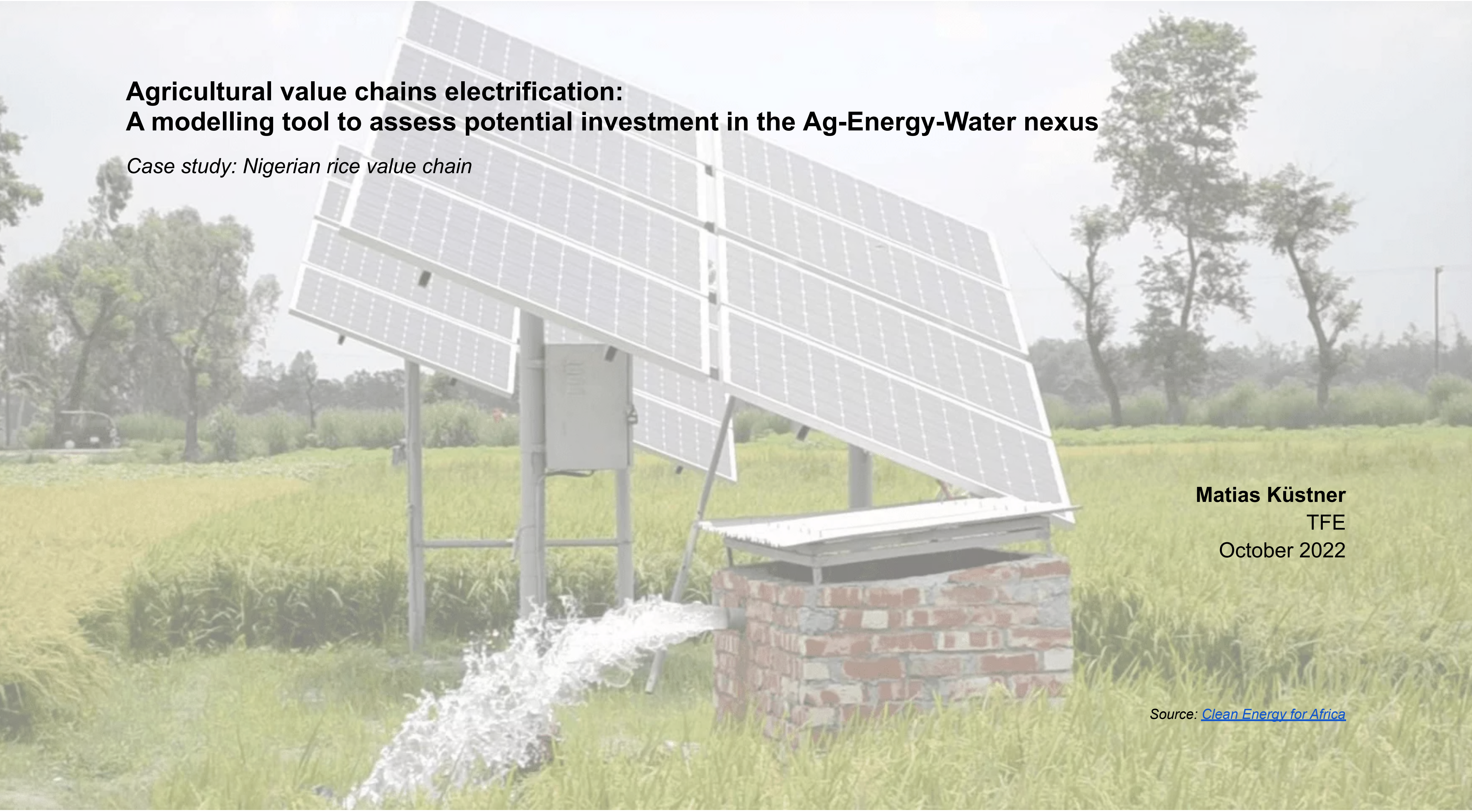

Agricultural value chains electrification: A modelling tool to assess potential investment in the Ag-Energy-Water nexus

