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E-Ratiba, the Energy Timetable: a planning tool for Energy Use and Revenue in Solar-Powered Schools in Nairobi

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ABSTRACT

Access to reliable, clean electricity is a critical barrier to education and economic development. In Nairobi's informal settlements, schools operate largely without dependable grid power, which limits learning in areas such as computer and science literacy, and clean cooking. The African SCENe (Sustainable Energy Networks) project addresses this by piloting solar photovoltaic (PV) installations that power the school while generating revenue through community-facing energy services to repay the system's cost. In this paper, we present E-Ratiba, the Energy Timetable, an offline desktop application that helps non-technical school staff schedule their energy demand and assess the financial viability of such a system. Existing PV planning tools are aimed at technical specialists, and typically do not integrate a school calendar with demand scheduling and revenue estimation in a format administrators can use. E-Ratiba was shaped by an iterative co-creation process with school staff and local partners, which defined its activity model of internal school services and revenue-generating community services, such as adult IT lessons, cooking, and laundry. It was built through vibe coding, with the authors working as the reviewers and testers of AI-generated code. The application pairs a physically based simulation of the PV and battery system with a familiar timetable interface. Users define typical-day schedules at five-minute resolution, assign them across an annual school calendar, and read off demand, peak load and revenue. At the same time, a set of economic tools returns the levelised cost of energy, net present value, internal rate of return and payback. In bringing these together, E-Ratiba shows that energy planning and the financial case a school depends on, usually handled separately and by specialists, can be placed in the hands of the school staff. The intention is to keep the system running in a viable way, while giving schools and their communities the confidence to take on a seven-year loan for the installation and repay it from the revenue the services generate. Its predictions will next be tested against measured generation, consumption and revenue in a planned field deployment, with future work adding short-term solar-generation forecasting and shortfall alerts.

KEYWORDS Photovoltaics, Co-creation, Productive use of energy, Building operation, Sustainable development

1. Introduction

Reliable electricity is critical for education and economic development, yet across sub-Saharan Africa, it remains scarce: the region now accounts for roughly 85% of the world's population without access to electricity (IEA *et al.* 2025). In Nairobi's informal settlements, supply is intermittent, often

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informally provided, and unevenly distributed; households in Kibera experience around 630 hours of outage a year against a national average of around 81 (Mensah 2022), and efforts to regularise it have been driven by local politics and engineering (de Bercegol and Monstadt 2018).

Schools serving these settlements are directly exposed to that unreliability. Many run on little or no grid power, which limits the two areas electricity would most transform: information-technology-based learning and cooking (Faisal *et al.* 2024; Moner-Girona *et al.* 2025). Cooking is the simpler case to address: the majority of Kenyan schools still cook with firewood (Mukonza 2025) at a cost to school budgets, to staff and pupil health through kitchen smoke, and to the surrounding environment. Solar photovoltaic (PV) generation can address both at once. One installation can run lighting and computers through the school day and an electric kitchen alongside, with no grid connection. However, in most cases, the main obstacle is the cost. A PV system large enough to power a school represents a significant capital investment that a school serving a low-income community cannot easily afford.

The African SCENe project (University of Nottingham 2024) addresses this through a set of linked innovations: it designs, sizes and installs the solar and battery systems; it brings information-technology-based learning, digital skills and teacher training into the classroom; and it replaces firewood cooking with clean electric cooking. At the centre of the project is a business model in which the capital and installation costs are met by newly generated revenue. Outside teaching hours, the school sells energy-enabled services to its neighbours (adult IT classes, space and equipment hire, laundry, water pumping), and that revenue offsets the system's cost (Fajardo *et al.* 2025; Kirubi *et al.* 2009). The school becomes, at once, an energy consumer and a small community energy service provider.

Among these innovations, this paper addresses the planning and decision-support layer, the piece that ties the physical system to the services and the school's calendar. The problem resides in turning that idea into something a school can act on. An administrator must decide which services to run, when, and at what price, and judge whether the income makes the business model and the system viable. These are decisions existing PV planning tools do not support, because they are built for technical specialists. The authors present *E-Ratiba* (from “ratiba”, Swahili for "timetable", and also called the Energy Timetable), a desktop planning tool, the design of which was co-created with schools in Nairobi, that lets non-technical staff schedule a school's energy demand against its own calendar and read off the demand, peak load and revenue that follow. The gap addressed is that no existing planning tool integrates school-calendar structure with demand scheduling and revenue estimation in a form usable by non-technical staff in an informal urban setting. The authors position E-Ratiba against related work, describe the co-creation behind it, its architecture, interface, and underlying models, then present the planned field validation and discuss contributions and limitations.

