing their technologies, like SunCulture, and Promethean, did not show evidence that their efforts to pursue gender equality had had substantial impact, as they did not have differentiated gender approaches to customers.

Market-based development programs like Powering Agriculture are likely to struggle to address issues of gender equality because the success of the innovators depends so heavily on the structure of the market in which they are attempting to operate. For instance, fish farmers in Bangladesh tend to be men; the impact on gender equality of a project like the University of Toronto's that focuses on fish farming is circumscribed by the gender composition of its prospective customer base. Lack of access to finance or land tenure issues that dictate whether women can purchase solar-powered irrigation pumps, for example, also limit efforts to improve gender equality. Innovators are poorly positioned to address these constraints.

Although many of the innovations had positive effects on gender equality, from enhancing female incomes to reducing the physical burden of fetching water or processing crops, in most cases gender equality issues were of secondary importance to the innovators. Virtually all the innovators had to focus on keeping their businesses, non-profit or for-profit, economically viable. Consequently, most projects were focused on increasing agricultural incomes so as to make their products attractive to prospective buyers, and did not have substantial impacts on gender equality.

6.7 Conclusions

PAEGC has had a tangible impact on increasing farm incomes from solar-powered irrigation. Rural households also enjoyed savings of up to 6.5 percent of their incomes from the substitution of electricity purchased from mini-grids for purchases of electricity generated by diesel generators or the use of kerosene or candles. Several of the innovations reduced emissions of greenhouse gases and other pollutants from the combustion of gasoline or diesel fuel. However, rural households in LMICs contribute little to global emissions of greenhouse gases; in aggregate these reductions are modest. Because so many smallholder farmers fall under the global definition of poverty, increases in agricultural incomes stemming from PAEGC reduce poverty. However, solar-powered irrigation pump manufacturers targeted higher income smallholders because of affordability issues. In practice, many of the PAEGC technologies, especially renewable energy cooling and heating and agricultural processing technologies, are too expensive for poor rural households. Virtually all the innovators had to focus on keeping their businesses, non-profit or for-profit, economically viable. Although many of the innovations had positive effects on gender equality, in most cases gender equality issues were of secondary importance to the innovators.

7. Assessment of other Powering Agriculture activities

PAEGC's funding of \$51.7 million supported four program components: (1) technology and business model innovation, (2) commercial financing, (3) mainstreaming and acceleration, and (4) knowledge management. PAEGC used \$24.5 million of this funding for direct grant awards to the 24 funded innovation projects. The rest of this funding has gone to activities that support these program components: technical assistance, training, and outreach; knowledge management; and support for financing through the Powering Agriculture Investment Alliance. In addition, BMZ through GIZ has separately funded 10 small-scale technology development pilot projects similar to the PAEGC awards that it has included under the PAEGC umbrella. It has also provided technical support to organizations working on issues pertaining to renewable energy and agriculture.

In this chapter we review and comment on these activities. We describe the activities and review outputs (e.g., number of training activities, number of participants) where data are available. Given the breadth of the activities and time and resource constraints, we were unable to conduct large-scale surveys of the intended beneficiaries, which would have been useful to provide quantitative measures of outputs. We have drawn on information from PAEGC Annual Reports, mid-term evaluations, innovator reporting data and other documents from Webmo, and interviews with PAEGC stakeholders regarding these activities. STPI also interviewed Tetra Tech, VentureWell, and innovators concerning business and technical assistance under Powering Agriculture. We probed the extent to which innovators knew of these supporting activities, participated in them, and benefitted from them. As part of the visit to Kenya, the STPI team visited the GIZ Hub to meet with staff and gain first-hand information regarding the GIZ Hub's activities and results to date. STPI staff also visited the Ngere Tea Factory to meet with participants in that GIZ pilot project—the KTDA energy efficiency training and measures for the Kenyan tea industry. We have also interviewed employees of AlphaMundi and Factor[e] who have supported Powering Agriculture through the Investment Alliance. We also discuss support for CLASP and subsidies for purchases of solar-powered irrigation pumps. Although we have incorporated the achievements and impacts of the 10 GIZ pilot projects in the chapters on outcomes and impacts above, in the last section of this chapter we compare the accomplishments and characteristics of those projects to those of the 24 innovator awards.

7.1 Technical assistance, training, and outreach

Technical assistance

Under PASTO, USAID contracted with Tetra Tech, a firm engaged in providing support for development assistance programs, to monitor the performance of the recipients and to provide them with technical support. PASTO has provided innovators with implementation assistance such as feedback on milestones, guidance on monitoring and evaluation, assistance with compliance with USAID policies and procedures, including award modification, and templates/manuals/guides for innovators' use. It has also provided training on gender integration, compliance with legal regulations, revising milestones, and monitoring. It has promoted innovator progress on the Powering Agriculture website, on social media (Facebook and Twitter), and has conducted media outreach (PAEGC 2019). In a mid-term survey, 81 percent of innovators ranked the performance of PASTO as good or excellent (PAEGC 2016).

The PAX program is part of PASTO. Under PAX, VentureWell, in association with Investors' Circle, was subcontracted by Tetra Tech in September 2015 to assist innovators to accelerate the development of their businesses by providing tailored advice on how to manage businesses problems and to attract investors, as well as on gender integration. VentureWell has supported innovators after the end of the innovators' awards. It is a 25-year old non-profit whose original mission is to help companies get innovations out of the laboratory and into the market. It brought that expertise to Powering Agriculture.

VentureWell provides technical assistance to PAEGC innovators by drawing on its business accelerating techniques for science and technology, and expertise on customer discovery, business model development, fundraising strategies, team building, and knowledge of the innovator's product and market. It has assigned portfolio managers to implement customized work plans developed based on ongoing innovator specific needs assessment (PAEGC 2019). It also provides remote coaching based on demand, holding monthly calls or monthly touchpoints with the PAEGC innovators. During these contacts, VentureWell reviews marketing materials, business plans, and other documents and materials, and helps innovators find contacts and resources. VentureWell does not provide advice on engineering issues. In some cases, VentureWell has undertaken field visits to provide on the ground training for PAEGC innovators. VentureWell has also held three workshops for the innovators. The workshops broke the innovators into groups based technology, stage of development, and organizational structure. Their goal has been to improve the chances that innovators will meet milestones (Interview with VentureWell).

In our interviews with PAEGC innovators, those who have availed themselves of VentureWell's services were highly complimentary. However, during our phone interviews, several of the innovators said they had been unaware of VentureWell's and other PASTO's services prior to the PAX workshops. According to one of the mid-term evaluations, PAX is viewed by several innovators as having helped to accelerate the development of their businesses (Raetzell and Seidler 2016 p. 24, 27). Feedback from innovators concerning the workshops has been generally positive, although one innovator wished the workshops had provided more detailed, advanced information and included more innovator collaboration to utilize their collective experiences.

As noted above, PASTO also provided innovators with assistance in gender integration, including a gender assessment and on-demand assistance to improve data collection practices and knowledge of female beneficiaries. PASTO helped produce six guides providing practical advice for integrating gender into business practices (PAEGC 2020). Assistance with gender integration evolved over time. Initially, Sida took the lead and conducted a study. This was followed by the development of on-demand gender technical assistance. However, innovators were often slow to use this assistance. PAEGC found that innovators need concrete actions that they can take with regard to gender integration, but these actions must also help improve profitability and business operations if they are to be adopted (interview data).

Some innovators, such as EarthSpark and VIA made gender equality primary components of their business strategies. However, despite PASTO's assistance to help innovators make gender equality an important component of their business strategies, evidence that innovators had a tangible impact on gender equality was often limited to anecdotes pertaining to just a few beneficiaries.

GIZ set up a regional hub in Nairobi in January 2016 to support GIZ projects for East Africa, including those that fall under PAEGC. The hub links PAEGC innovators to other GIZ activities and facilitates exchanges among innovators and other stakeholders through events and workshops (Raetzell and Seidler 2016). The section of the hub that supports Powering Agriculture has focused heavily on solar powered irrigation, 30 to 40 percent of its efforts. The remainder of its activities have been devoted to energy efficiency, cooling, and agro-processing using renewable energy (Interview in Nairobi with GIZ). One of the hub's major activities has been the implementation of the Kenya tea energy efficiency pilot project.

The GIZ team at headquarters with support from the GIZ hub has been continuously working on the development of the Toolbox on Solar-Powered Irrigation Systems (SPIS). GIZ developed the SPIS Toolbox in collaboration with the Food and Agriculture Organization (FAO). It is designed to enable advisors and practitioners in the field of solar irrigation to provide broad hands-on guidance to end-users, policy makers and financiers (Nexus 2017). The Toolbox consists of eight modules supplemented with 14 tools that can be used to assess water requirements, compare the financial viability of proposed projects, determine farm profitability, and highlight critical workmanship quality aspects of proposed solar-powered irrigation systems. The key target group is advisors, not end-users (Interview with GIZ). The Toolbox has

been used by large numbers of extension agents and distributors to determine if it makes sense for a farmer to invest in solar-powered irrigation, and if so, what technologies are most appropriate (Interview with GIZ). It was officially launched in April 2018 at the Forum on Solar Powered Irrigation in Rome and has also been downloaded nearly 65,000 times. GIZ has invested heavily in the product and continues to refine it. It is currently working on making an app to host the tools on phones rather than using Excel sheets on laptop.

Powering Agriculture's support for the 2019 Global LEAP+RBF program for solar water pump bulk procurement has resulted in the subsidized procurement of 3,104 solar water pumps from 47 selected distributors in 7 countries. PAEGC innovators Futurepump, Kickstart and SunCulture were among those manufacturers whose pumps have been qualified. Powering Agriculture has allocated \$458,000 for these bulk incentives; the total amount of the bulk procurement incentives spent through early 2020 was \$240,703. The program also provided training in solar-powered irrigation (PAEGC 2020).

We lacked adequate information to evaluate this Powering Agriculture activity. On the one hand, providing subsidies from which all qualified purveyors of solar-powered pumps can benefit promotes economic efficiency by leveling the competitive playing field. Purchases are not skewed towards a particular product because of the subsidy. On the other hand, subsidies can result in overinvestment in solar-powered irrigation pumps. As an example of unwanted consequences of subsidies, subsidies on biodigesters have resulted in the installation of large numbers of biodigesters in East Africa. We were informed that more than half these digesters are no longer being used. Subsidies for biodigesters encouraged households to install them even though the households were not committed to using them. In some instances, we found a similar situation with solar-powered pumps; some smallholders that had received the pumps for free or at heavily subsidized prices, only used them occasionally (site visit observation).

Training

Demand for training on SPIS has been high, attesting to the success of the product. GIZ has played a major role in providing training in support of SPIS and in disseminating the program. Initially, GIZ was the primary purveyor of training for SPIS, but demand has become so large that GIZ has had to build a training base to train the trainers. In order to contribute to the sustainability of the Toolbox beyond the Powering Agriculture program, GIZ started to conduct training of trainers. So far, GIZ has trained 29 trainers. The course involves both hands-on and theoretical training. Individuals who pass the course are entered into a database that includes their name, contact information, language, and background. Certified trainers include individuals from Kenya and other countries in East Africa, francophone West Africa (Mali, Côte d'Ivoire etc.), Tunisia, Italy, and the Middle East. The trainers need to have a good knowledge of the local context, of solar PV, and irrigation. Students of the training sessions include civil servants, project managers, entrepreneurs, and employees of NGOs. Training has played an important role in the diffusion of solar-powered irrigation systems by educating a wide range of trusted, knowledgeable individuals about the systems who have been able to guide farmers to systems that are most appropriate to the farmers' needs.

GIZ has also developed and offered the Massive Open Online Course (MOOC) on Sustainable Energy for Food. The course, first offered in 2016, introduces students to solutions for sustainably providing energy throughout all stages of agricultural value chains. It provides detailed information on conducting energy efficiency audits, calculating benefits and costs of renewable energy technologies, reviewing agricultural technologies that use energy on day-to-day basis, and measuring emissions of greenhouse gases from agriculture. Students analyze challenges concerning the use of renewable energy in agriculture, examine concrete technologies for providing access to clean energy, and investigate market conditions, politics, and financing schemes of "Powering Agriculture-type" projects. Learning materials include readings and videos and weekly assignments that employ newly learned skills (Powering Agriculture 2016a).