Case study: Nigerian rice value chain

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October 2022

Source: Clean Energy for Africa

Purpose of the model

Awareness of the Agri-Energy-Water nexus opportunity is building in the energy planning and investment fields. At the same time, distributed renewable energy increasingly offers the cheapest, most appropriate solution for new power generation. However, the commercial investment needed to scale energy access is still notavailable for the majority of the sector. Investors struggle to make a profitable case when approaching high risk opportunities (such as the small-scale agricultural sector) individually. Targeting the agriculture and energy nexus from a value chain perspective - from production to market - could potentially provide a better suited scenario for increasing access to clean energy, expanding value addition towards small-scale upstream stakeholders and enlarging the appetite for aggregating investment along these unrealized, highly productive activities.

Investment decision making relies more and more on accurate and data-driven indicators. In light of recurrently facing lack of information, PwC Nigeria clearly indicates that “satellite images coupled with Geographic Information Systems (GIS) and Global Positioning systems (GPS) are becoming more frequently employed, providing important data which details objective estimations of crop conditions and yields” [1]. GIS techniques are becoming openly available and are unlocking previously inaccessible information.

A comprehensive geospatial, techno-economic and value chain model that considers the Agri-Energy-Water nexus can serve as the first step for identifying and de-risking investment opportunities. Valuable outputs can be extracted from mapping high-potential locations for electrification of value chain activities and their consequent investment and return levels.

A few open-source geospatial models have been partially addressing the gap of considering agricultural energy demand as productive use in electrification planning tools. Some models try to incorporate agriculture into electrification planning. The Energy Access Explorer from World Resource Institute [2] or the Integrated Energy Planning Tool from Sustainable Energy for All [3] for example. Even though these tools integrate agricultural productive use, they remain generic approaches for a sector that requires complex analyses. Such approaches only ponder one activity within a specific value chain, or offer total agricultural production levels as an individual layer within electrification tools.

Most electrification planning tools, however, do not convey agricultural value chains into their models. Demand estimation has typically taken the form of residential loads until now. Some productive loads may be considered from time to time, for example commercial and institutional loads (education and healthcare facilities). However, electricity demand from agriculture and agri-businesses are typically forgotten.

Aside from the two major tools mentioned, two distinctive open-source geospatial data processing platforms are the Multi-sectoral Latent Electricity Demand (M-LED) [4] and the Agrodem [5] model. Both models are able to estimate electricity demand from agricultural value chain activities.

Three main knowledge gaps are found in the existing tools which are addressed with the creation of this model:

- Value chain perspective: Energy consuming activities within an agricultural value chain can be assessed altogether, not only to account for interdependent factors such as yield increase from irrigation affecting post-harvesting processing, but also to identify highest potential value activities and prospective investment aggregation;

- Market-driven outputs: Most models and studies reviewed target policy makers or development agencies and thus analyse agricultural demand from a high-level. There is opportunity to account for crop-specific distinctions and offer tailored results to interested parties such as commercial investors or even agricultural agencies and cooperatives;
- Crop-specific standardisation: Even though concepts like “crop-specific” and “standardisation” seem to oppose each other, there is space for flexible modelling in order to rapidly accommodate particular differences in value chains resulting in comparable outputs.

In order to tackle these gaps, the main objective of this piece of work is the creation of a suitable methodology and further geospatial, data-driven, and commercial energy investment decision tool to evaluate the potential of electrifying agricultural value chains. This can be achieved by modelling two separate modules with different outputs:

a. Geospatial mapping of energy requirements from activities within a specific value chain according to crop-specific yield and production datasets;
b. Techno-economic assessment of electrifying these activities with decentralized renewable energy sources from the perspective of a smallholder farmer or processor.

Methods and operation of the proposed model

The framework developed under this study aims at building a replicable methodology to be used across countries and value chains by any practitioners in the field. This methodology is translated and presented mainly in the form of a Python/GIS-based model to process available geospatial agricultural datasets into energy related and value-adding outputs.