2. Background and related work

E-Ratiba builds on an established line of work on community energy. The Sustainable Community Energy Networks (SCENe) project demonstrated a community energy scheme at the Trent Basin development in Nottingham, in the United Kingdom, integrating local solar generation, battery storage, demand management and energy retailing with new business models, and treating the success of such a scheme as a social as much as a technical question, in which engaging users and fitting energy use to their everyday routines is central (Cameron *et al.* 2018; Rodrigues *et al.* 2020). African SCENe applies that thinking in a very different setting. In place of a residential community in a high-income country with a strong grid connection, it works with schools in Nairobi's informal settlements, where a school hosts a solar installation and sells energy services to the surrounding community to help meet its costs. E-Ratiba, the subject of this paper, is the co-created planning tool developed within African SCENe to support that model.

Across sub-Saharan Africa, decentralised solar power, in the form of solar home systems and mini-grids, has become the leading way to close the access gap where extending the national grid is uneconomic (IEA *et al.* 2025), and mini-grids in particular are expected to play a central role in reaching those still unconnected (ESMAP (Energy Sector Management Assistance Program), 2022). In low-income communities, however, the demand households can afford is often too low to cover a system's fixed costs, and such installations struggle to remain financially viable (Kirubi *et al.* 2009).

Two responses to this were identified in the literature. The first is to stimulate the productive use of energy, so that putting electricity to income-generating work raises both demand and revenue. Studying a community-based micro-grid in rural Kenya, Kirubi *et al.* (2009) found that access to electric tools raised the productivity of small enterprises by 100–200% and their incomes by 20–70%. They improved the services delivered through village infrastructure, such as schools and water pumps. The economics of this are visible in operating systems, where productive-use customers, though a minority of connections, can account for a disproportionate share of an operator's income. In one mini-grid in Tanzania, productive-use customers accounted for only a quarter of customers but generated 44% of the operator's income and were responsible for the daytime demand peak (Hartvigsson *et al.* 2021). The second response is to secure an anchor load, a large and predictable consumer whose steady daytime demand supports the system and lowers its risk for an operator. These ideas come together in the Anchor-Business-Community (ABC) model, which pairs an anchor customer with local businesses and household consumers to build a viable base of demand (Ramchandran *et al.* 2016; UKRI Innovate UK 2020).

Public institutions can serve as that anchor. Because private operators tend to avoid low-demand areas, the electrification of schools and health facilities has been used to provide the steady, predictable demand that makes a system financially viable, although success depends heavily on local engagement (Liu and Bah 2021). The African SCENe project builds on this logic but recasts it (University of Nottingham 2024). Instead of treating the school as a single business customer behind a separate commercial anchor, it makes the school itself the institutional anchor and has that same institution sell energy-enabled services to the surrounding community. The school is therefore both the predictable daytime load that justifies the system and the provider that earns the revenue to offset its cost.

Tools to plan such systems already exist. Established packages such as HOMER (NREL 2004) and PVsyst (Mermoud 1994) size generation and storage and estimate costs with considerable rigour, and a range of online calculators offer simpler versions of the same. Similar to E-Ratiba, bottom-up demand models build a load from individual appliances and user behaviour, such as LoadProGen (Mandelli *et al.* 2016) and the open-source RAMP model (Lombardi *et al.* 2019). These construct the demand from the ground up rather than assuming a fixed profile, which is the same reasoning behind E-Ratiba's activity scheduling. However, all these share a feature. They are built for engineers and analysts; they reason in kilowatts, kilowatt-hours and component specifications, and they assume a user familiar with those terms. None is organised around how a school actually runs its year, and none estimates the revenue a school might earn by selling services in local currency, based on its own calendar. They also provide little support for the repeated, term-by-term planning a school must do from one year to the next and are not entirely customisable to support the ever-changing needs typical of schools in informal settlements.

This leaves a gap at the point where the decision is made. The people who plan energy use in an informal settlement school are administrators and teachers rather than energy specialists. They reason in lessons, cooking sessions, school terms and shillings, often with limited IT literacy and little spare time, and a tool intended for them must work in those terms. Designing such a tool well is difficult from the outside without a real understanding of the schools' underlying needs and the opportunities offered by local communities. In addition, the PV system had to be primarily designed to be affordable. Therefore, classic engineering design principles that usually allow for some redundancy in PV and battery capacity had to be disregarded. This is why E-Ratiba was developed

through co-creation with the schools themselves, in the participatory tradition that treats prospective users as partners in design (Sanders and Stappers 2008). The next section describes that process.