Based on interview information from people who have taken the course in Kenya, interviews with GIZ staff in Nairobi, PASTO reports, and the number of students who have taken the course, MOOC has been well received. As of 2020, more than 1,700 individuals from around the world had participated in the 8-week course, of which over one-third have been women (PAEGC 2020). Students have been predominantly from Sub-Saharan Africa (40 percent), Europe, and Asia. Based on our own interviews and interviews with stakeholders conducted during the mid-term evaluations, the program has been regarded as a success, providing training for a wide range of individuals across a large number of countries (Raetzell and Seidler 2016 p. 29). Building on its successes, the MOOC materials and case studies were adjusted for the Caribbean region. The course named CaribOOC was piloted in spring 2017. It ran in partnership with GIZ Project REETA (Renewable Energy and Energy Efficiency Technical Assistance), GIZ Academy for International Cooperation (AIZ), and the Inter-American Institute for Cooperation on Agriculture (IICA) with support from TH Köln and the University ISA, Santiago, Dominican Republic.

Through PASTO and with additional support from SIDA, PAEGC made a concerted effort to provide training and other support to assist innovators to integrate gender into their operations. SIDA developed a gender gap analysis and tools to help innovators integrate gender into their business strategies and plans (PAEGC 2020). PASTO provided innovators with a gender assessment, on-demand assistance to improve data collection practices and knowledge of female beneficiaries, and produced 6 guides providing practical advice for integrating gender into business practices (PAEGC 2020). Early on in the program PASTO hired a gender specialist to further expand gender integration support for all Innovators with a focus on gender equity. Many of the innovators designed products that were beneficial to women, but interest in the services provided by the gender specialist was mixed (interview data). Innovators who had not previously focused on gender equality issues generally did not place a primary emphasis on gender equality (interview data).

PAEGC also financed Empowered Entrepreneurship Training, a program put on by Johns Hopkins University (PAEGC 2020). Because the training took place after the research phase of this Summative Evaluation, STPI was unable to conduct its own assessment of the Training. However, PAEGC was pleased with the uptake, and almost all of the companies engaged were going forward with plans to roll-out the training (PAEGC 2020). The training helped the innovators to better integrate gender into their operations. Innovators were complimentary concerning the program. However, many companies lack the expertise and time to identify practical actions that can support their underlying business practices (PAEGC 2020).

Both GIZ and PASTO have developed other training materials, course curricula, and documentation related to using renewable energy solutions in the context of agriculture. GIZ has provided support to Strathmore University's Energy Research Centre for training courses in energy management, solar irrigation pumps, transmission and distribution grid servicing, among others (Strathmore University ud.). The Centre provided training in support of GIZ's Energy Efficiency in Kenyan Tea Factories project.

Outreach

Powering Agriculture has conducted outreach through conferences, workshops and at international development meetings pertaining to sustainable agriculture and the energy-agriculture nexus. As discussed in the Knowledge Management subsection below, Powering Agriculture has also actively engaged in outreach activities through Internet sites, including the Energypedia portal.

PAEGC has hosted workshops, events, and promoted or financially supported innovators to attend conferences such the Social Capital conference (SOCAP). The purpose of these activities has been for innovators to share experiences with one another and meet investors. VentureWell has used these meetings to hold its workshops on business development. Solar Cooling Engineering's DIY training

course on configuring and building cooling units with local materials is another avenue through which Powering Agriculture has conducted outreach concerning renewable energy cooling technologies.

Feedback we gathered from innovators concerning these conferences, especially SOCAP, has been very positive. We met with almost a dozen individuals who had participated in the Powering Agriculture Solar Cooling Engineering Technical Training and Promotion Conference held in Nairobi in March 2019. The individuals were highly complimentary of the training and outreach effort, as it brought together stakeholders who had not previously known each other at a venue where they could discuss and share solutions to major problems (Site visit interviews).

Post-conference surveys of participants at other Powering Agriculture events have also been positive. After the January 2018 PAX workshop in Nairobi, 95 percent of those who took the survey said the workshop met or exceeded their expectations, 63 percent stated that their own projects would improve as a result of their participation in the workshop, and 96 percent said the workshop was “very” or “extremely effective” in helping them connect with fellow innovators (PAEGC 2019).

7.2 Knowledge management

GIZ on behalf of BMZ has taken chief responsibility for knowledge management under Powering Agriculture. Activities are designed to communicate Powering Agriculture’s objectives and activities, share innovator success stories, build awareness of the nexus between clean energy and agriculture, and disseminate results and knowledge that have been gathered or generated by Powering Agriculture (Powering Agriculture 2019).

Powering Agriculture uses print and online media outlets and social media to communicate with its stakeholders. Its primary mechanisms include its website, poweringag.org, which focuses on communicating information concerning the program. As of 2020, the website had 239,932 total sessions, 176,616 total users, and 482,996 visits (PAEGC 2020). The Powering Agriculture Portal on energypedia.info provides a wide range of information and knowledge as well as training materials on the clean energy agriculture nexus; it publicizes activities and innovator successes and provides networking opportunities among experts (Raetzell and Seidler 2016). It also provides a forum to communicate research and exchange knowledge.²³ The portal had received 129,628 visits as of end 2019 (PAEGC 2020). The *Powering Agriculture E-Newsletter* publicizes activities and innovator successes. The GIZ newsletter *Solar Pumping and Irrigation* has been published three times and presents the latest developments in the field of solar pumping and irrigation. Powering Agriculture also uses social media like Twitter and Facebook. These social media platforms amassed 6,850 followers (PAEGC 2020). The Powering Agriculture Dashboard informs senior management and partners about programmatic and innovator updates.

In our view, Powering Agriculture’s knowledge management efforts have been positive. Powering Agriculture has established its brand name: it has received substantial coverage in the development press. The popular press has written articles about innovators supported by Powering Agriculture and covered the program itself. Although innovators have complained about lack of information about some Powering Agriculture services, including PAX, in general websites are easily navigated and program information is kept up to date and available.

²³ The portal is at www.energypedia.info/wiki/Portal:Powering_Agriculture.

7.3 Powering Agriculture Investment Alliance

As part of its activities, in 2018 PAEGC set up the Powering Agriculture Investment Alliance (Powering Agriculture 2019). The purpose of the Alliance is to catalyze private sector financing for businesses that have been recipients of PAEGC grants or that provide clean energy solutions to increase agriculture productivity or value in developing countries. AlphaMundi, a Swiss-based impact investor, and Factor[e], a U.S.-based venture development firm focused on sustainable energy in LMIC countries, form the core of the Alliance. Powering Agriculture has provided them funding to help offset costs associated with identifying early-stage companies in the energy-agriculture nexus and assisting them in obtaining follow-on funding. The award is designed to catalyze \$25 million in private sector finance from and through these partners for ventures in the provision of clean energy to the agricultural sector in LMICs (Powering Agriculture 2019).

To conduct its review of the Alliance, STPI interviewed managers from both companies and representatives of companies in which the two have invested. STPI also interviewed innovators, other beneficiaries of the Alliance, and other stakeholders and visited offices of some of the companies in which the two organizations have invested on our site visit to Kenya and Uganda. STPI also used information gathered on the Internet about the investors and companies and from PAEGC documents.

Although it is too early to compare results from PAEGC funding for innovators with those from the Alliance, we found some notable difference between the two programs. Although like PAEGC, AlphaMundi has issued a global call for proposals, it and Factor[e] employ more proactive mechanisms than the requests for proposals used by PAEGC to attract applicants for the innovator funds. Both companies use outreach at industry events and conferences to identify potential investment targets. Factor[e] also conducts business plan competitions. They also set more constraining criteria for selecting recipients of funds. The companies they target generally have to have a well-developed technology that has been piloted and validated, although at times Factor[e] does invest in companies with early stage technologies. In most instances the product is already on the market and the company has well-articulated plans for expanding sales and becoming profitable. AlphaMundi assists companies to overcome one or two hurdles to receiving additional funding and therefore to expanding their operations toward commercialization. AlphaMundi Foundation's technical assistance efforts focus more on corporate governance and operations than on developing new products or engineering R&D.

Based on its investment criteria, out of the companies to which AlphaMundi has provided assistance under the Alliance, only two were recipients of Powering Agriculture innovator awards. One interviewee said that the relatively low number of Powering Agriculture innovator awardees reflects the failure of most of the awardees to have developed clear plans to commercialize their products and expand product sales.

Beneficiaries of the program were highly complimentary. A major problem for the PAEGC innovators has been raising funds to expand their operations. The advice and investments provided by AlphaMundi Foundation and Factor[e] were considered invaluable by those who have benefited from them.

7.4 GIZ pilot projects

The GIZ pilot projects differed from the innovator awards in several respects. First, GIZ pilots were funded at much lower levels than the 24 PAEGC innovator projects. Most projects were funded for under 200,000 euro (\$240,000), at times less. In contrast, the PAEGC innovator awards for round two were split into two groups, both of which had higher funding thresholds: Clean Energy Solution – Design of up to \$500,000 with almost all awards near \$500,000 in value, and Clean Energy Solution Scaling Up/Commercial Growth with awards ranging between \$500,000 and \$2,000,000.

The GIZ projects were focused on a more limited set of technologies and had more of a technological focus than the PAEGC projects. Five of the eight GIZ case studies solely developed or piloted technologies: Solar Milk Cooling in Kenya and Tunisia, Cold Rooms for Fruit and Vegetable Growers in Nigeria, Solar Bubble Dryer Optimization, Improved Solar Drying, and Solar-Powered Sesame Oil Production. The solar powered irrigation case study focused on developing software and analytical tools. The most successful project, Energy Efficiency in Kenyan Tea Factories, included the development of energy auditing instruments, training, and support for energy committees in tea factories in Kenya. RaSeed Solar-Powered Irrigation in Egypt was more commercially focused: it involved installing a large solar array to run irrigation pumps on a large farm in Egypt.

In contrast to the PAEGC innovator projects, the GIZ projects had more recurring partners. One participant, the University of Hohenheim, participated in four of the eight projects, although participants included different departments within the university. None of the projects was led by for-profit firms; four were led by non-profit organizations headquartered in the country where the work was performed: for example, the Smallholder Foundation in Nigeria.

We evaluated the outcomes and impact of the GIZ pilot projects in conjunction with our assessments of the 24 PAEGC awards to innovators. All of the GIZ pilot projects achieved or mostly achieved technological objectives. In contrast, four (one-eighth) of the PAEGC innovators did not achieve or only partially achieved technological objectives.

Not surprisingly, because it was not their focus, the GIZ pilot projects did less well than the PAEGC-funded innovators funded in achieving objectives for business development and diffusion. We assessed only two of the eight projects, the energy efficiency project for Kenya's tea plants and the solar milk chilling case study, as having achieved or mostly achieved business development objectives. In contrast, we assessed 13 of the 24 PAEGC-funded innovators as having achieved or mostly achieved business development objectives.

We ranked the GIZ energy efficiency pilot project for Kenya's tea plants as the only project among all the projects as having fully achieved objectives for diffusion. However, of the rest of the GIZ projects, six did not achieve and one partially achieved objectives for diffusion. In contrast, three of the PAEGC-funded innovators mostly achieved objectives for diffusion and nine partially achieved objectives. In short, the GIZ pilot projects were more focused on developing technologies than the PAEGC-funded projects.

GIZ projects resulted in the spin out of Solar Cooling Engineering and ColdHubs. Solar Cooling Engineering has successfully reduced costs of its SelfChill Cooling Unit to 400 euro, 30 percent less than the model that had been developed with GIZ support. However, outside of these two spin-offs and the energy efficiency project for Kenya's tea plants, in general the projects did not result in the development of businesses or the diffusion of technologies. Like some of the other Powering Agriculture innovators who focused on developing new products and technologies, the costs of the products generated by the GIZ pilot projects were often too high to be commercially viable. Although costs could be reduced if the products were to be manufactured at scale, in general the GIZ pilot projects did not have a formal plan for moving the technologies to market and encouraging broad diffusion. Although business development and product diffusion were not the focus of the GIZ projects, many of the technologies face the risk of never being commercialized.

