

# **Report: Integrating Electricity Use for Small Scale Irrigation into Electrification Planning**

## **Problem Statement**

Electricity access is an essential ingredient for sustainable development yet millions of people in sub-Saharan Africa (SSA) still live without it. About 600 million people in the region lived without electricity access as of 2021. In addition to electricity access challenges, SSA is also the most food insecure region in the world with high dependence on food importation. In terms of food production, SSA lags behind the world in major staples due to high dependence on rain-fed farming. Only about 5% of the region's arable land is under some form of irrigation partly due to lack of access to low-cost energy sources. Meanwhile, most of electricity utilities in SSA are loss-making partly due to lack of sufficient electricity demand for sustainable economic operation, particularly in rural areas. Integrating the deployment of productive use infrastructure like irrigation into electrification planning raises demand for electricity, thereby improving the sustainability of electricity utility operations, both centralized grids and minigrids. On the other hand, access to low-cost electricity for irrigation has potential to enhance small-holder farmer incomes, alleviate food insecurity and increase resilience to drought and climate change. We have developed a model to spatially map opportunities for investment at the intersection of irrigation and electricity infrastructure to facilitate integrated planning of both sectors.

## **Mapping Opportunities for Investment at the Electricity-Irrigation Nexus**

Several models, such as Open-Source Spatial Electrification Tool (OnSSET) and the Reference Electrification Model (REM), have been developed to facilitate geospatial electrification planning. Most of these models are based on residential electricity demand, ignoring productive use of electricity (PUE) in critical sectors such as agriculture. The omission of these potential loads risks the development of electricity systems that are unable to support important productive use applications.

Because these loads do not yet exist, they must be modeled, rather than measured, for inclusion in planning models. Since agriculture is the heart of most rural economies in SSA, and post-harvest processing loads are a function of primary production, irrigation is a natural starting point for understanding potential electricity demand from the agricultural sector. The resource introduced in this report is an integrated model for assessing small-scale irrigation water and electricity demand, and associated benefits from improved crop yields. The outputs of the model are essential inputs in geospatial electrification planning and policy development for agricultural modernization and food security.

The modeling process integrates a biophysical crop growth model, AquaCrop developed by the Food and Agricultural Organization (FAO), with an engineering-based irrigation model to estimate crop yield, net irrigation water requirement and the associated pumping electricity requirement for pressurized groundwater-fed irrigation. AquaCrop is a water-driven model that simulate crop yield in response to water using soil characteristics, crop physiological characteristics, and climatological data as inputs. Using remote sensed input data on historical climate, soil and water resources, the model can be used to generate spatial maps of irrigation potential. The model is summarized in Figure 1 and described in detail in Izar-Tenorio et al. 2021<sup>1</sup>.

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<sup>1</sup> J Izar-Tenorio, P Jaramillo and NJ Williams, *Techno-economic feasibility of small-scale pressurized irrigation in Ethiopia, Rwanda and Uganda through an integrated modeling approach*, Environmental Research Letters, Vol. 16, Num. 10, 104048, October 2021

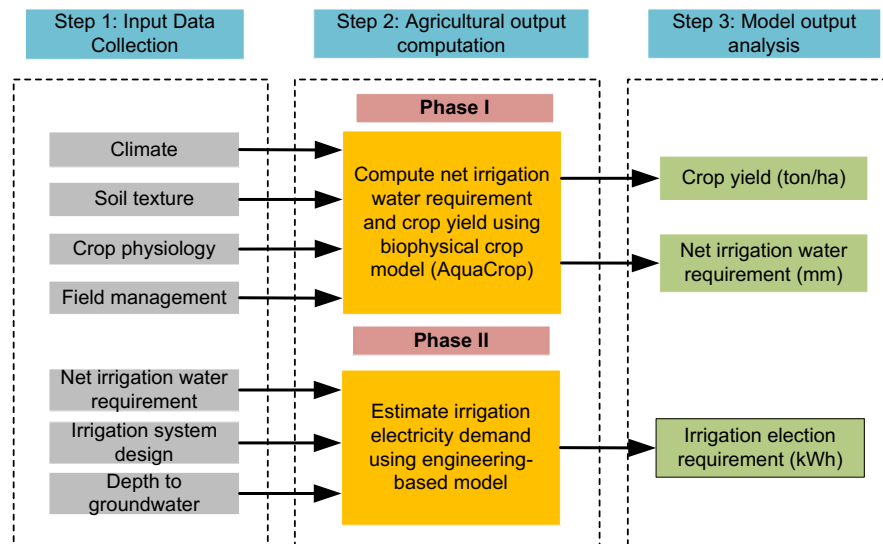


Figure 1. Description of input data, modeling elements, and outputs of the integrated modeling approach.

Figures 2 and 3 visualize the model outputs for average electricity requirements for irrigation and average yield increases due to irrigation for four crops using Rwanda as a case study, with the model run on a district level. The averages are based on simulations of ten years of historical climate data. Such maps can be used to identify areas with high potential for electricity consumption from irrigation (making them attractive to electricity providers) and high potential of increased yields (making irrigation an attractive technology for farmers to adopt).