3. Co-creation methodology

E-Ratiba was shaped through its users' participation from the start. The approach was pragmatic rather than a strict application of a single design methodology, though it was methodical. It followed a sequence of in-person workshops, each building on the last, interleaved with technical survey work and software development. It sits within the participatory and co-design tradition, in which the eventual users of a technology help to determine both its features and its form (Sanders and Stappers 2008), and it draws in particular on community-based co-design, which adapts those methods to specific local contexts and communities (Till *et al.* 2022). The work was led jointly by teams from the University of Nottingham, Smartklub Ltd, and Strathmore University in Nairobi, both of which were on site, and began in 2025. It remains ongoing, since the tool continues to be refined through use.

Three co-creation workshops were held. The first, in July 2025, was a needs assessment that formalised the concept with the schools. The second, in November 2025, demonstrated the first working version with participants working over a paper wireframe, sketching changes and discussing how the tool would fit their school's routine. The third, in March 2026, was a hands-on session in which participants used the application themselves, providing comments and suggested improvements based on their experience testing the co-created design. Using the tool exposed some issues, from unclear service names to the way holidays were input that would not align with the school calendar, and led to changes that shaped the application, such as personalised activities, a refined five-minute resolution for the timetable, clearer colour coding, the printable monthly report, and the guided tools to define activity pricing. Some changes were made to the model's formulas, such as pricing laundry by the cycle rather than by the hour. The participants did not write the code themselves, but they raised needs, and the team worked out feasible solutions. All three sessions were held in person in Kibera and Kangemi and were facilitated and co-led by researchers from Strathmore University, who are in weekly contact with the schools.

Participants were drawn from eight schools, with two or three staff from each, including administrators, head teachers and teachers, alongside community members and staff from the local partner organisations. The schools had been recruited during an earlier feasibility study for the wider project. School selection was undertaken in two stages. First, candidate schools and resource centres were identified in collaboration with Map Kibera, drawing on their local knowledge and expertise. Schools were initially screened against criteria including willingness to participate, governance readiness, land tenure security, infrastructure suitability, and diversity of needs and contexts. Second, shortlisted schools were assessed against a broader range of technical, operational and community factors, including energy access, infrastructure suitability, stakeholder support, scalability and learning potential. This process ensured that the final selection balanced feasibility, community support, diversity and the opportunity to generate evidence to inform future scale-up.

All participants provided prior and informed consent to participate and have been actively engaged in shaping and providing feedback on subsequent project deliverables. The first spreadsheet model of E-Ratiba was built to guide the business model development during the feasibility study and was later used in school discussions to define the entire Community Energy Hub concept.

The engagement shaped the tool's activity model, and especially the distinction between internal and external services. Internal services came from asking what the schools were already doing and how reliable electricity might enable them to do it better and more cheaply, such as replacing firewood with electric cooking. External, revenue-generating services came instead from open discussion of what was feasible in each setting: which services had a local market, how easily they could be fitted into the school timetable, and what assets a school already held. Some schools, for example, had a borehole but no power to run a pump, so they had no way to sell water to their neighbours. The activities were proposed by both the communities and the designers, and they were

discussed to identify the most suitable ones. The set bundled with the tool came directly from the workshops, and the activity registry was deliberately left open so that each school could add services specific to it, which addressed participants who expected to take on further, more specialised activities in the future. In the same way, the tool's school-year structure was built around the Kenyan Ministry of Education's three-term calendar, then confirmed and adjusted with the schools.

The engagement also shaped how the tool is operated. An early version used half-hour scheduling slots; participant feedback led to the adoption of a simpler hourly grid. The need for the tool to be legible to non-specialist staff produced its colour-coded interface, which responds as the user edits, together with an export function so that a finished plan can be shared with the rest of a school's staff. Setting an hourly price for each service proved one of the hardest tasks for participants, so a set of guided rate calculators was added to provide consistent, reasonable figures rather than blind guesses.

Two decisions came from the project team rather than from the workshops, although both were negotiated with participants and accepted. The first was to build a desktop application rather than a mobile or web tool. This suited the low-connectivity deployment context, the limited IT literacy of many prospective end users, and the view that annual energy planning should be a considered activity rather than an incidental one. The second was to give each school its own pre-configured installation, with the hardware and financial parameters set by the project team and not editable by the user. These parameters were drawn from technical surveys and baseline-demand monitoring at each school; they describe a fixed physical system that does not change in normal use, so exposing them would add no value and could lead to errors. Locking them also ensures that each copy of E-Ratiba reflects its own school's energy and financial situation.