The proposed methodology is meant to analyse one specific value chain at a time, and can be divided into three different stages of analysis, as observed in Figure 1 below. The first stage focuses on performing a qualitative crop- and country-specific value chain analysis, not only to be able to better understand the dynamics, operations, and current practices within that value chain, but also to collect the necessary data points that will serve as input for the geospatial model.

The second and third stages make use of the tool. The former evaluates agricultural electricity demand: agricultural water requirements are quantified and prospective electricity from groundwater and surface water pumping are estimated for areas that are currently rainfed. Considering these areas with irrigation, increased production yields are computed and used to estimate the total production available for post-harvesting processing activities and their respective electricity requirements. The latter stage evaluates the economic impact of these potential electrification actions: a techno-economic assessment is carried out to geospatially map investment needs and profitability indicators from a farmer’s perspective, such as payback time and energy enabled value addition.

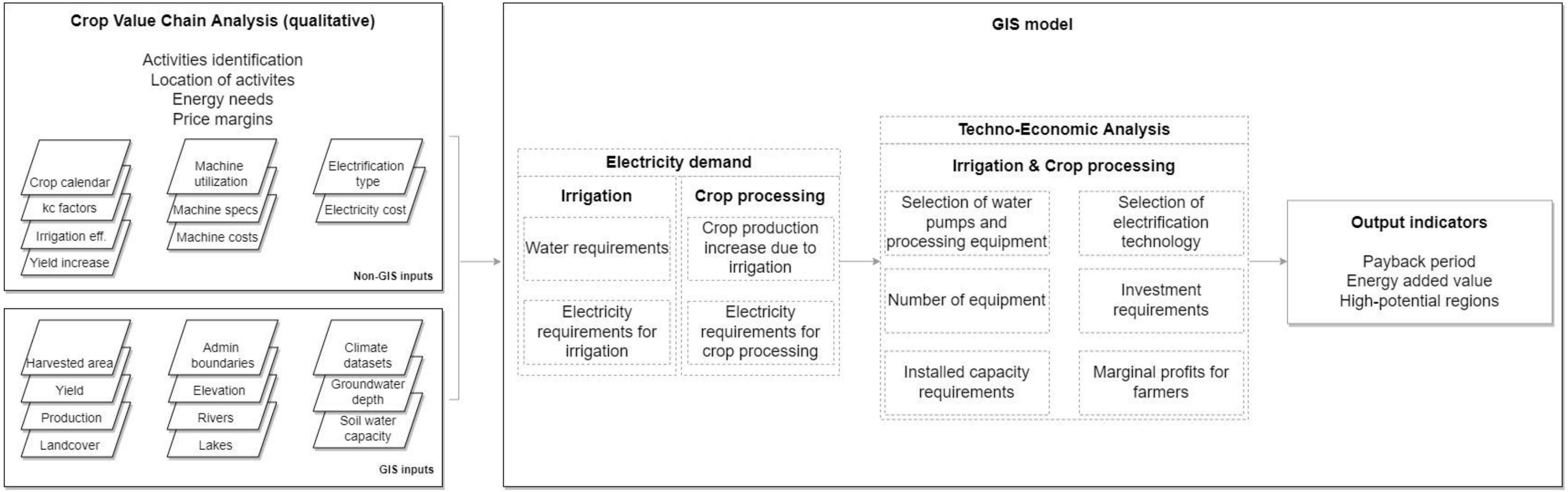


Figure 1: Proposed methodology

Part of the model development has been based on an existing model called Agrodem [5]. Agrodem's repository can be found on https://github.com/akorkovelos/agrodem and the user's guide in [6]. The model is meant to be as flexible as possible so that the final economic outputs can easily be adjusted by the users according to their needs.