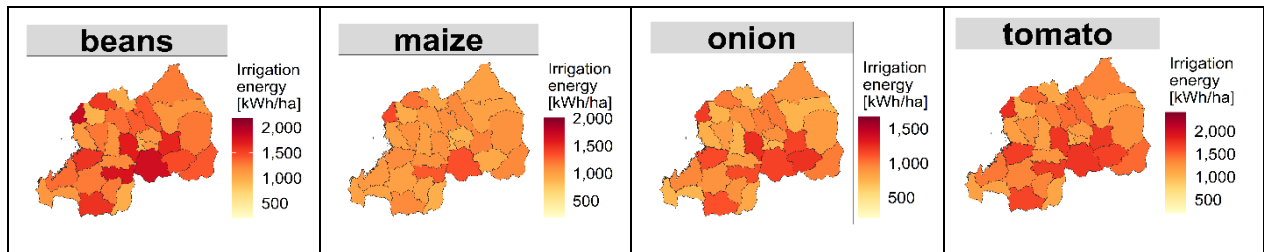


Figure 2. Annual average electricity demand per hectare for irrigation over ten years (2010-2019) of simulated crop growth. The maps measure electricity for irrigation in kilowatt-hours per hectare of cropland (kWh/ha). Note that the scale of the color scheme is different for different crops.

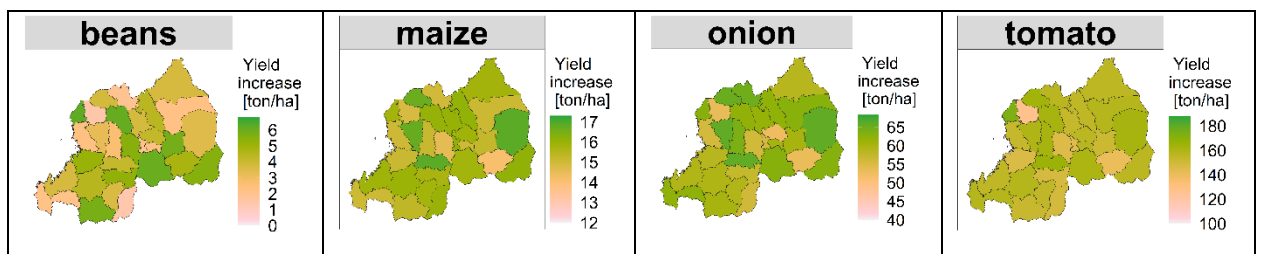


Figure32. Annual average yields over ten years (2010-2019) of simulated crop growth for improved yield cultivars grown with non-limiting soil fertility. The maps measure the yield increase from rainfed to irrigated crops in metric tons of fresh weight per hectare (ton/ha). The geographical scale of each country's map is different for better appreciation.

## **How to Use (and not to Use) Model Outputs**

The model benefits from reliance on publicly available inputs which are available across broad geographic regions. This allows the model to generate national, and even continental scale maps of irrigation potential using existing and freely available remote sensed data for a large number of crops that are supported by AquaCrop. Model outputs like electricity requirements and yield gains can then be used by policy makers, entrepreneurs and electricity service providers to quickly identify areas ripe for joint investment in electricity and irrigation infrastructure. They can be further processed to more directly assess costs and benefits for both farmers and electricity providers. Estimates can as well be incorporated into electrification planning models to account for product loads in spatial electrification plans. A case study using the OnSSET model in Ethiopia found incorporation of irrigation loads in Agricultural Commercialization Clusters significantly shifts the least cost electrification approach from standalone systems towards mini-grids and grid extension which support higher consumption of electricity. Additionally, because the model is run over several years of historical climate data, analysts can also assess variability of water use, electricity demand and yield gains over time. These sorts of analyses are important to sizing systems to accommodate climate variability and assessing the drought resilience benefits that irrigation provides farmers which is not captured by averages.

It is important however to understand the limitations of this approach. While using remote sense data permits a fast and low-cost analysis over a large geographic region, those remote sensed inputs also have varying temporal and spatial resolutions, as well as varying precision. In principle, the model can be run at any spatial resolution, however, the utility of producing highly spatial resolved maps is limited by the precision and spatial resolution of input data. We therefore caution against using the data to make highly localized siting decisions but rather to identify areas of promising potential for further exploration on the ground. Further, because remote sensed data will always be less accurate than ground data and assumptions of farm practices and field conditions may not be accurate, water, electricity and yield estimates should be taken as first order estimates. Where ground truth is available, this can be used to complement remote sensed inputs. Any final system designs and economic forecasts should be supported by field data. Finally, it is well understood that our climate is changing. Estimates based on historical data do not account for future climate change. Work is in progress to understand how climate change may affect future water needs which can be used to assess climate vulnerabilities that can be mitigated with irrigation.

## **Conclusions**

In order to capture the full benefits of investment in electricity access, electrification planning needs to integrate productive uses of electricity. Small-scale irrigation in particular has potential to provide immediate benefits to communities and small holders including increased yields and incomes, drought resilience and food security. At the same time, incorporation of productive use into electrification planning improves the financial sustainability of rural electrification projects. The model described in this report provides decision makers with critical information to support joint investment in electricity and irrigation infrastructure. Decision makers in both the public and private sector can leverage these data products to inform integrated planning. Data products derived from remote sensed products can provide fast, low-cost insights to identify promising areas for investment, saving time and cost associated with ground data collection in areas that can be screen out at an early stage. Detailed design and implementation of projects will also require collection of data on the ground but products like these can make identification of opportunities faster and more cost effective.