Language was at times a barrier, especially concerning the process of adoption of a *new* technology; the tool is currently in English, due to that being the shared language of the system designer and the teachers the tool was co-created for, while also being an official language for Kenyan curriculum taught subjects, such as STEM. However, a Swahili version of *E-Ratiba* is planned so that in future, the tool more accurately reflects the local context in which it was designed. With a hands-on version now in use, the same iterative process continues, and the field deployment described in section 7 will turn participants' planning assumptions into viable data for the main project.

4. Architecture and model

E-Ratiba was developed through vibe coding (Sarkar and Drosos 2025), a practice in which software is produced primarily, though not solely, by instructing a code-generating language model in natural language rather than writing code directly. Specifically, both ChatGPT (OpenAI 2023) and Claude (Anthropic 2025) models were used. Consistent with that study’s finding that vibe coding redistributes programming expertise rather than removing it, the author's role throughout was that of reviewer, tester and debugger: evaluating the generated code, identifying and correcting its errors, and deciding when to intervene manually. Trust in the output was built through iterative verification rather than blanket acceptance. This section describes how the application is assembled (4.1) and the model of activities and assumptions on which its calculations rest (4.2). A summary of the app structure is shown in Figure 1.

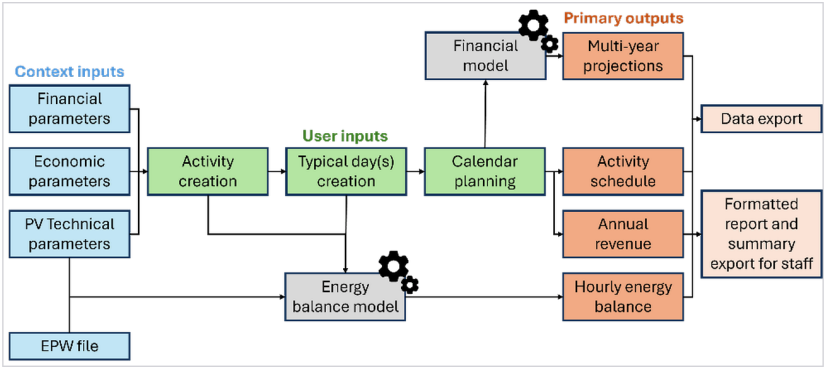

Figure 1. E-Ratiba architecture schematisation.

4.1. System architecture

E-Ratiba is a single-window desktop application written in Python, with a graphical interface built on the Qt framework through PySide6. It runs entirely offline and is packaged for each school as a standalone executable. The interface layer is organised in four calculation modules: an energy module for the photovoltaic and battery simulation, a financial module for cost and revenue metrics, a set of rate-calculator tools, and a reporting-summary module.

The calculations rest on a two-stage simulation. When the application starts, it runs a full annual simulation: using the open-source pvlib library (Holmgren *et al.* 2018), it reads a Typical Meteorological Year weather file for Nairobi (Wilson Airport) and computes solar generation for all 8,760 hours of the year, from which it derives a single 24-hour average generation profile. This expensive step runs only once. Thereafter, whenever the user changes the timetable, a fast daily simulation tracks the battery's state of charge hour by hour, using the average generation profile and the day's scheduled load. Separating the two keeps the interface responsive while keeping the model physically grounded.

The hardware and financial parameters on which the calculations depend are stored in two plain-text configuration files alongside the executable. The application reads them at startup and falls back to built-in defaults if they are missing. This is how each school receives an installation configured for its own system: the parameters describe a fixed physical installation, are set by the project team, and are not editable through the interface. Plans and assumptions are saved as JSON files, and completed plans can be exported as PDF documents.

4.2. Activity and assumptions model

Demand in E-Ratiba is built from activities rather than from a raw load profile. The application holds a registry of named activities, each defined by three values: the rated power of one device, a revenue rate in shillings per device per hour, and a peak fraction. Each activity also has a limit on the number of devices that may be in use at once, customisable at the school level. Activities are divided into internal services, which the school runs for its own use and generate no direct revenue apart from avoided costs, and external services, which the school sells to the community to generate revenue. Examples of common internal services are lighting, electric cooking, and IT lessons. Adult IT classes, laundry and cooking time sold to neighbours are external. The registry is not fixed: as described in section 3, the bundled activities came from the co-creation workshops, and a school can add its own.