Crop value chain analysis

In order to increase input data accuracy in the model, an initial crop- and country-specific value chain analysis (VCA) needs to be performed. Ideally, such a VCA is required every time a new crop or AoI is studied. The VCA is based on the following aspects:

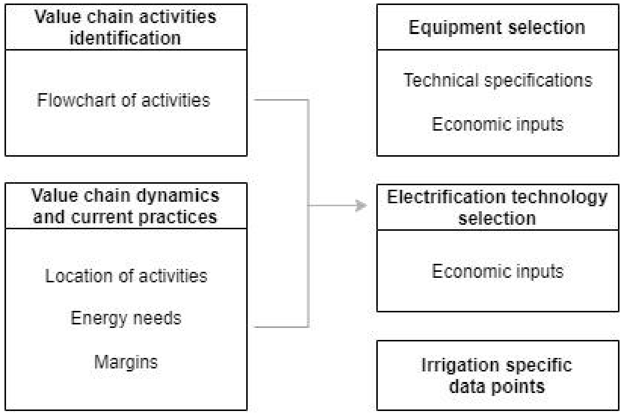


Figure 2: Crop value chain analysis overview

The main objectives of this stage is to:

- **Identify agricultural activities within the selected value chain:** a flowchart of the energy related processes involved in the value chain is obtained in order to provide the required context to the study.
- **Identify activities' current practices:** Qualitative energy needs are found, identifying if each activity is currently being performed manually, powered by diesel / gasoline, or already electrified. In addition, the location of each activity needs to be known, i.e. activities typically being performed at farm level (irrigation), village level (small scale processing), or at aggregated hub level (large scale processing). Finally, market related flows and stakeholders need to be distinguished, mainly buyers, sellers, and profit margins at each stage of the value chain.

GIS model

The general structure of the model is shown in Figure 3. Each block represents a different python or QGIS code / file. A first set of blocks is used to calibrate the input datasets that serve to evaluate the irrigation electricity requirements. Crop processing electricity needs are then quantified from the irrigation module results, and finally the techno-economic analysis is performed to obtain different economic indicators.

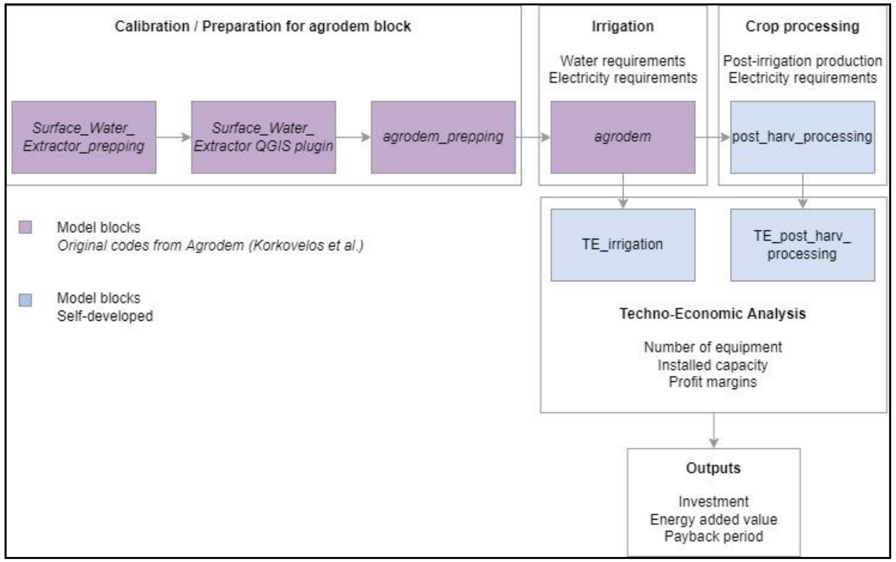


Figure 3: Model blocks and structure

The first four blocks (incl. the irrigation block) are the most intensive in terms of geospatial processing. The base GIS layer that gives birth to the model is a MapSPAM csv file which contains information about the crop harvested area, yield and production. Ideally this layer would differentiate between rainfed and irrigated areas, which is essential to the study. If that is not the case, the base layer can be overlaid with a cropland extent layer containing these distinctions. The temporal and spatial distribution of this data together with the monthly weather data is distributed throughout the crop calendar and the respective planting, growing, and harvesting seasons. A number of processing and manipulation techniques allow evaluation of the theoretical crop water need, the actual water requirements and the monthly electricity demand of powering solar water irrigation pumps.