7.5 Conclusions

In general, innovators were complimentary concerning technical support provided by PAEGC. Tetra Tech's support through PASTO was rated favorably by innovators. PASTO provided feedback on milestones, guidance on monitoring and evaluation, assistance with compliance with USAID policies and procedures, including award modification and training in gender integration. VentureWell's provision of

tailored advice through PAX on how to manage businesses and to attract investors was highly praised. In particular, the workshops where innovators met with each other and jointly worked on solving problems were highly rated. GIZ-supported knowledge products like the SPIS Toolbox and the MOOC offered on Sustainable Energy for Food were considered highly useful by those who have participated in the courses. The Toolbox, in particular, has contributed to the diffusion of solar-powered irrigation pumps in East Africa. Among Powering Agriculture outreach activities, innovators were the most enthusiastic about support for conference attendance. SOCAP, in particular, was found to be an excellent venue to contact potential investors.

The Powering Agriculture Investment Alliance has been tasked with catalyzing at least \$25 million in private sector finance for innovators in renewable energy and agriculture from its two partners, AlphaMundi and Factor[e], who are social impact investors. The Alliance partners had invested \$1.2 million of their own funds by December 2019 and have invested in three companies. It fills a need identified by innovators in one of the mid-term reviews. However, few PAEGC innovators meet their criteria for investment. AlphaMundi and, for the most part, Factor[e] do not invest in companies that are still in the product development phase, excluding a substantial share of Powering Agriculture innovators.

8. PAEGC processes

Although the primary focus of this summative evaluation has been on the outcomes and impacts of PAEGC, we also assessed the processes and procedures employed by PAEGC. We drew on information provided from our interviews with innovators and PAEGC stakeholders, site visits, and the two mid-term evaluations (Raetzell and Seidler 2016; Powering Agriculture 2016). Each section begins with summaries of results from the mid-term evaluations before introducing new data collected as part of the outcome evaluation. Interviewees are not identified by name to protect the confidentiality of their responses.

8.1 Application process and selection of awardees

Application process

The mid-term evaluations found that applicants considered the application process to be straightforward, logical, and well run, although some concerns were noted, especially with respect to communications by the partners with the applicants and the length of the application and review process. These concerns were mitigated during the second round of awards (Powering Agriculture 2016; Raetzell and Seidler 2016). The mid-term evaluations' findings were replicated in STPI staff's interviews with the innovators. In general, innovators were positive about the two-stage grant application process. One innovator said the process was straightforward. However, the innovator was familiar with the application format and acknowledged that the application might not be as simple for applicants from smaller companies with less experience in applying for grants. Two innovators said grant applications for PAEGC were less demanding than other USAID awards for smaller amounts of money. In contrast, another innovator said that while the award application process was not difficult, he found it to be more work in comparison to other grants that he had received in the past.

Selection goals

Awardees could apply to Powering Agriculture for a range of activities: developing a new technology, piloting a technology for commercialization, expanding their business, or using the award to enter new markets. The mid-term evaluations found that innovators considered their projects to be split between those that were still at the concept stage at the point of application and the other half that had begun or completed development of their products. The evaluations also found that innovators recommended that the program define distinct criteria for early-stage projects and for projects that had already shown themselves to be developing technically feasible solutions (Powering Agriculture 2016).

The STPI evaluation finds that PAEGC funds were successfully used for all these purposes. For some of the smaller companies, PAEGC award funds represented a large proportion of their funding stream. The funds served to “de-risk” the companies—making them more attractive to investors. The PAEGC award was important for the financial survival of several companies, allowing them to develop a new technology or a new business to the point where they were sufficiently mature to attract investors. For several companies that were building mini-grids, PAEGC provided enough capital to sustain them through long regulatory approval processes. The association with a program sponsored by major donor agencies, including USAID, facilitated efforts by one company to arrange meetings with ministry officials to resolve regulatory issues. For several companies, PAEGC made it possible to introduce existing products into new markets in other countries.

Selection criteria

Business development and diffusion

The mid-term evaluations found concerns that PAEGC did not place sufficient emphasis on market analyses and the feasibility of the business models in its application processes and that reviewers did not sufficiently emphasize business feasibility in their consideration of applications. The evaluation recommended that in future calls, applicants, even those seeking support for developing a new technology, should be required to provide a better assessment of local markets and potential demand for their product (Raetzell and Seidler 2016).

We also identified this concern in our own interviews. Companies that provided technical assistance in attracting investment for Powering Agriculture awardees were critical of the failure of the program to demand that applicants more realistically explain how their innovations could be moved to market and once on the market, how sales were to be expanded. All three of the organizations that provided advice to innovators under Powering Agriculture found that most of the awardees were not in a position to either create a commercially viable company to sell their innovation or, if they had become commercially viable, to expand sales to the point where the innovation would be widely diffused. AlphaMundi mostly awarded technical assistance and other grants to organizations and companies that were not PAEGC awardees; it only funded two innovators who had won PAEGC grants. It found most of the PAEGC-funded innovators were not in a position to use technical assistance to attract additional investment from social impact investors. VentureWell has an eight-point checklist that it uses to focus companies on the steps they need to take to successfully bring their products to market and expand sales. The checklist can also be used to screen out companies that are unlikely to be successful. VentureWell found that many of the PAEGC innovators did not pass the checklist.

Although a strength of Powering Agriculture is that it provides awards to innovators at various stages of developing products or introducing them to the market, we echo the technical assistance providers in noting that all awardees should have a realistic plan to move from innovation to market to broader scale diffusion. The lack of realistic plans to commercialize products was especially problematic with university awardees. None of the university awardees except two had developed mechanisms to move their innovations to a company that would build and market the product. One university awardee who did set up a company to build and market the innovation had not successfully reduced costs to a point where the product was commercially viable.

Geographic spread

In the mid-term evaluations, some concerns were raised regarding the geographic diversity of the funded projects. Some interviewees suggested that PAEGC should focus on particular countries or regions, while others did not (Raetzell and Seidler 2016). We also found the wide geographic spread of the innovators problematic. The global coverage of the grants increased monitoring and evaluation costs, as more travel was involved. It also limited the ability of both the partners and the innovators to benefit from learning from common challenges and problems associated with the region in which the projects were located. On a positive note, awardees focused on solar-powered irrigation in Africa and South Asia were numerous enough and concentrated enough to have the potential to learn from each other about technologies and markets. In contrast, there was just one award for agricultural processing equipment in Vanuatu and Indonesia, making it difficult for the awardee to learn from potential alternative innovations.

Awardees without locations and experience in LMICs had poorer results than those that do. Although awardees in developed countries did send graduate students to the target countries, they found it difficult to address technical and implementation problems quickly and efficiently. As a consequence, innovation cycles were stretched out. In many cases involving awardees from developed countries, the products

were not brought to market or were unable to be sold at prices that covered manufacturing or other costs. SimGas is a case in point.

New entrants

The mid-term evaluation found that despite the program's intent to involve new participants in development challenges, innovators were more successful in moving their projects forward if they had a local presence in-country and experience in LMICs (Powering Agriculture 2016). Our outcome evaluation results are in agreement with this finding. In general, awardees with a track record of working in LMICs achieved better outcomes than those that had not. Powering Agriculture did not identify a large number of innovators with successful new technologies or business approaches to address major development challenges that the development community had not previously tapped. This may be because small innovative companies do not traditionally tap development assistance programs to finance their development and growth. AlphaMundi and Factor[e] engaged took a more proactive stance in identifying potential innovators. They also participated more actively in conferences that small companies engaged in LMIC markets of interest were more likely to attend.

8.2 Monitoring

Indicators

Both mid-term evaluations identified concerns regarding the collection of indicator data. The mid-term evaluation focused on innovators found that the 2013 innovators did not see value in collecting the data during pilot field tests of their projects (Powering Agriculture 2016). The second mid-term evaluation that was focused on program evaluation reiterated this initial finding and identified gaps in data related to development impacts more broadly and greenhouse gas emissions avoided, specifically (Raetzell and Seidler 2016).

STPI's interviews with innovators and other stakeholders identified similar concerns. We heard the most complaints from innovators about collecting indicator data about impacts. One innovator called for using more qualitative reporting. Virtually none of the innovators was in a position to collect information about impact indicators measuring increases in agricultural output and incomes, reductions in emissions of greenhouse gases, reductions in poverty, or improvements in gender equality. Many complained about the time needed to try to collect these data. In most cases, innovators did not have access to this information. They often resorted to asking customers for it, an activity that was not part of their normal operations. Their efforts to obtain these data added appreciably to costs, yet the data collected were frequently of poor quality, unreliable, and unverifiable. One innovator said that he had had to dedicate a large fraction of award funds to collecting this information and had had to use non-award funds to accommodate the requirements. If he had known the extent of the demands of this information, he might not have accepted the award.

Customers, in turn, often did not collect or keep track of this type of information and did not have a baseline from which to calculate increases. Innovators were not in a position to validate information provided by their customers. For example, customers bought solar-powered irrigation pumps for a variety of reasons: to save a crop during a period of drought; to increase yields from traditional crops; water poultry or livestock; operate fish hatcheries; or grow one or two additional crops per year, usually vegetables. The farmers we interviewed and those interviewed in the Tetra Tech site visits often had a hazy sense of how much yields had increased because of irrigation, especially as they often rotated crops on specific fields. Information on increased sales of milk stemming from milk cooling equipment provided by customers was better documented.

GIZ's Green Innovation Center faced similar problems estimating increased yields from its programs. In the case of its sweet potato project, the GIZ team concluded that the only valid method to estimate increases in yields was to harvest a portion of a field themselves and measure the result. This is not an activity in which innovators are well-equipped to engage.

Innovators did have access to their own sales data. Sales data show whether farmers and other customers are willing to buy the product. Customers would not purchase the product unless it leads to increased incomes or other benefits. Sales are, therefore, an easily collected, verifiable, reliable indicator of the impact of the innovation on the incomes of farmers and other customers.

Process

PAEGC asks innovators to report their data for monitoring and evaluation on Webmo, the online platform used as a central location to store data and documentation. The mid-term evaluations identified some dissatisfaction with Webmo. Half of the innovators said the Webmo platform is unintuitive and disjointed; the other half indicated that it was effective as a centralized system through which to provide documentation (Raetzell and Seidler 2016). In our interviews, several innovators also expressed dissatisfaction with the Webmo platform, describing it as more complicated and clunky than necessary. Several innovators suggested that they be supplied with templates to fill in indicators or be given clearer instructions about the required reporting format.

Milestones

The mid-term evaluations identified some concerns regarding the milestone-based approach. Most innovators described having to revise milestones as their projects progressed. Some innovators identified delays in milestone approvals as an administrative concern, although there appeared to be differences across project officers with respect to the speed of milestone review and approval. Other concerns identified are that the milestones were not necessarily clearly stated and reached in numerical order, leading to confusion, and that the funding associated with individual milestones did not necessarily correlate with the innovators' required effort to achieve them (Raetzell and Seidler 2016; Powering Agriculture 2016).

Many innovators spoke favorably about the flexibility of milestone achievements. They described instances in which the goals of the projects had changed, requiring the milestones to be adjusted. They found PAEGC award managers and contract support to be understanding, flexible, relatively hands-off, and ready to help reassess which milestones would be a feasible next step for the company. However, a few innovators said the process to change milestones was arduous and required considerable paperwork and a long chain of approvals. One innovator recalled a milestone that required considerable spending to achieve, but when it was completed and he received the milestone disbursement, he realized that he was no closer to achieving the goals for the innovation.

One innovator recommended that the next award solicitation include clearer guidance about the funding disbursement process and limit, the length of the approval process, and the steps needed to receive funds. Another innovator found the disbursement policy unclear; he did not know that milestones could be structured or restructured to provide cashflow when needed, for example, that milestone payments could be frontloaded.

8.3 Support

PASTO and PAX

PAEGC offered a variety of resources and support through PASTO and PAX, in addition to the partners, award managers, and the Powering Agriculture Investment Alliance. The mid-term evaluations found PASTO provided valuable support. PASTO's role with respect to conducting project assessments related to gender equality and suggesting improvements was specifically noted during the evaluations. Some concerns were identified, however, related to potential lack of clarity of roles between PASTO and the partners themselves. The evaluations also found that the PAX-provided support was highly beneficial to the innovators, although some innovators did not have sufficient knowledge of the range of services available to them to have taken full advantage of them. In recognition of the value of these services, the evaluations recommended that PAX support should be extended to the innovators even subsequent to the completion of their awards (Raetzell and Seidler 2016; Powering Agriculture 2016).