When an activity is placed in a timetable slot, its energy use is computed from a two-parameter load model that avoids treating a device as either fully on or fully off. For a fraction of the slot, given by the activity's peak fraction, the device is assumed to draw its full rated power; for the remainder, it draws a fixed proportion of that power, set by a system-wide off-peak factor (0.80 by default). The energy used by an activity in a slot is therefore summarised in Equation 1.

$$E = P \cdot n \cdot \left[k + (1 - k)f\right] \cdot \left(\frac{u}{60}\right) \quad (1)$$

Where E is the energy used in the slot (Wh), P is the rated power of one device (W), n is the number of devices, k is the peak fraction (0–1), f is the off-peak factor (0–1), u is the duration of the activity in the slot (minutes).

The off-peak factor is used only in the energy calculation. The peak demand used to check the installation's limits always uses the full rated power, P·n, so that the safety margin against the inverter's rated output remains strict while energy and revenue rest on a more realistic, time-averaged power.

The system-level assumptions on which these calculations depend, namely the average daily generation, the battery capacity, the inverter's rated output and the project's capital cost, are taken from the simulation engine and the configuration files described in 4.1. Like the hardware parameters, they describe a fixed installation and cannot be edited through the interface.

5. The planning interface

Planning in E-Ratiba happens across two linked views. The Typical-Day Editor describes the energy use of a single representative day, and the Annual Calendar Planner places those days across the school year.

5.1. Typical-Day Editor

The Typical-Day Editor (Figure 2) represents a day as a row of 24-hourly slots, each representing an hour from midnight to midnight. The school's activities are assigned to these slots. For each slot, the user chooses an activity, the number of devices in use, and the duration for which they run, entered in five-minute increments from 0 to 60 minutes. This gives the resolution of a five-minute grid while keeping the simpler appearance of an hourly one.

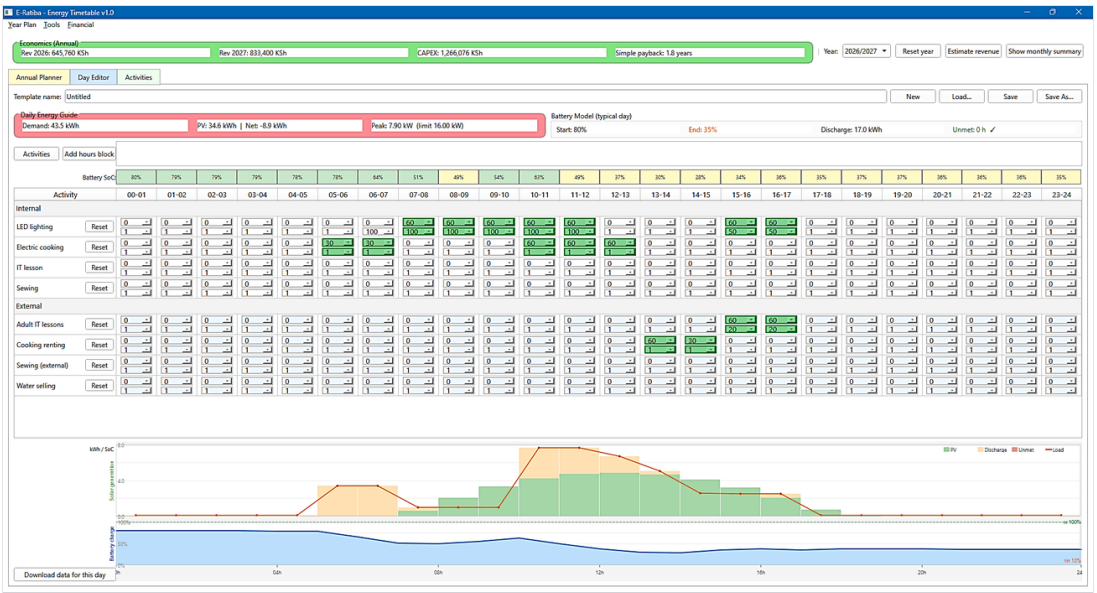

Figure 2. The Typical-Day Editor. Activities are assigned to 24 hourly slots, each with a device count and a duration in five-minute steps. The panel reports peak demand against the inverter limit, the day's total energy, photovoltaic generation against load, and the battery's state of charge, all updating as the schedule changes.