The crop processing block and both the techno-economic blocks are self-developed codes. These blocks do not add more geospatial layers to the analysis, but rather take the previous results and incorporate inputs from the crop VCA to obtain the new outputs. Crop production values from irrigated areas are updated and technical specifications of processing machinery are used to estimate the corresponding electricity demand.

During the techno-economic analysis, both irrigation and processing activities are approached similarly, estimating the number of pumps and machines needed to cover the throughput in each area and comparing profits of current practices versus the electrified practice of each activity. This way, marginal profits are assessed and the economic indicators can be extracted from the model, i.e. payback period and energy added value.

Data collection

Both non-GIS and GIS inputs need to be collected. The former range from stakeholder and value chain dynamics to crop calendars, kc factors, irrigation efficiencies, yield increase due to irrigation, machinery technical and economic specifications (throughput, power rating, upfront and operating costs), electrification technology costs, and crop prices across value chain activities. The latter include geospatial vector and raster datasets such as crop-specific data (production, yield, harvested area), administrative boundaries, climate data (temperature, irradiance, wind speed, precipitation), and land data (elevation, hydrological basins, groundwater table depth, soil water storage capacity, agro-ecological zones).

The bulk of the raw data can be gathered through primary data collection (surveys, interviews, focus groups) or literature review. On top of this, validation of these inputs is always required, mainly for information collected from desktop research.

Model applied to Nigerian rice value chain

Rice value chain analysis

Different sources ([7],[8]) have allowed the identification of the activities involved in the rice value chain from pre-production to wholesale stages in Nigeria. Figure 4 below shows the categorization of activities according to their location, current energy use, and most suitable electrification technology. Highlighted in bold and in blue are the activities selected to be included in the model. These are irrigation, threshing, milling, and destoning activities, and have the highest potential to be electrified.

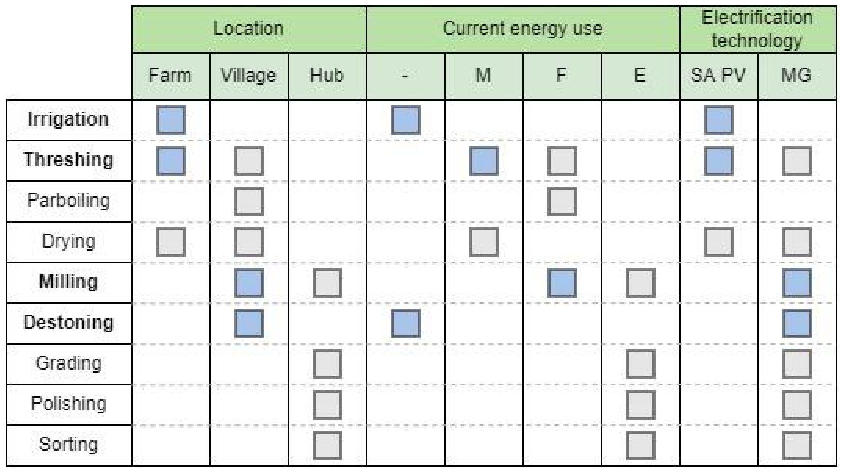


Figure 4: Location, current energy use, and suitable electrification technology for rice value chain activities[1]

[1] Acronyms current energy use: “-” = no activity; “M” = manual; “F” = fuel (diesel / petrol / wood); “E” = electricity
Acronyms electrification technology: “SA PV” = standalone PV; “MG” = mini-grid

Electricity demand

Annual electricity demand for rice irrigation is derived from the annual water requirements (wet + dry season) evaluated during the first part of the model, while demand for processing activities is based on the irrigated rice production volume and the corresponding machine power ratings. The regions that exhibit the greatest total electricity demand needs are circled in orange in Figure 5 below. As observed, the highest electricity demanding regions are located in Taraba, Nasarawa, Benue, Niger, Kaduna, Kano, and Gombe states. The annual electricity requirements for the four activities in Nigeria is **471 GWh/year**.