Innovators said Tetra Tech and VentureWell provided a wealth of knowledge and support for the innovator through PASTO and PAX. Many continued to have extended correspondence with the support teams following the award period. One company has remained in contact with VentureWell after the end of the award to gain advice on advanced marketing strategies for their products; several others reported remaining in contact with PASTO and VentureWell to occasionally discuss business strategies and progress. Most of our interviewees complimented PASTO, stating that PASTO was helpful in explaining monitoring and evaluation (M&E) requirements and providing assistance with their completion. One innovator found it helpful to communicate regularly with award managers through progress update calls to navigate M&E requirements. However, to make these calls more efficient, one innovator suggested using alternative means of communications, like e-mail, to convey intermediate results so that time spent during check-ins with award managers was dedicated to problems, not reporting updates. A few innovators said that the M&E served the dual purpose of helping them comply with award requirements, as well as facilitating the growth of their company.

Many innovators stated during interviews that the PAEGC contract support team helped to prepare them to increase the competitiveness of their technologies and enhance their business strategies. Innovators spoke of VentureWell's support in generating ideas for commercialization, scaling, attracting the attention of investors, and identifying changes in their businesses needed to raise capital and equity. For one award recipient, unclear regulatory and legal requirements posed an obstacle to completing its milestones. PASTO worked with the local and national entities to help innovators fulfill the necessary requirements to move forward towards their milestones.

While many innovators benefited from the support of PAEGC partners, management, and contractors, several innovators said that they had not been fully cognizant of the full breadth of resources available to them until close to the end of their projects. When one innovator finally utilized some of PASTO's additional services, he greatly appreciated PASTO's ability to connect him to potential investors and distributors.

PAEGC partners

During the mid-term evaluations, observers and stakeholders noted that the PAEGC partners are all actively involved, work well with each other, and that their roles in PAEGC are clearly assigned (Raetzell and Seidler 2016), although as mentioned above there was some confusion regarding the relative roles of the U.S. Government project managers and the PASTO contractors. In our evaluation, we also identified that almost all of the innovators were highly complimentary of the PAEGC award managers, stating that they were supportive, patient, flexible, and understanding throughout the entire award process. Innovators said PAEGC partners were focused on finding solutions to their problems with the program.

One company specifically attributed its overall satisfaction with the award to the PAEGC award management team. The support innovators received from award managers took different forms, from monthly and quarterly progress calls, to discussions about work-plan adjustments, contractual compliance, and milestone deliveries. However, one innovator thought the program should have been built to be more flexible and understanding that building a business and technological development are an iterative process. He said the structure of PAEGC made it difficult to adapt to lessons learned during the award process, making it difficult to support the project as it changed in response to field testing and external factors. Several innovators experienced delays in project implementation due to political, natural, financial, or regulatory challenges; they found PAEGC award managers to be flexible, helping them solve their problems, while leaving them enough room to shift their project goals as necessary. One innovator who had experienced difficulties in navigating a heavily regulated industry suggested incorporating a requirement within the application process that the awardee demonstrate a working knowledge about the local regulatory environment before receiving permission to conduct a project within that region. One innovator thought the PAEGC would have benefited from employing more full-time staff with fewer people involved in approval processes.

The mid-term evaluation faulted the PAEGC partners for failing to coordinate with their other assistance programs. The evaluation states that “there is mostly no systematic integration of the funded projects into the bilateral structures” (Raetzell and Seidler 2016). The mid-term evaluation also noted that the lack of integration limits opportunities to mainstream PAEGC’s approach into bilateral programs and that it missed an opportunity to provide further support to awardees or to scale up funding for innovation.

We heard similar comments during our interviews with innovators and during the site visits. Innovators had little or no contact with the country or regional offices of the partners and did not know of any avenues through which to seek support from them. We found that USAID staff in Kenya were aware and supportive of PAEGC, but also heard that because PAEGC was run out of USAID headquarters in Washington, D.C., it has not received the same level of support and attention as programs that are run out of country or regional offices. Based on our observations and interviews, the team at GIZ’s hub in Nairobi collaborated well with teams managing other GIZ activities out of that office. The GIZ Green Innovation Center in Kisumu was supportive of PAEGC projects but, not surprisingly, its primary focus is on its own activities.

Post-award support

The mid-term evaluations recommended that PAX support to innovators be continued post-award, but this recommendation was tailored to innovators in the commercialization and scale-up phase, instead of those still in the R&D phase (Raetzell and Seidler 2016). PAEGC chose to provide support to all innovators who engaged with PAX consistently, but curtailed support for those who did not seem able to take advantage of it. However, PAX had to end with PASTO’s hard stop date in December 2019, so 2015 awardees did not get as much time to use PAX as the 2013 awardees.

In our interviews, many innovators spoke about their need for an established way to obtain follow-up support after the award. Some wanted this follow-up in the form of advice and guidance, while others expressed an interest in receiving follow-on financial support. One innovator mentioned that it would have been useful if the PAEGC team had made more of an effort to prepare them with the knowledge, tools, and connections necessary to raise private capital independently.

Other observations

Overall, many innovators felt the award played a crucial component in their success as a business. Many innovators said they would have found it helpful to interact with each other more, since many of them faced similar challenges. More could have been done to facilitate communication between innovators in the same industry or region. One innovator argued that the number of awards should be reduced, so that

each awardee would be given a larger proportion of total resources. That innovator also advocated for the creation of a digital directory that organized resources available to innovators.

8.4 Conclusions

Outside stakeholders recommended that in future calls for proposals, applicants should be required to provide more detailed assessments of local markets and potential demand for their product, even if their project is primarily focused on developing a technology. Several promising innovations are unlikely to be commercialized because the innovator lacks incentives or the means to bring the innovation to market. In general, awardees with a track record of working in LMICs achieved better outcomes than those that had not. The large geographic spread of the innovators increased monitoring and evaluation costs, as more travel was involved. It also limited the ability of the innovators to learn from each other about how to best address the problems they encountered in their region.

The current impact indicators are not useful. Neither innovators nor beneficiaries have the ability to collect reliable information for the current impact indicators: measuring increases in agricultural output and incomes, reductions in emissions of greenhouse gases, reductions in poverty, or improvements in gender equality. Innovators resorted to asking customers for this information, an activity that added appreciably to costs, yet customers also did not have or collect this information.

Innovators complimented the PAEGC award managers for being supportive, patient, flexible, and understanding throughout the entire award process. Observers and stakeholders noted that the PAEGC partners are all actively involved, work well with each other, and that their roles in PAEGC are clearly assigned.

9. Conclusions and recommendations

We first summarize our central conclusions following the DAC framework's impact categories. We then present our conclusions relating to the program's theory of action. We conclude with recommendations taken from the evaluation for WE4F, the follow-on Grand Challenge to Powering Agriculture.

9.1 Outcomes

Relevance

To what extent are the objectives of PAEGC still valid?

STPI's analysis suggests that the overarching objective of PAEGC—funding innovators to develop solutions to secure clean, inexpensive energy for agricultural purposes—remains valid. Many, if not most, farmers in LMICs still lack access to energy needed for many agricultural processes. Energy is needed for irrigation, to avoid losses due to spoilage, and to process crops into higher-value products. Liquid fossil fuels like gasoline and diesel, a major source of energy for agriculture in these communities, are expensive and polluting. Electricity from the grid is often intermittent and often generated using fossil fuels, emitting greenhouse gases. Countries such as India and Kenya have adopted national policies to support renewable sources of electricity, but many LMICs have not. A recent report on the off-grid market for solar power found a continuing need to increase agricultural productivity (GOGLA 2019). PAEGC fulfilled a need that is still largely unmet in LMICs.

One of the challenges of any development program that lasts for several years is to address changes in partner priorities. As we understand it, the initial goals of PAEGC were to increase agricultural output and incomes and reduce emissions of greenhouse gases. Although gender equality was important for donors, it did not become a specific criterion of evaluating innovator proposals until the second round. Reducing poverty was never an explicit selection criterion. PAEGC innovators faced challenges in adjusting to shifts or increases in emphasis on specific goals by partners.

Are the activities and outputs of PAEGC consistent with the overall goal and the attainment of its objectives?

The activities of the program are broadly consistent with the overall goal. The program funded innovators to develop solutions at the agriculture-energy nexus, both through the 24 PAEGC awards and the GIZ pilot projects. The Investment Alliance catalyzes private sector financing for businesses that have been recipients of PAEGC grants or that provide clean energy solutions to increase agriculture productivity or value in developing countries. Knowledge management activities communicate Powering Agriculture's objectives and activities, share innovator success stories, build awareness of the nexus between clean energy and agriculture, and disseminate results and knowledge that have been gathered or generated by Powering Agriculture. GIZ-supported training efforts such as the development of the SPIS Toolbox and the MOOC offered on Sustainable Energy for Food have been successful both in their own right and in fostering knowledge of the solar-powered irrigation solutions that PAEGC has supported. One weakness highlighted in matching the program's activities and outputs with attaining its overall goal and objectives is that the selection criteria for PAEGC awards did not necessarily result in identifying innovators with strong plans and capacity to launch products or expand businesses; nor did the selection criteria sufficiently prioritize awardees with locations and experience in the LMICs in which the project was to be implemented.

To what extent are the objectives of PAEGC addressing the needs and requirements of the beneficiaries, global priorities, partners' and donors' policies?

PAEGC-supported projects were well received by project beneficiaries. Although some projects encountered engineering difficulties and others developed technologies that proved uneconomic, no projects were judged to have failed because they would not provide benefits to smallholder populations.

We interviewed representatives from all the innovators. Despite some specific criticisms about processes and procedures, all said they were satisfied with the program. For many innovators, the award was crucial to developing a new product or technology or moving into a new market. The innovators praised program and technical support staff for their deep engagement and their flexibility in managing the awards.

The program was also consistent with Sustainable Development Goals (SDGs). In particular, it targeted reducing poverty (Goal 1) and hunger (Goal 2), fostering gender equality (Goal 5), providing affordable, clean energy (Goal 7), supporting sustainable economic growth (Goal 8), innovation (Goal 9), climate action (Goal 13), and partnerships for goals (Goal 17) (United Nations 2018). Through its focus on raising agricultural incomes in LMICs, PAEGC contributes to the achievement of Sida's mission of reducing poverty in the world (Sida ud.), BMZ's goal of strengthening the development capacity of African states (BMZ ud.), and USAID's goal of promoting a prosperous world and reducing poverty (USAID ud.)

The program, as implemented, was true to the goals and policies of the partners. PAEGC provided support for the "development and/or adaptation of affordable technologies focused on clean energy generation, storage, and more efficient end-use within the agriculture sectors of developing countries that have potential for achieving commercial scale. This support may be for new technologies that are still in the incubation/demonstration stage, and/or existing technologies that are modified to respond to the demands of a specific target market." We found that PAEGC-supported projects developed or adapted clean energy technologies for agricultural communities. PAEGC supported a mix of new technologies and existing technologies modified for use in LMIC contexts. Nevertheless, the results of the program did not meet all of the partners' goals, especially with respect to impacts.

Are the activities and outputs of PAEGC consistent with its intended impacts and effects?

Many of the projects were designed to replace manual labor by smallholder farmers with agricultural equipment powered by renewable energy, whether for irrigation or agricultural processing.

Cooling/refrigeration projects were intended to bring cooling technologies to smallholders or village-level cooperatives. In several instances, these projects had the potential to achieve one impact, such as raising incomes of smallholder farmers, but failed to achieve others, such as reducing greenhouse gas emissions by displacing fossil fuels.

Some of the more successful innovators targeted commercial businesses or wealthier farmers or larger agricultural processors rather than smallholders. Ariya's, ECO Consult's, and ICU's projects and the GIZ Egypt solar pilot targeted medium-sized or large farms. Promethean's market consists of larger commercial milk collection operations. We found these projects often had large impacts on increases in the incomes of the beneficiaries and reducing greenhouse gases. However, the impacts of these projects on reducing rural poverty, although real, are indirect and difficult to trace and measure; impacts stem from trickle-down effects.

