Supporting Information

Burney et al. 10.1073/pnas.0909678107

SI Text

Context. In 2007, Benin ranked 161st out of 182 countries in Human Development Index (HDI) (1); fortunately, unlike the majority of the poorest countries in the sub-Saharan Africa and the world, Benin has been peaceful for decades. Like other coastal countries of West Africa, Benin spans a diversity of agro-ecological zones, from the humid coastal south to the Sudano–Sahel in the north. Several important indicators of development also vary from south to north within the country: The coastal region features stronger infrastructure, higher incomes and living standards, and lower levels of malnutrition, infant mortality rates, and anemia (2).

In the northern region (Kalalé District, Borgou Region) studied in this paper, approximately 105,000 inhabitants in 44 villages have access to minimal local infrastructure: Kalalé lies 100 km from a paved road, has no secondary school, and no electricity grid (although the main village does have a diesel generator). In the Borgou region, 46.8% of children under five yr of age suffer from stunted growth (-2 SD in height/age) (2). Some services have recently been extended to Kalalé: Cellphone coverage began to reach certain areas in October 2007 and has expanded since, and construction on a hospital has recently begun.

In the district, 85–90% of households depend entirely on agriculture for their livelihoods, including production of staple crops, livestock, and some cash cropping of cotton and, more recently, cashews. The median household (seven individuals) typically owns (or has been allocated through traditional systems) several 0.5–1 ha plots of land, one of which is used for a root crop, like cassava or yam, and one of which is used for a cereal crop, like sorghum, maize, or millet. Additional plots are often fallowing after a yam harvest or used for small-scale production of cotton or cashews. Households have access to fruits and vegetables largely through village mango trees and the cultivation of okra, hot peppers, tomatoes, and several varieties of greens during the rainy season; access to these sources of micronutrients becomes very limited during the dry season, and prices rise significantly.

Project Background. The solar-powered drip irrigation project in northern Benin commenced when members of l'Association de Développement Économique, Sociale, et Culturel de Kalalé (ADESCKA), a local community development organization, approached the Solar Electric Light Fund (SELF), a nongovernmental organization (NGO) based in Washington, D.C., about bringing solar power to Kalalé. Given the high agricultural dependence and malnutrition levels, the organizations decided together to pursue solar-powered drip irrigation, and enlisted the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Niamey, to provide expertise in irrigated horticulture. The plan for the project pilot was chosen for funding in the World Bank Development Marketplace competition in 2006, and system installation and training of local technicians took place in 2007 in time for the dry season beginning in November. The pilot PVDI systems were meant to be part of a 2 yr evaluation period, after which the technology and management package could be refined and the project expanded with different financing options if deemed effective, appropriate, and sustainable.

Pilot Village Choice and Women's Agricultural Groups. Almost all of the villages in Kalalé have women's agricultural groups; these groups engage in activities from vegetable production to collective harvesting of members' fields to value-added activities, depending on the group and village. The pilot (and control) villages were chosen from a large subset of villages in which the women's agricultural groups were engaged in vegetable production to leverage their existing group infrastructure. To test the PVDI concept with both surface and groundwater sources, one village with each type of source was chosen. The pilot PVDI systems were donated to the women's groups; however, they contributed all labor and, through the revenues of the common plots in the gardens and their own dues systems, now pay for input and repairs.

Implementation and Technical Sustainability. To promote technical sustainability, the local community development organization hired a project team (director, solar technician, and agricultural technician) to oversee installation and maintenance, to facilitate operations, to provide continued training for farmers, and to lay the foundations for project expansion. The impact of having highly educated local staff members eager to work long term on a project in their home district cannot be underestimated. At each step of installation, additional technicians were trained: Local masons learned to construct and repair the large concrete reservoirs, pump mechanics and electricians learned to install and monitor solar-powered pumps, and the farmers learned to use and care for the pumps, drip irrigation lines, and filters. As part of the project pilot, the farmers using the PVDI systems benefitted from several visits from ICRISAT technicians, who led trainings on irrigated vegetable production, seed multiplication, pest management, and crop selection and marketing.

Additionally, the long-term commitment made by project implementers has served an important role in technical sustainability. Whereas this commitment is relatively low-level, in that all daily operations and maintenance are managed locally, SELF and ICRISAT have continue to consult with the local development organization and project team. This has helped connect the project team with suppliers and facilitate inputs purchases, as well as to help gather information about prices in local and regional markets that the team and farmers can use to generate a crop calendar for maximum profit.

Social Impacts and Social Sustainability. As noted above, many women's agricultural groups in Kalalé were engaged in small-scale vegetable production before project implementation; as such, this PVDI project fit within social and cultural norms. Nevertheless, project implementers worked closely with village elders through the design and installation process, modifying the systems to accommodate local traditions and beliefs, including building a metal-free intake system for the surface water PVDI systems: Culturally sacred crocodiles live near the stream, and the villagers pay homage to their habitat by not placing metallic objects in the water.