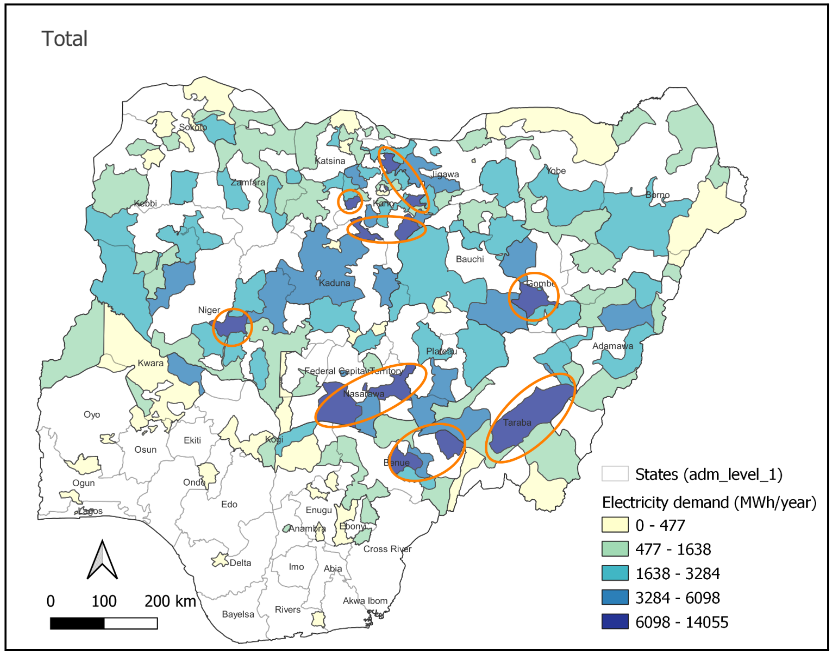
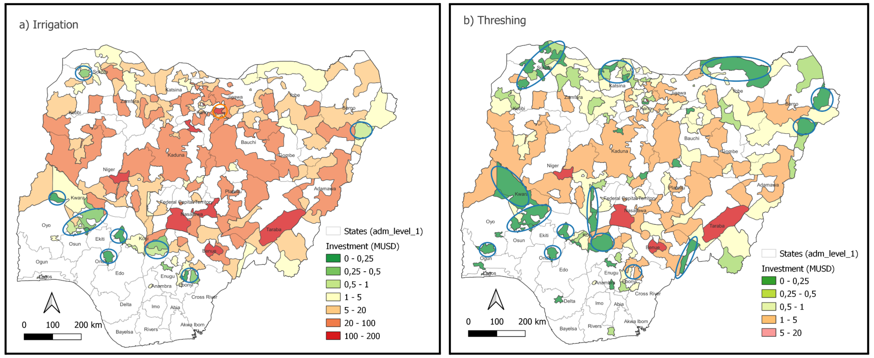


Figure 5: Total electricity demand to electrify rice value chain in Nigeria

Irrigation represents almost three quarters (70%) of the total electricity requirements given the need to irrigate lands during the dry season. Across the processing activities, milling is the most energy intensive activity (20% of total electricity demand) due to the electric mill power rating - 15 kW, compared to 3 kW and 1.5 kW for electric threshing and destoning, respectively.

Techno-economic analysis

The total number of water pumps and processing machines needed, together with the corresponding cost for their electrification, represent an investment of approximately **5,622.2 million USD**. The geographical and activity-specific distribution of the investment can be observed in Figure 6 (a-d).