Powering Agriculture's concrete effects on gender equality were hard to measure. Innovators were cognizant of gender equality issues and in many cases designed their products to be more ergonomic for female customers. Out of the 24 PAEGC innovators, 54 percent articulated a specific goal of promoting gender equality, such as saving women time through the use of the innovation (PAEGC 2016e). But only a few of the Powering Agriculture innovators were able to point to direct impacts on gender equality from

their projects. Some projects, such as EarthSpark's, worked proactively to involve women at the design stage, to prioritize providing women with employment opportunities, and to involve female entrepreneurs as project stakeholders and beneficiaries. But innovators who were most successful at diffusing their technologies, like SunCulture, and Promethean, did not show evidence that their efforts to pursue gender equality had had substantial impact, as they did not have differentiated gender approaches to customers.

Effectiveness

To what extent were PAEGC's objectives achieved or are likely to be achieved?

Powering Agriculture awardees have had some success in developing new solutions and moving them to market. Almost all the innovators successfully developed their technologies: 22 out of 32 (68 percent) fully achieved the development of their technology; of the remainder, six mostly achieved technology development objectives. Only two innovators partially achieved and only two failed to achieve technology development objectives.

Five innovators fully achieved business development objectives and 10 innovators mostly achieved business development objectives. One notable finding is that non-profits (but not universities) were at least as likely to achieve or mostly achieve business development objectives (6 of 9 projects) as were the for-profit businesses (8 of 14 projects). The University of Hohenheim did successfully spin out a company to commercialize the knowledge and technology developed through its work in Africa on solar milk chilling, but none of the other university-led projects achieved or mostly achieved business development objectives. Five projects achieved or mostly achieved diffusion objectives; four were for-profit companies; none were universities.

In our view, Powering Agriculture has enjoyed one of its greatest successes in fostering the growth of solar-powered irrigation markets in LMICs, especially in Sub-Saharan Africa. Several innovators supported by Powering Agriculture have introduced solar-powered irrigation pumps catering to a variety of hydrological conditions and farm sizes. The market has become sufficiently promising to induce established manufacturers and distributors of irrigation pumps, like Davis & Shirliff in East Africa, to develop their own solar-powered pumps. Even if these competitors eventually squeeze out Powering Agriculture-supported innovators, Powering Agriculture will have helped catalyze the development of this market.

Powering Agriculture has supported a number of promising mini-grid projects. In most LMICs, mini-grid developers face substantial technical and regulatory challenges, especially when dealing with the incumbent electric utilities and new regulatory offices. Powering Agriculture has promoted market development by supporting technically promising approaches, like EarthSpark's and the Universidad del Valle de Guatemala's, helping to finance the internal costs of seeking regulatory approvals, and helping countries to institute policies that support the development and operation of mini-grids.

What were the major factors influencing the achievement or non-achievement of PAEGC's objectives?

One major problem with many of the technologies supported by Powering Agriculture is the mismatch between the cost of the product and the ability of the smallholder farmer to afford it, even when the innovator provides access to financing. Many of the technologies developed under Powering Agriculture awards have proven to be costlier to manufacture and distribute than the innovators had projected in their proposals. To sell these technologies, innovators have had to shift focus to a more limited market than envisioned: commercial clients or wealthier farmers who can afford the product.

Some types of innovators were more likely to achieve programmatic goals than others. Larger projects were more likely to be commercialized than smaller projects. Projects that developed complex, novel

technologies were less likely to reach commercial scale than simpler or more established technologies. SunDanzer, Rebound, and Motivo all applied high-technology expertise to Powering Agriculture challenges; none of their technologies have yet been commercialized. All the biogas projects except Husk's (e.g., SimGas for cooling, Horn of Africa for industrial processing) encountered technical and commercial problems. In general, the literature has found that biodigesters have not generated expected economic benefits. The need to ensure sufficient quantities of manure on a daily basis, the high capital costs of the installations, and social as well as economic issues have resulted in disappointing results for many biodigester projects (See, for example, Shallo and Sime 2019 or Buysman and Mol 2013.).²⁴ While the innovators attempted to overcome the challenges of biodigesters as part of their awards, none appears to have done so. Not surprisingly, projects in which the products were already being sold or close to market entry achieved more of the objectives for business development and diffusion. Both AlphaMundi and Factor[e] channel their investments to companies that are further along in the commercialization process, although Factor[e] will invest in companies earlier in the process of developing a new technology. This strategy generates more successes than investments in projects that have not yet commercialized their products. The two investors have primarily invested in companies other than PAEGC innovators.

Projects led by universities were less likely to achieve business or diffusion goals than projects led by non-profits for for-profit businesses. While university-led projects piloted novel technologies (e.g., Columbia University's Earth Institute's micro-grid to power multiple irrigation pumps using solar PV), they lacked the incentives, organizational structures, and partners to move the technologies to commercial scale.

What is PAEGC's additionality? To what extent can results be solely attributed to PAEGC rather than PAEGC being one of several sources of support that catalyzed development and diffusion of innovations?

The evaluation found that projects achieving business and diffusion objectives tended to have begun work on their solutions prior to the Powering Agriculture award. Those organizations that had previously worked in development or whose home and home market were in developing countries, were more likely to be successful than innovators, especially those located in developed countries, that had little or no previous experience with LMIC markets. Innovators with less experience in LMICs often focused on developing a new technology without first investigating the target market. In contrast, those innovators who were more familiar with their target market tended to enjoy more success than new entrants. At the same time, for some of the smaller companies, PAEGC award funds represented a large proportion of their funding stream and served to "de-risk" the companies and make them more attractive to investors. The PAEGC award was important for the financial survival of several companies, allowing them to develop a new technology, a new business, or for several companies that were building mini-grids, enough capital to sustain them through long regulatory approval processes. In particular, the earlier stage innovators and those innovators least likely to receive commercial funding probably experienced the most additionality from the awards. Those that were already commercial successes were probably less in need of funding, although those innovators stated that without funding from PAEGC they would not have been able to expand their businesses by developing new PAEGC-funded projects or entered the new market for which they used PAEGC funding. While outcomes cannot be attributed solely to PAEGC, many of the innovators either would not have survived or would not have expanded as rapidly as they did without Powering Agriculture funding.

²⁴ Sistema.bio, on the other hand, appears to have surmounted these problems.

Efficiency

Were the activities cost-efficient?

We assessed whether the projects funded by Powering Agriculture have been cost-efficient from the standpoint of the number and percentage of projects that have achieved their objectives and advanced toward commercialization. We found that as of the end of 2019, 28 of the 32 projects (88 percent) had achieved or mostly achieved technology development objectives, 15 (47 percent) had achieved or mostly achieved business development objectives, and 5 (16 percent) had achieved or mostly achieved diffusion. Studies of the U.S. Small Business Innovation Research (SBIR) program, which funds companies to develop technologies, have found approximately half of projects funded reached commercial sales (Link and Scott 2010). Studies of Small Business Technology Transfer (STTR) projects, which involve collaborations between companies and research institutions to develop technologies, found that approximately 40 percent of those projects reach commercial scale (National Academies 2016). As noted above the size of grants in these programs is comparable to those of Powering Agriculture in terms of size and objectives. The PAEGC evaluation's results—that 47 percent of PAEGC projects entered commercialization—are respectable when compared to the results of those programs.

Link and Scott's study of SBIR found that the probability of commercial success is positively correlated with leveraging outside investment (Link and Scott 2010). Most of the PAEGC innovators have successfully mobilized additional funding in the form of grants and, in the case of the for-profit companies, outside investment. Additional grants and investments are twice the amounts of the awards innovators have received, and roughly equal to the total \$51.7 million funding for PAEGC. In particular, the ability of the innovators to raise additional funding indicates that investors and grant funders see these projects as promising. From the standpoint of developing solutions and seeding new entrepreneurial ventures, the program appears to have been efficient.

Were the objectives achieved on time?

When attempting to measure impacts from a program like Powering Agriculture, evaluators need to provide adequate time to measure program outcomes. For example, based on the extensive Department of Defense commercialization database they used, Link and Scott (2010) concluded that most projects take at least 2 years to reach the market after the end of a Phase II award and do not generate peak revenue until several years later. Setting arbitrary targets to be met at a specific point in time, such as the number of beneficiaries reached by a set date, can be counterproductive, as innovators try to hit poorly crafted deadlines rather than focusing on the organic growth of their businesses.

Reflecting the difficulties in rapidly moving to substantial sales, timeliness has proven a challenge for PAEGC innovators, especially for the mini-grid projects, which require regulatory approvals. The EarthSpark, Universidad del Valle de Guatemala, Ariya, and Husk projects have all encountered delays that have slowed progress towards completion. Only Ariya; iDE's partner in Bangladesh, RREL; and EarthSpark have installed more than one mini-grid. RREL and EarthSpark have gone on to install an additional mini-grids outside of the PAEGC project.

Was PAEGC implemented in the most efficient way compared to alternatives with respect to the impact goals of increasing agricultural output and incomes, greenhouse gas mitigation, reducing poverty, and increasing gender equality?

Payments to cover financing of sales of solar-powered irrigation pumps provided a way to estimate minimum additional income accruing from those projects. Annual sales data and savings accruing from displacing gasoline or diesel fuel provided a means of assessing increases in income from other Powering Agriculture innovations. STPI estimated that the three innovators with the largest current sales revenues (Futurepump, SunCulture, and Promethean) could increase beneficiaries' incomes by

approximately \$50 million per year by 2025 (almost as much as the total cost of Powering Agriculture), if they enjoy projected increases in sales. Were these annual increases in income to be realized, PAEGC would have generated a return on investment in the form of increases in agricultural incomes of 100 percent per year. However, most projects only reached tens of beneficiaries during their lifetime, and the additional income generated did not match the cost of their awards. Very large increases in aggregate incomes may be more likely from larger, more established companies. Davis & Shirliff's rapid introduction of its own line of solar-powered irrigation pumps suggests that larger manufacturers and distributors may be able to scale innovations more rapidly and thereby increase agricultural output and incomes for their customers than small start-ups.

Several of the innovators were insufficiently knowledgeable about the size of the potential markets that they were addressing and consequently overly optimistic about the potential for sales. Poorer smallholders frequently lacked the financial resources to purchase innovators' products. In some instances, like solar powered irrigation, smallholder households lacked the time, knowledge, or resources to introduce new crops and expand the number of cropping cycles that would be necessary to make the use of a solar-powered irrigation pump profitable. Scaling was an issue for agricultural processing equipment. The capacity and cost of some of the commercially available equipment used by some PAEGC innovators were more than one household could use or afford. In this regard, the goal of Powering Agriculture to reduce poverty conflicted with the use of markets to develop and disseminate new technologies. The gap between the cost of the technology and the ability of poor households to pay for it is sometimes such that the technology can only be widely disseminated with the help of subsidies.

With the exception of the Kenya energy efficiency project, the short-term greenhouse gas emission reductions associated with PAEGC projects were small through 2019. PAEGC was not initially designed with improving gender equality as a major objective; poverty reduction was not a primary goal. This said, PAEGC is clearly inefficient in the short term from the standpoint of improving gender equality or reducing poverty. Few of the solutions introduced through PAEGC were accessible initially to poor smallholders, given their high initial purchase costs and the difficulty smallholders face in accessing financing. As the solutions diffuse and purchase costs decline there is the hope that they will become more accessible to poorer smallholders, but a program focused on alleviating poverty would require the use of alternative mechanisms more directly aimed at targeted beneficiary groups.

Similarly, while some of the solutions developed may have benefited individual female farmers—there was no guarantee that those solutions that diffuse will be the ones with the greatest potential for improving gender equality. Market-based development programs like Powering Agriculture are likely to struggle to address issues of gender equality because the success of the innovators depends so heavily on the structure of the market in which they are attempting to operate. For instance, fish farmers in Bangladesh tend to be men; the impact on gender equality of a project like the University of Toronto's that focuses on fish farming is circumscribed by the gender composition of its prospective customer base. Lack of access to finance or land tenure issues that dictate whether women can purchase solar-powered irrigation pumps, for example, also limit efforts to improve gender equality. Innovators are poorly positioned to address these constraints. Virtually all the innovators had to focus on keeping their businesses, non-profit or for-profit, economically viable. Consequently, most projects were focused on increasing agricultural incomes so as to make their products attractive to prospective buyers, and did not have substantial impacts on gender equality. Relying on technology development and market mechanisms represents an indirect and probably inefficient path to achieving the goal of increasing gender equality.

Impact

What has happened as a result of the program or project?

Five projects achieved or mostly achieved diffusion objectives. These projects are already having substantial commercial impact and are the most likely to continue to diffuse their solutions over time. GIZ's tea efficiency project is the only project to have completely achieved diffusion objectives, while the other four mostly achieved them. Two of these projects manufacture or sell solar-powered irrigation pumps; one was a mini-grid project, and one sells commercial coolers.