It is unclear as yet how this new source of revenue will affect local gender roles. For most of the women farmers, the income from the PVDI systems is the first they have earned. Many were initially nervous to report their yields and sales to project staff, worrying that their money would be stolen if the information became public. These fears dissipated after several months, facilitated by the consistent support of the local staff and ICRISAT technicians, who encouraged the women's groups to formalize their land holdings through the Mayor's office, to open accounts at the local agricultural bank, to concretize their group structures, and to register as independent NGOs in Benin.

While there is not yet statistically significant evidence of increased school enrollment for PVDI users' children, there is reason to think enrollment rates may rise in the near future: During the baseline survey, only 4% of farmers reported that they planned to use their earnings in the coming year to pay school fees for their children; after one year this rose to 22%. Furthermore, there is no evidence that children are being kept out of school to work in the gardens: Farmers unanimously report spending less time working on their plots in the PVDI gardens than on their previous hand-watered plots, and only 24% report that anyone in their family ever helps them with their work.

1. UNDP Human Development Report (2009) Benin. Available at: http://hdrstats.undp.org/en/countries/data_sheets/cty_ds_BEN.html (last accessed October 20, 2009).
2. World Health Organization (WHO) (2009) Benin. Available at: http://www.who.int/nutgrowthdb/database/countries/ben/en/ (last accessed July 15, 2009).

Fig. S1. Maps of Africa and Benin, showing location of Kalalé District.

Table S1. Baseline (2007) data from preimplementation survey for treatment and matched-pair control villages

	Treatment village A	Treatment village B	Control village A	Control village B
Population (2002 National Census)	3169	5521	4539	3398
Water extraction system	Surface PVDI	Groundwater PVDI	Manual	Manual
Road type	Main dirt	Small dirt	Main dirt	Small dirt
Village administrative status	NA	Subprefecture	NA	Subprefecture
Median daily per capita consumption expenditure				
Whole sample	$0.83	$0.74	$0.92	$0.97
Women's groups	$0.69^^	$0.74	$1.16	$1.29^^
% of households under the "dollar-a-day" poverty line, $1.25 2005 PPP				
Whole sample	81%	80%	75%	70%
Women's groups	97%^^^	68%	53%^^	59%
Median food % of total consumption expenditure (whole sample)				
Whole sample	62%	61%	59%	62%
Women's groups	66%^^	63%	53%	72%
Median household produce consumption, kg/month				
Whole sample	8.0	14.0*	11.8	9.0*
Women's groups	6.9	16.1	4.8^^	11.3
Number of village (non-women's group) households in panel	23	25	29	26
Number of women's group households in panel	30	19	15	17

All monetary amounts are given in USD at purchasing power parity (PPP). Asterisks (*) denote a difference between treatment and control villages (both members of the comparison pair are marked); carets (^) denote a difference between the women's group subsample and the entire village sample within a village. [*,^ p<0.1 **,^^ p<0.05 ***,^^^ p<0.01]

Table S2. Parameters for economic analysis of 0.5 ha (surface) photovoltaic and liquid-fuel engine-driven drip irrigation systems. All monetary amounts are given in $USD at purchasing power parity (PPP).

Photovoltaic drip irrigation system (PVDI)			
	Frequency (yr)	Total (USD)	Per Person (USD)
Expenses			
Equipment and installation			
—Panels and installation (3 price models)	25	9,000/6,000/3,000	225/150/75
—PV-compatible pump	10	1,500	38
—Reservoir	10	3,500	88
—Drip irrigation lines and pipes	5	4,000	100
Operational costs			
—Farming inputs	1	3,800	95
—Extension services and support staff	1	1,950	49
Revenues			
—Vegetables, first year	1	10,000	250
—Vegetables, all other years	1	16,000	400
Liquid-fuel pump drip irrigation system			
	Frequency (yr)	Total ($USD)	Per person ($USD)
Expenses			
Equipment and installation			
—Pump, pipes, and maintenance	5	1,500	38
—Reservoir	10	3,500	88
—Drip irrigation lines and pipes	5	4,000	100
Operational costs			
—Farming inputs	1	3,800	95
—Extension services and support staff	1	1,950	49
—Fuel (3.75 L/day at $0.50/$1.00/$1.50 L)	1	684/1,369/2,053	17/34/51
Revenues			
—Vegetables, first year	1	10,000	250
—Vegetables, all other years	1	16,000	400

Revenues are derived from garden-level yield and sales data over the first 1.5 yr of PVDI system use. Per person costs assume 40 farmers with 120 m^2 individual plots in each garden.