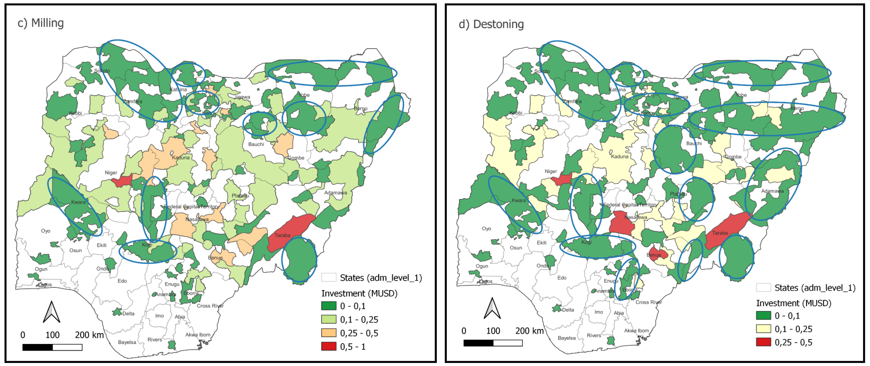
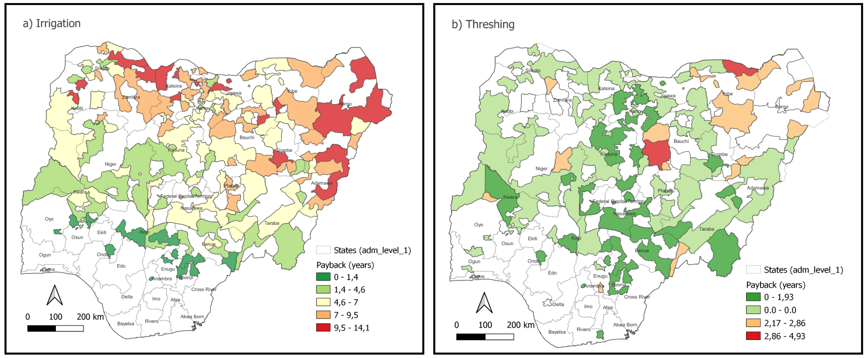


Figure 6: Potential investment in (a) solar water pumps; (b) electric threshers; (c) electric mills; and (d) electric destoners in Nigeria

The most impactful activity in terms of investment is irrigation, accounting for values 10 to 50 times higher than the processing activities. This occurs due to the amount of water pumps needed to cover the entire water requirements for irrigating farms during dry seasons.

The payback period is obtained from the investment of electrifying the different value chain activities. Figure 7 (a-d) presents the estimated payback time for each one of them[2].



[2] Note that the scale in each Figure is different from the other, meaning that the payback time ranges change as seen in the respective legends.

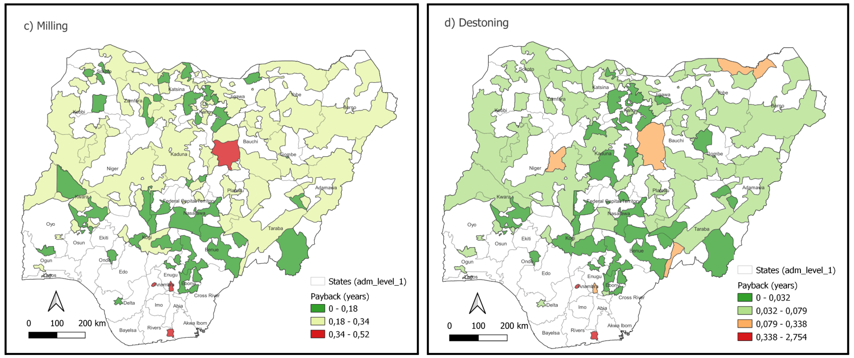


Figure 7: Payback time to electrify (a) irrigation; (b) threshing; (c) milling; and (d) destoning activities of rice in Nigeria

Regions with shorter payback times appear in darker green, while longer payback times are marked in red. The results are already filtered in order to show payback times lower than 15 years. Only irrigation presents payback times longer than 10 years. Threshing, milling, and destoning activities in all the colored regions (not blank) present payback times shorter than 5 (five), 1 (one), and 3 (three) years, respectively.

High electrification potential regions in Nigeria

A few high-potential regions in Nigeria seem to repeat the pattern of presenting the lowest payback periods for the four activities combined. As observed in Figure 8, these regions are mainly located in the states of Taraba, Benue, Ebonyi, Kogi, Ondo, Kwara, FCT (Federal Capital Territory), Kaduna, and Kano. They represent the short-listed regions to start focusing on when targeting locations for rice value chain electrification interventions.