What real difference has the activity made to the beneficiaries?

The nature of the difference that PAEGC projects have made for the beneficiaries varies with the type of project. The solar-powered irrigation projects have allowed farmers to increase their crop yields and decrease costs associated with purchasing diesel fuel for irrigation pumps or manually hauling water. Some of the heating and cooling projects have allowed smallholders to increase their revenues from selling their produce, while others, focused on commercial installations, have increased the efficiency of those operations and thereby provided indirect benefits to the farmers from whom produce is sourced. The mini-grids offer beneficiaries enhanced and more consistent access to electric power, which increases their quality of life and catalyzes commercial opportunities and increases businesses' revenues. The benefits associated with the other projects vary given their heterogeneity, but include enhanced storage and processing of agricultural crops, leading to higher revenues and reduced waste of produce.

How many people have been affected?

The PAEGC monitoring system lists 72,242 beneficiaries as of the end of FY 2019 (PAEGC 2020). This includes nearly 13,000 beneficiaries associated with solar-powered irrigation projects (mostly associated with SunCulture and iDE/Futurepump), more than 9,000 associated with heating and cooling projects (almost all associated with Promethean), more than 8,000 associated with the mini-grid and micro-grid projects (mostly associated with Ariya and Husk Power), and more than 24,000 beneficiaries associated with other projects (almost all associated with Village Infrastructure Angels). The extent of the benefits to these individuals varies widely. We estimate that those benefitting from solar-powered pumps received benefits running from \$224 to \$811 per year, which is substantial for a poor smallholder household. Benefits from mini-grids were smaller, about \$40 per year per household. We found the extent of benefits to other beneficiaries was small.

Were there unintended outcomes (positive and negative) that resulted from PAEGC, and might there be future unintended consequences stemming from funded projects?

The nine identified Market Stimulation outcomes represent positive unintended benefits associated with PAEGC awards. Powering Agriculture has led to corporate spin-outs and stimulated the entry of competitors into nascent markets in small-scale cooling with renewable energy and into expanding markets for solar irrigation pumps. EarthSpark spun out a separate company, SparkMeter, which sells a smart meter that is not only used in EarthSpark's PAEGC award but also in two other PAEGC mini-grid projects. Solar Cooling Engineering was spun out of a University of Hohenheim GIZ pilot to support commercialization of the modular solar milk chilling technologies the project developed. ColdHubs spun out of a Smallholders Foundation GIZ pilot to commercialize the solar-powered cold room that the project helped to optimize. Futurepump, Monarch Tractor, and Thermogenn were spun out by innovators from

the 2013 PAEGC cohort. Given a few more years, the 2015 PAEGC cohort is likely to spin out its own set of companies.

Sustainability

To what extent did the benefits of a program or project continue after donor funding ceased?

For-profit firms have been more successful in mobilizing investments to continue activities related to their awards than non-profits or universities, raising more than 10 times the funding per award of the awards made to NGOs and universities. Tapping capital markets has allowed companies such as Husk, Claro, and SunCulture to mobilize investments many times their original PAEGC awards.

Several projects were intended solely as pilots or demonstrations. These projects were often led by university innovators, although some were led by for-profit companies or non-profits. They were not designed with an integral plan to transition the technology to a business partner who would bring it to market. Prospects for sustainability have been less for these projects than for most of the projects led by non-profits or for-profit businesses. As a result, some potentially promising technologies developed by universities do not appear likely to be commercialized and therefore show no signs of sustainability.

Developing technologies that rely on expensive, complicated designs and components are less likely to be sustained. The Rebound, Motivo, and SunDanzer projects—all led by high-technology companies located in developed countries applying their core technologies to LMIC contexts—succeeded in piloting their products, but have not identified routes to commercialization because of cost and technical issues.

What were the major factors that influenced the achievement or non-achievement of sustainability of the program or project?

Involving for-profit companies in the program has led to a complex set of sustainability-related issues. One rationale for involving for-profit companies in the Powering Agriculture initiative is that the profit motive provides an incentive to sustain, improve, and market the products developed through award funds in ways that university-conducted applied research activities, for example, might not. Commercial sales and revenues also represent concrete, quantifiable evidence of a project's success and post-award sustainability. As of the end of 2019, companies such as Promethean, Husk, and Futurepump are functioning businesses with millions of dollars per year in revenues and plans for expansion and further innovation.

One downside to the inclusion of for-profit companies is that they are more vulnerable to market pressures. While some PAEGC-supported firms are growing, others, like SimGas, have gone bankrupt. Designing development programs to involve for-profit firms requires partners' acceptance of the risk that not only will some projects fail to achieve their technical goals, but also that some of the companies involved may disappear over the life of the program.

Another complication in assessing the success of a program such as Powering Agriculture that relies on markets and competition is that the initial success of awardees may encourage other, larger firms to enter the market. The example of Davis & Shirliff's introduction of its own line of solar-powered irrigation pumps in Sub-Saharan Africa represents both a potential program success and a caution for the PAEGC partners. The initial successes of PAEGC-supported innovators such as Futurepump and SunCulture may prove evanescent should larger firms with more mature manufacturing and distribution networks introduce their own product lines. While the clearest evidence of success would be for Powering Agriculture-supported innovators to become market leaders and globally recognized firms, a more likely scenario is that Powering Agriculture will have helped to demonstrate the commercial potential of products and services in renewable energy and agriculture to existing larger companies, speeding the

introduction of these technologies into LMIC markets, even if most of the PAEGC-supported entrants fail or are absorbed.

Several NGOs, not just for-profit innovators, have also successfully brought their projects to commercial scale. EarthSpark's incubator model, for example, has led to spin-outs of companies to commercialize and sustain technologies such as the SparkMeter. Similarly, iDE spun out Futurepump to develop its solar pump commercially. KickStart has a long history selling manual irrigation pumps. Commercializing a solar-powered irrigation pump does not change the organization's approach to generating revenue through a mix of direct sales and grant funding. Given that this evaluation has found that for-profit and non-profit organizations are equally likely to commercialize PAEGC technologies, we find that non-profit organizations with experience in development activities and strong partnerships and plans for commercialization can be successful in advancing innovations in the context of a Grand Challenge.

In short, several for-profit companies and non-profits are successfully diffusing PAEGC supported products; university innovators have been less successful. Organizations without close ties to LMICs or pursuing the development of complicated technologies have been less successful at diffusing their products than those that have focused on simple technologies that can be produced at lower cost.

Were the projects environmentally sustainable?

The overall focus of PAEGC on projects incorporating renewable energy into agriculture has created a number of sustainable environmental benefits. The substitution of solar energy for irrigation, chilling, mini-grids and agricultural processing rather than diesel fuel—the primary alternative—not only reduces emissions of greenhouse gases, it also reduces emissions of the other principal pollutants from combusting diesel and gasoline: carbon monoxide, hydrocarbons, particulate matter, and nitrogen oxides.

Despite the environmental advantages of solar panels or cooling using renewable energy, these technologies also damage the environment. The production of solar panels requires materials like sodium hydroxide and hydrofluoric acid, lead and cadmium, many of which are toxic and need to be recycled and handled in an environmentally responsible manner (Nunez 2014). Mining these materials often involves environmental degradation and the use of substantial amounts of fossil fuels (Nunez 2014). Once solar panels reach the end of their economic life, they need to be disassembled and recycled so as to avoid leeching carcinogenic materials like cadmium into the environment (Shellenberger 2018). Both lithium and lead-acid batteries were used in some innovations, although a substantial number avoided their use to reduce costs. Lead is toxic (Albright et al. 2012). Lithium is not a toxic heavy metal, but lithium batteries use nickel, cobalt, or manganese in their electrodes, which have negative impacts on the environment (Albright et al. 2012). Some innovators, like Promethean, deliberately employed more environmentally friendly technologies. Promethean used a unique patented thermal battery, which uses a phase change material, like ice, and a heat transfer fluid comprised of water and isopropyl alcohol. The thermal battery has more storage capacity than lithium-ion and lead-acid and does not use heavy metals or require extensive mining operations, is cheaper, and can be recycled without leaving harmful chemicals in the environment.

The cooling and heating projects sponsored by the PAEGC award used a variety of refrigerants, of different levels of toxicity, potential effects on global warming through emissions greenhouse, and ozone reduction potential. For instance, Promethean used the refrigerant R404a, which is a mix of three different hydrofluorocarbons (HFCs). While recognized as a less potent greenhouse gas and less likely to be acutely toxic than the banned hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs), it is gaining more scrutiny due to its high global warming potential, and is more potent in terms of greenhouse gas effects than alternatives like propane. SunDanzer's solar-powered milk-chiller used R134a, a common refrigerant used in a wide variety of refrigeration and air conditioning, automotive and industrial applications. It is a potent greenhouse gas, and is the most abundant HFC within the atmosphere. GIZ's solar powered cold rooms for fruits and vegetable growers in Nigeria used the refrigerant R290, also

known as CARE® 40, a refrigerant-grade propane, whose use is increasing due to its low environmental impact. It is non-toxic with no ozone depletion potential, and low global warming potential.

Solar-powered irrigation systems provide many benefits by helping to increase and diversify food production. However, improved access to water can lead to overwatering crops and growing higher-value, more water-intensive crops. Depletion of ground water resources for irrigation has become a major environmental issue across the globe (Pluschke and Hartung 2018). Irrigation demand contributes to about 20 percent of non-renewable groundwater extraction worldwide. Solar-powered irrigation runs the risk of potentially overstressing groundwater sources, especially in India, North Africa, and the Middle East. Pumping from underground aquifers is especially problematic in India, where about 30 percent of aquifers are considered critically low. In many cases, the use of solar powered irrigation systems may be more effective if coupled with other water management systems such as drip, sprinkler irrigation, and rainwater harvesting (Pluschke and Hartung 2018). However, the use of drip irrigation does not necessarily reduce water usage, as a farmer may shift to more water-intensive crops or expand the use of irrigation to more land.

Detrimental impacts of increased solar-powered irrigation depend on the water tables on which the farmers are drawing and technologies employed. Some pumps only draw on surface water, so the effects on water tables are indirect, as water that might have percolated into the soil is used for irrigation. In many parts of East Africa, a region on which PAEGC innovators have focused, water tables are not yet overdrawn. In India, solar-powered irrigation primarily replaces irrigation using diesel pumps. In some respects, solar-powered irrigation is more beneficial than irrigation using diesel pumps because flow rates are lower. In India diesel fuel and grid electricity are heavily subsidized. Replacing these sources of energy with solar power improves economic efficiency. In Jordan, however, assistance agencies were critical of PAEGC-sponsored irrigation projects because irrigation already draws from underground reservoirs at unsustainable rates.

Nonetheless, our overall assessment of PAEGC's effects on environmental sustainability is highly positive. Despite some of the environmental downsides of manufacturing solar panels, the substitution of solar panels for diesel generators and pumps reduces emissions of greenhouse gases and conventional pollutants. Solar-powered irrigation in East Africa did not seem to threaten water tables; in India, it substitutes for heavily subsidized diesel fuel. Only in Jordan and elsewhere in the Middle East did solar-powered irrigation potentially compound existing problems of overutilizing ground water.

Did projects or the program as a whole lead to large-scale or systemic changes in participating countries that might contribute to reaching social or environmental sustainability goals?

With the exception of the expansion of solar-powered irrigation pumps, there is no evidence that as of the end of 2019 individual projects or the program as a whole has yet led to large-scale or systemic changes in participating countries that might contribute to reaching social or environmental sustainability goals. However, PAEGC funding of cooling and heating technologies and agricultural processing technologies powered by renewable energy has been pioneering, focusing interest on these technologies by providing funding.

9.2 Other Powering Agriculture activities

In general, innovators were complimentary concerning technical support. VentureWell's provision of tailored advice on how to manage businesses problems and to attract investors was praised highly. In particular, the workshops where innovators met with each other and jointly worked on solving problems were highly rated.

Most innovators believed that channeling program support through a regional hub, like GIZ's in Nairobi, would provide better access to support. There would be more opportunities to meet face to face.