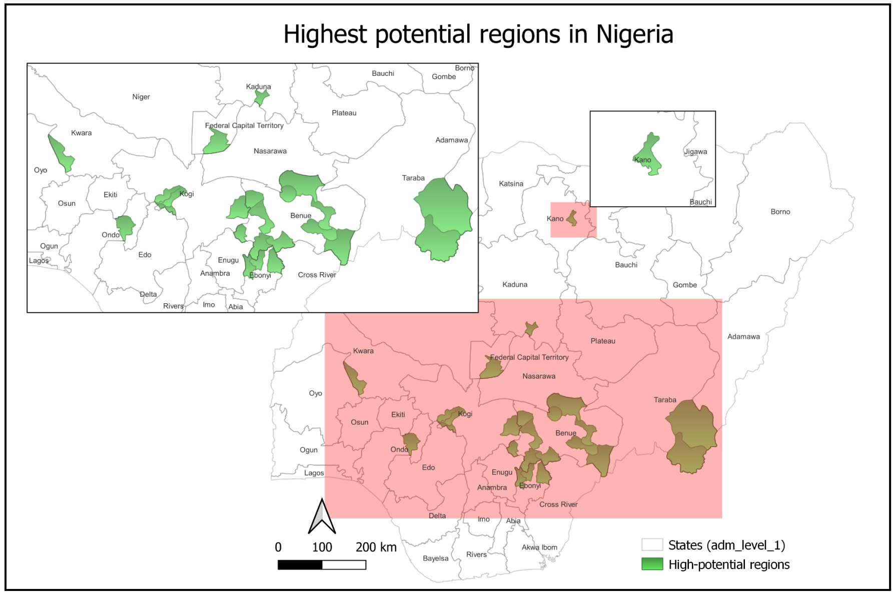


Figure 8: High-potential regions to target for rice value chain electrification interventions

Future development

The methodology and model developed under this study is a promising achievement showing huge potential. However, it also requires further development to increase its accuracy and usefulness. In this sense, the limitations of the current model have to be acknowledged.

The inclusion of several aspects that have not been considered yet could enhance the interest of the tool to other types of users or stakeholders. The most relevant points that could be included and developed further are listed next:

- Temporal dimension: future scenarios considering climate change;
- Sustainable agriculture dimension: land degradation, depletion of water sources;
- Energy dimension: grid extension inclusion, evaluation of hourly demand profiles;
- Value chain dimension: crop losses, markets mapping, transportation costs.

Value of the model

The proposed model shows how qualitative research data can be merged with geospatial quantitative datasets within a single analytical tool in order to obtain comprehensive, decision-making, and commercially-driven outputs.

Several important indicators and outputs can be obtained from the proposed model depending on the interests of the user. Each one of them can serve different purposes. For example, the geospatial distribution of raw water requirements can already serve agricultural associations and cooperatives to the Ministry of Agriculture or Ministry of Energy to target locations that are most in need of support. Furthermore, the mapping of electricity requirements can potentially help private sector energy service providers to target new locations for expansion, or even the Ministry of Energy and development agencies to identify areas where support is highly recommended. Finally, outputs from the techno-economic model such as the total required investment, payback period, and their respective geospatial distribution, can provide private and public investors the possibility to reduce investment risks or aggregate high-potential locations under a single investment portfolio.

Even more, this model has the potential to provide both precision and scalability. Precision is achieved due to the country- and value chain-specific focus of the analysis, which is closer to a bottom-up approach, without falling into broader and higher level approaches such as considering uniform value chain behaviours or homogeneous practices across countries. Scalability or the replicability of the proposed methodology can be performed with probably somewhat more effort than other top-down models. This tool relies on country- and value chain-specific data that needs to be collected for each case, facing the challenges of lack of sufficient data in many cases. However, since qualitative, quantitative, and geospatial data becomes more and more available, the proposed analysis can continue to be exploited and replicated in the future.

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