GIZ's support for the SPIS Toolbox and the MOOC offered on Sustainable Energy for Food were useful. We concluded that the Toolbox provided a major contribution to the diffusion of solar-powered irrigation pumps. By educating thought leaders, like agriculture extension agents and employees of non-profits serving rural communities, about solar-powered irrigation options and by providing them a tool to help individual farmers select solar-powered irrigation systems best suited to them, the Toolbox contributed to overcoming suspicions about the technology and to ensuring that early adopters are purchasing the appropriate technology—factors that contribute to more rapid diffusion as neighbors see the fruits of these systems.

Among Powering Agriculture outreach activities, innovators were the most enthusiastic about support for conference attendance. SOCAP, in particular, was found to be an excellent venue to contact potential investors.

The Powering Agriculture Investment Alliance fills a need identified in the mid-term evaluation for support for innovators to develop their businesses so that the technologies that have been developed under Powering Agriculture are more broadly diffused. The two partners in the Alliance, AlphaMundi and Factor[e], are highly respected social impact investors. However, the difficulties they have had in finding innovators supported by Powering Agriculture that pass their criteria for investment raise a question about the selection of Powering Agriculture recipients. Powering Agriculture took a broad view of potentially qualifying projects, ranging from the development of unusual, out-of-the box technologies to support to established companies with products that were already generating solid sales. AlphaMundi and Factor[e] do not invest in companies that are still in the product development phase, thereby excluding a substantial share of Powering Agriculture innovators from support from the Alliance.

9.3 PAEGC processes

Selection criteria

The mid-term evaluators, VentureWell, AlphaMundi, and Factor[e], all noted that in future calls for proposals, applicants should be required to provide more rigorous assessments of local markets and potential demand for their product, even if their project is primarily focused on developing a technology. Several promising innovations funded by Powering Agriculture seem unlikely to be commercialized because the innovator lacks incentives or the means to bring the innovation to market. This observation applies to GIZ pilots as well.

Based on some of the choices of the selection committees, especially for the 2013 cohort, it appears that the committees did not include a sufficient number of individuals knowledgeable about the markets that some of the innovators were targeting.

Awardees located in developed countries had poorer results than those located in or with activities and experience in LMICs. In general, awardees with a track record of working in LMICs achieved better outcomes than those that had not. Powering Agriculture did not identify a large number of innovators with successful new technologies or business approaches to address major development challenges that the development community had not previously tapped.

The large geographic spread of the innovators increased monitoring and evaluation costs, as more travel was involved. It also limited the ability of the innovators to learn from each other about how to best address the problems they encountered in the region in which they were located. Many innovators said they would have found it helpful to interact with each other more, especially those in the same region.

Indicators

Virtually none of the innovators was in a position to collect accurate, reliable information about the impact indicators: measuring increases in agricultural output and incomes, reductions in emissions of greenhouse gases, reductions in poverty, or improvements in gender equality. They resorted to asking customers for this information, an activity that added appreciably to costs, yet customers also did not have this information. For example, customers who bought solar-powered irrigation pumps often only had a hazy sense of how much yields had increased because of irrigation. Consequently, the impact data were of poor quality, unreliable, and unverifiable. GIZ's Green Center addressed the problem of estimating changes in yields from its programs by harvesting portions of control and pilot fields.

Sales data, which the innovators do have, provide a better, alternative measure that can be used to estimate impacts. Farmers make investments to generate a return. By calculating the increases in income needed to purchase a piece of equipment, PAEGC could estimate implicit rates of return for the various technologies based on sales—a verifiable, reliable indicator.

Innovators were highly complimentary of the PAEGC award managers. They found them supportive, patient, flexible, and understanding throughout the entire award process. Observers and stakeholders noted that the PAEGC partners are all actively involved, work well with each other, and that their roles in PAEGC are clearly assigned.

Many innovators spoke about their desire for follow-up support after the end of the award. Some wanted advice and guidance, while others would like assistance in obtaining follow-on financial support and investment. The Midterm Evaluation recommended that PAX support to innovators be continued for an additional 3 years after the end of the award or that awards be lengthened.

9.4 Theory of Change

PAEGC, like the other Grand Challenges, is predicated on the belief that science and technology, when applied appropriately, can have transformational effects on international development, and that engaging the world in the quest for solutions is critical to instigating breakthroughs to solutions to hard development problems (USAID 2012c). These Grand challenges focus on surmounting key barriers to success through science and technology and by facilitating scaling. The theory of change that underlies USAID's Grand Challenges states that "by engaging and mobilizing diverse, global solver communities, USAID and its Partners can source, select, incubate, test, and scale up science and technology innovations that will overcome critical barriers to development and accelerate the pace at which the world's most pressing development problems can be addressed" (Raetzell and Seidler 2016 p. 10). In PAEGC's case, the focus is on technologies and other solutions in renewable energy and agriculture. It is predicated on the assumption that awards ranging from \$500,000 to \$2,000,000 can catalyze the development, commercialization, and wide-scale diffusion of new renewable energy technologies coupled with new agricultural technologies.

We found many positive attributes of Powering Agriculture. As opposed to funding activities that need repeated, ongoing support, Powering Agriculture was focused on fostering the development of vibrant, sustainable markets for new technologies. It was designed to help to seed a market, generate attention, facilitate an enabling environment, attract investment, and test innovations that have the potential to move to adoption through commercialization or other scaling pathways. Because funding is flexible and payments are based on milestones, recipients have more flexibility to use the funds to address emerging technological, regulatory, and business challenges. Grand Challenges are among the few, if not the only assistance programs that fund the development of new technologies by small organizations.

As reported below, in many instances, however, Powering Agriculture did not validate the underlying theory of change:

- *Powering Agriculture was to combine solutions to provide rural households with renewable energy and increase agricultural output or incomes.* Fusing renewable energy technologies with technologies to process crops and animal products had mixed success. Several projects ended up focusing on one technology or the other. Some innovators had intended to use renewable energy to power their technologies, but found that traditional sources of energy were better suited. The agricultural processing component of many of the mini-grid projects did not work out. Rural communities benefited from access to electricity, but the prime use of the electricity was not for processing agricultural products. For example, EarthSpark successfully created a mini-grid and developed a business model to collect revenues to operate the grid in a town in Haiti. However, locals did not use the agricultural processing equipment to be run off the mini-grid.
- *PAEGC was to scale up science and technology innovations.* Few innovators reached commercial scale during the award period, only one attained wide-scale diffusion.
- *PAEGC was to engage and mobilize diverse, global solver communities.* Those organizations that had previously worked in development or whose home and home market were in developing countries, like Promethean, were more likely to be successful than innovators, especially those located in developed countries, that had little or no previous experience with LMIC markets. Innovators with less experience in LMICs often focused on developing a new technology without first carefully investigating the target market. In contrast, those innovators who were more familiar with their target markets tended to enjoy more success than new entrants.
- *PAEGC was to incubate and test science and technology innovations that will overcome critical barriers to development.* Projects focused on developing new products performed more poorly than projects that focused on improving existing products or expanding sales of existing products into new markets.
- Along the same lines, addressing regulatory barriers, providing sustainable financing to poor households, or attracting investment were often more important for achieving PAEGC objectives for business development and diffusion than developing new technologies.
- The greatest technological challenge facing PAEGC innovators is designing products that can be sold at a price that poor smallholder farmers can afford, not creating new technologies. Successful innovators used or adapted off-the-shelf components and manufactured in cost-competitive countries like China and India. For example, although innovators devoted substantial efforts to improving solar-powered irrigation pumps, the rest of the package consisted of off-the-shelf products. Setting up sustainable financing programs was also important.

9.5 Recommendations

WE4F Program Design

The WE4F Grand Challenge statement reads:

“WE4F’s mission is to expand the sustainable scale of small and growing enterprises (SGEs) that impact the sectors of food and water, food and energy, or all three sectors at the nexus (food, water, energy) to increase the sustainability of agricultural food value chains and address environmental and climate resilience in developing countries and emerging markets – with a particular focus on the poor and women.

WE4F will capitalize on the vast resources and learnings from Securing Water for Food: A Grand Challenge for Development (SWFF) and Powering Agriculture: An Energy Grand Challenge for

Development (PAEGC) and adopt the most promising innovations/innovators identified and nurtured in those programs and support these innovations to grow and scale.

WE4F has the potential to bring about transformational change and large-scale impact in the food sector, assisting millions of people across the globe who are involved in the food chain. For this purpose, the WE4F programme strives to achieve the following impacts:

Increase in food production through a more sustainable and efficient usage of water and/or energy

- Increase in income for women and men in both rural and urban areas
- The scaling of new solutions of the innovators to challenges in the WE4F nexus
- Customers in the market are buying the newly developed products or services of the innovators
- Increase investments into enterprises at the WE4F nexus (WE4F ud.).”

The Grand Challenge statement incorporates many elements of the PAEGC approach. STPI’s evaluation of PAEGC concludes that while these goal statements are laudable, they are very ambitious. Our core recommendation is that WE4F should do the following:

- As noted above, there is a tension between market-based solutions and entrepreneurship and short-run impacts on reducing poverty and gender equality. Small businesses introducing new solutions will need to focus on profitable market segments, which are unlikely to be the poorest smallholder farmers. Similarly, while it is possible that profitable solutions will specifically benefit women and increase gender equality, there is no guarantee that those two goals will be aligned. We recommend that the partners temper expectations concerning goals for improving gender equality and short-term reductions in poverty from programs like Powering Agriculture and WE4F.
- The experience of social impact investors and other government programs, like SBIR, designed to foster the development and commercialization of new technologies shows that seven or more years are needed for market success for new innovations. WE4F should take a longer view than the initial horizon for PAEGC projects. Seven or more years is likely to be necessary to move incipient technologies to the point where they are more widely available. If WE4F wishes to disseminate solutions more quickly, it will probably need to provide incentives to existing mid-sized or larger enterprises to invest in bringing existing solutions to increasing agricultural output and reducing emissions of greenhouse gases in LMICs. Non-profits and small businesses are not able to scale as rapidly as established businesses.
- Small organizations face serious challenges to rapidly expanding sales of their innovative products. To achieve large-scale impacts in the short-term, WE4F may wish to provide incentives to existing mid-sized or larger enterprises to invest in bringing existing solutions to increasing agricultural output and reducing emissions of greenhouse gases in LMICs. While PAEGC’s efforts to foster entrepreneurship and investment in promising new small businesses are valuable and may in the long term have transformative impact, these approaches require time to have a large cumulative impact. Larger firms have access to capital (financial capital and funding, human capital, physical capital and production infrastructure) that facilitates reaching manufacturing economies of scale so that solutions can be diffused more widely and more quickly. They can also more easily build new markets. To the extent to which solutions they implement and diffuse are aligned with the partners’ development-related goals, they are more likely to generate substantial impact more quickly.
- Universities, in particular, lacked the means to bring their innovative technologies to market. If WE4F wishes to continue to support the development of novel solutions, especially by universities, the partners should insist on innovators providing a realistic avenue by which their solution will eventually come to market and be broadly disseminated. Innovations that did not

have a solid path towards the market have not been broadly disseminated and do not appear likely to be so.

- One of Powering Agriculture's greatest successes was its support for the development of the solar-powered irrigation pump market in Africa. Although providing funding to more than one set of technologies is important to allay risks, based on the experiences of Powering Agriculture, WE4F should focus on providing funding to help surmount technological or market barriers facing a small set of early stage technologies rather than opening up the solicitation to any novel solution. Such an approach could help open up new markets, as PAEGC has done with solar-powered irrigation, but concentrate resources on supporting innovations with better prospects for wide diffusion and broad impact.

Project selection

Innovators with little experience in LMICs had poorer outcomes than those that were located in LMICs or had substantial experience in those markets. The selection process should favor innovators located in or with long experience in LMICs. Projects focused on commercializing a product or expanding into new markets should be favored over projects focused on developing early-stage technologies, although the program should still be broad enough to fund some projects involving earlier-stage technologies. As noted above, Grand Challenges are one of the very few development programs that provide funding to small organizations to invest in early-stage technologies, so some investments along these lines are in order, especially in light of the achievements of organizations that invested in solar-powered irrigation pumps. To diversify risks, the program should continue to fund projects across a range of solutions; it should not concentrate funding on just one favored solution. All proposals should include a detailed, credible plan for bringing the product to market and ensuring that it can eventually be sold at a profit. Proposals should demonstrate a working knowledge of the local regulatory environment as well as the local target market.

The selection committee should include individuals familiar with the markets that prospective innovators are addressing. The members of the selection committee should be knowledgeable about competing technologies, prospective competitors, the size of the market, and key price points.

WE4F may wish to employ a two-stage award process. First round winners would receive funding of less than \$500,000 as under the current Clean Energy Solution – Design category, to pilot their business case. Successful innovators would then be eligible for an additional, larger and longer award.

Indicators

Many of the impact indicators, such as increases in agriculture output or incomes, were unreliable. These impact indicators are not useful. PAEGC has attempted to collect information on impacts before innovations have been piloted. In only a very few cases were the innovations widely diffused. We recommend that WE4F only estimate impact indicators after products have been commercialized. WE4F should ensure that all milestones are based on technological or business goals that measure organic growth by the innovator in terms of quantity of products sold and profitability.

In the course of this evaluation, we calculated potential increases in agricultural incomes and reductions in greenhouse gas emissions stemming from the innovations on the basis of financial, sales, and technical data. We believe these estimates provide a standard means of calculating comparable impacts on changes in incomes and reductions in emissions of greenhouse gases across projects. We recommend that WE4F focus on collecting similar data on sales, prices, revenues, and product specifications rather than anecdotes from the innovators and selected beneficiaries to estimate impacts. WE4F should also try to collect information on the total size and growth in the market.

Success for WE4F should be measured by overall dissemination of successful technologies, not just the performance of the innovators it funds. WE4F should hire third-party evaluators to measure the growth in

markets that it is targeting and to determine the characteristics of the customers in those markets. This information can be used to assess whether the technology or market selected have had impacts and to assess the extent to which WE4F innovators have contributed to the growth of the market.

For more in depth assessments of all impact measures, we recommend WE4F hire third party evaluators at the beginning of selected projects to track the effects of the innovation on changes in the impact indicators over time. The evaluators would also be responsible for measuring reductions in poverty and improvements in gender equality. Because of cost considerations, probably only a few innovations will be able to be evaluated in this fashion.

Program management

PAEGC invested heavily in site visits so as to obtain a grounded view of what was transpiring. By taking a delayed, more realistic approach to collecting indicators and providing smaller initial grants, WE4F could rely more heavily on photographic and other evidence of progress on the project with less need for in-person site visits. In-person site visits could be confined to projects that receive larger second awards.

Innovators valued interactions with each other as well as with PAEGC technical staff. WE4F should proceed with its plan to manage the program through local support hubs like GIZ's hub in Nairobi. The hubs could organize more innovator meetings, a request from many innovators. They could also serve as an additional check on award recipients as the hubs should be able to stay in closer contact with awardees.

Ongoing support and capacity building

Innovators found the PAX and the Powering Agriculture Investment Alliance valuable sources of advice and support. They noted, however, that their need for this assistance was greatest when the project was nearing its end. Many wished to continue to have access to these organizations after the end of the project. We recommend that WE4F include similar organizations and services in its program and that it ensure that awardees have access to these services for an extended period of time.

Renewable technologies are new and unfamiliar to most potential beneficiaries. WE4F should continue to include efforts to educate potential beneficiaries, civil servants, and other stakeholders about these technologies to facilitate their diffusion and to assist both suppliers and customers to use them effectively through knowledge management.

WE4F should also incorporate measures to work with local and national governments to design regulatory systems that foster the adoption and proper use of renewable energy solutions in agriculture. In particular, WE4F should work with electricity regulators to ensure that micro-grids can be built and profitably operated in rural communities without grid access. It should also ensure that solar-powered irrigation systems are regulated in a manner that does not overtax underground sources of water.

Appendix A: List of interviewees

Table A.1: List of interviewees by organization and mode

Organization	Mode of Interview	Name
Azuri Technologies	Kampala, Uganda	Richard Awuor
Biogas Solutions Uganda Limited	Kampala, Uganda	Michel Muvule Pinto and Florence N. Kintu
Davis and Shirtliff	Kampala, Uganda	Salesperson
SolarNow	Kampala, Uganda	Sandra Bos
SolarNow (SunDanzer)	Kampala, Uganda	Sam Ssenkandwa
Uganda Solar Energy Association (USEA)	Kampala, Uganda	Joyce Nkuyahaga
University of Georgia (Thermogenn)	Kampala, Uganda	Joseph Galiwango
Davis and Shirtliff	Kisumu, Kenya	Salesperson
Futurepump	Kisumu, Kenya	Collins Oluoch
GIZ Green Innovation Center	Kisumu, Kenya	Sophie Grunze and Lucas Zahl
KickStart	Kisumu, Kenya	Chris (Last name unknown)
Millennial Legacy	Kisumu, Kenya	Simeon Ogonda, Vistor Torres Toledo
SolarNow	Kisumu, Kenya	Julien W. Malimasi
Agsol	Nairobi, Kenya	Matt Carr
Ariya Finergy Limited	Nairobi, Kenya	Jenny Fletcher
Enviu	Nairobi, Kenya	Denis Karema
GIZ Hub	Nairobi, Kenya	Lucie Pluschke
GIZ Hub	Nairobi, Kenya	Macben Makenzi
KickStart	Nairobi, Kenya	Fred Obudho
Ngere Tea Factory	Nairobi, Kenya	Lucie Pluschke and factory employees
Strathmore University	Nairobi, Kenya	Sarah Odera
SunCulture	Nairobi, Kenya	Jon Saunders
Sunny Irrigation	Nairobi, Kenya	Rick Sheridan
USAID mission	Nairobi, Kenya	William Madara
USAID mission	Nairobi, Kenya	William Madara and Fredrick O. Ochieng
African Bamboo	San Francisco	Khalid Duri
Claro Energy	San Francisco	Soumitra Mishra
Futurepump	San Francisco	Helen Davies
Husk	San Francisco	Manoj Sinha
International Development Enterprises (iDE)	San Francisco	Conor Riggs
KickStart International	San Francisco	Martin Fisher
KickStart International	San Francisco	Alan Spybey
Promethean Power	San Francisco	Jitendra Ghelani
SunDanzer	San Francisco	David Bergeron

University of Georgia Research Foundation/Thermogenn	San Francisco	William Kisaalita
Village Infrastructure Angels	San Francisco	Stewart Craine
Alphamundi	Washington, D.C.	Lisa Willems and Christine Roddy
EarthSpark	Washington, D.C.	Madie Sturgess
Factor[e]	Washington D.C.	Tim Sherwood
Fintec	Washington, D.C.	Mark Sevier
OPIC	Washington, D.C.	Bruce Cameron
Tetra Tech	Washington, D.C.	Headly Jacobus, Jeannelle Blanchard, Mikael Matossian
USAID	Washington, D.C.	Augusta Abrahamse, Simone Lawaetz, Ryan Shelby
PASTO gender specialist	Telephone	Jessica Menon
Africa Mini-grid Developers Association	Telephone	Daniel Kitwa
Development Ventures	Telephone	Andrew Varrow
DGridEnergy, LLC	Telephone	Eugene Faison
Earth Institute at Columbia University	Telephone	Vijay Modi and Jack Botts
EcoConsult	Telephone	Ra'ed Daoud
GIZ	Telephone	Jennifer Braun, Maria Weitz
Horn of Africa	Telephone	Mekuria Argaw and Negasu Tefera
Institute for University Co-operation (ICU)	Telephone	Danielle Bonetti and Larissa Setaro
Motivo Engineering	Telephone	Praveen Penmetra
ReBound	Telephone	Kevin Davis
Sida	Telephone	Pia Lindstrom, Sara Karlsson, Thomas Melin
Sistema.bio	Telephone	Alexander Eaton
University de Valle Guatemala	Telephone	Monica Stein
University of Hohenheim	Telephone	Victor Torres Toledo
University of Hohenheim	Telephone	Steffen Schock
University of Toronto	Telephone	Amy Bilton
VentureWell	Telephone	Jeff Engell, Christina Tamer, Laura Sampath
Village Infrastructure Project	Telephone	Carl Bielenberg

Appendix B: Interview protocol

Introduction

- What is STPI?
- Why are we doing this evaluation?
- Would you be willing to give us permission to record?

Project Selection/Project Intent

- What was the impetus for your project? How did you identify the technology and business need/agricultural application/potential beneficiaries?
- How did you identify your partners for the project?
- What were your goals for the project/what did you intend to achieve?
- What specific powering agriculture-related challenge(s) was your project intended to overcome?
 - Follow-up: Was your solution intended to increase farmer income/output? If so, how?
 - Follow-up: Was your solution intended to reduce poverty in the LMIC country/countries to which it would be applied. If so, how?
 - Follow-up: Was your solution intended to reduce GHG emissions? If so, by how much per unit?
 - Follow-up: Was your solution designed to reduce gender inequities? If so, how?

Project Results

- How much progress have you made in advancing the technology/business model toward commercial scale?
 - [Follow-up if 2015 award/award still active only]: What stage of commercial development to you expect to reach by the end of the award?
- To what extent is the technology developed superior to existing technologies in terms of productivity, cost, reductions in greenhouse gas emissions, and other such factors?
 - Follow-up: Do you know actual GHG avoided per unit (per year/lifetime)?
 - Follow-up: Has your solution achieved its aims with respect to increasing incomes, decreasing poverty, and/or reducing gender inequities? Describe.
- Have you received additional funding from sources outside Powering Agriculture post-award to continue development of the technology?
 - Follow-up: How much/from whom?
- [For those that have completed a demonstration/market acceptance step only:] Does the technology show commercial promise?
 - Follow-up: Have targeted users purchased the technology? If so, how many purchases have been made?
 - Follow-up: What do users like and dislike about the technology?
 - Follow-up: Can the technology be manufactured at a commercial scale?
 - Follow-up: Can the technology be sold at a price competitive with existing alternatives?
 - Follow-up: Have you been able to sell the product at a price that covers the costs of producing and selling the product?
- [For those reaching/approaching commercial scale only]: Is the technology commercially scalable?
 - Follow-up: Have you produced and sold the product at a scale that will make the company a going concern?
 - Follow-up: What are your company's annual revenues today? What percentage of them derives from the Powering Agriculture technology?
 - Follow-up: Do you require additional capital to scale up production and marketing? If yes, how much, and how are you planning to raise that capital?

- Final questions
 - What role did Powering Agriculture play in terms of moving your solution forward?
 - Follow-up: Strengths and weaknesses in working with program staff?
 - Follow-up: Strengths and weaknesses in working with PASTO/Tetra Tech?
 - Follow-up: Strengths and weaknesses in working with VentureWell?
 - What major challenges did you identify over the course of your project and how did you work to overcome them?
 - What recommendations might you have for USAID and the Powering Agriculture partners going forward?
 - Are there any final thoughts you have to share/anything important that we've missed in this conversation?

Appendix C: Data tables used to estimate potential reductions in greenhouse gases

We used data from Natural Resources Canada to convert combustion of diesel, gasoline, and kerosene into emissions of greenhouse gases. The parameters were the following: 1 liter of diesel fuel emits 2.66 kilograms of carbon dioxide; 1 liter of gasoline, 2.29 kilograms; and 1 liter of kerosene, 2.46 kilograms (Natural Resources Canada ud.).

Consumption of diesel fuel by generators is provided below.

Generator Size	Approximate diesel fuel consumption by generator size			
	1/4 Load (liters/hr)	1/2 Load (liter/hr)	3/4 Load (liters/hr)	Full Load (liters/hr)
8kW / 10kVA	0.9	1.2	1.7	2.1
10kW / 12kVA	1.0	1.4	2.1	2.6
12kW / 15kVA	1.3	1.8	2.6	3.2
16kW / 20kVA	1.7	2.4	3.5	4.3
20kW / 25kVA	2.1	3.0	4.3	5.4
24kW / 30kVA	2.6	3.6	5.2	6.4
32kW / 40kVA	3.4	4.8	7.0	8.6
40kW / 50kVA	4.3	6.0	8.6	10.7
60kW / 75kVA	6.4	9.0	12.7	16.1
80kW / 100kVA	8.3	11.9	16.1	21.4
120kW / 150kVA	10.9	17.3	24.1	32.1
160kW / 200kVA	14.1	22.9	32.7	42.8
200kW / 250kVA	17.4	28.6	40.8	53.5
280kW / 350kVA	23.7	39.3	56.0	74.9
400kW / 500kVA	33.3	55.6	79.6	107.0

Source: www.ablesales.com.au

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