As the user edits, the editor recalculates and displays the consequences immediately. A peak-demand readout reports the highest instantaneous power the schedule would draw, evaluated at five-minute resolution and at each device's full rated power, and warns when it approaches or exceeds the

inverter's rated output. A running figure gives the day's total energy use. A chart shows photovoltaic generation against the scheduled load throughout the day, and a second curve traces the battery's state of charge hour by hour, based on the per-day simulation described in section 4, highlighting any hour in which demand cannot be met. Activities are colour-coded, so the shape of a day can be read at a glance, and every change is reflected immediately.

5.2. Annual Calendar Planner

The Annual Calendar Planner (Figure 3) lets the user build a set of day templates, each a complete typical day defined in the editor, for example, an ordinary teaching day, a Saturday running community services, or a holiday. Each template is given its own colour. These templates are then assigned to dates across the school calendar, which follows the Kenyan three-term structure, over a two-year horizon. As days are filled in, the planner keeps running totals. Revenue from external services accumulates and is set against the system's capital cost, providing an indication of progress towards the target payback period, set at 7 years. The user can therefore see how a particular pattern of activities across a term or a whole year translates into income and the time it takes for the installation to pay for itself. The financial calculations behind these totals, including avoided costs, are described in section 6.

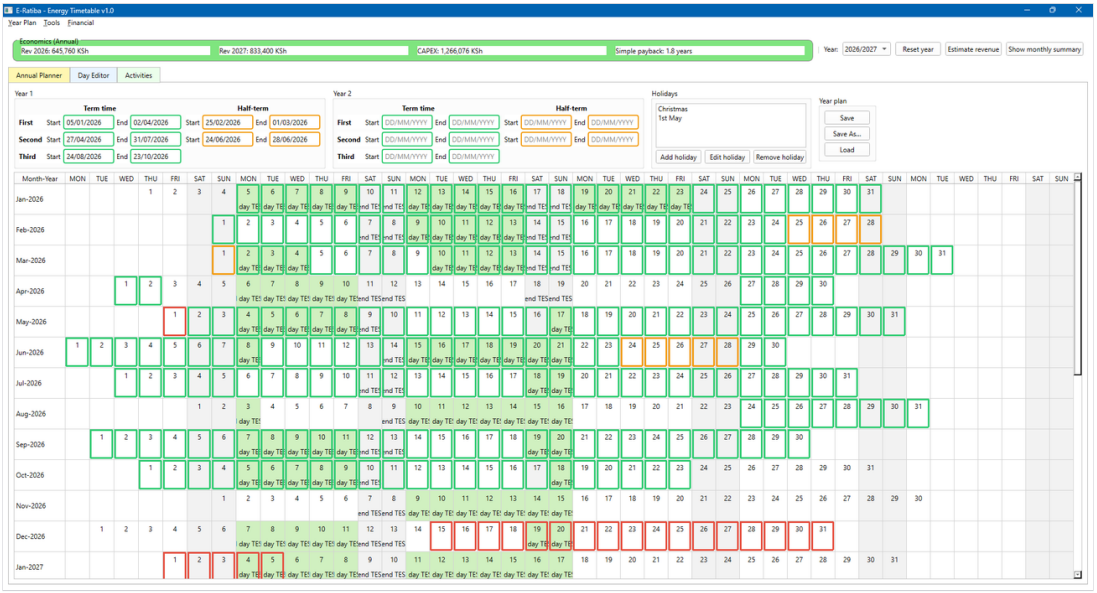

Figure 3. The Annual Calendar Planner. Colour-coded day templates are assigned to dates across the Kenyan three-term calendar over a two-year horizon, with running totals of revenue against capital cost and progress towards the target payback period.

6. Energy balance and financial model

The figures shown in the planning interface are produced by two models. An energy-balance model determines how much of the scheduled demand the installation can meet, and a financial model converts the resulting energy and revenue into economic indicators. The first is described in 6.1, the second in 6.2.

6.1. PV and battery dispatch

The energy available to the school is estimated in two stages, separated for the reasons given in section 4. The first stage, run once at startup, simulates a full year of photovoltaic generation. Using pvlib and the Typical Meteorological Year file for Nairobi (Lawrie and Crawley 2026), the model computes the solar position and the plane-of-array irradiance on the tilted panels with the Perez transposition model (Perez *et al.* 1990). It then corrects the output for cell temperature using a

nominal-operating-cell-temperature model (Ross 1976) and for the angle at which light strikes the panels, before applying a performance ratio that combines the inverter, soiling, and wiring losses. The yearly result is reduced to a single 24-hour average generation profile representing a typical day.

The second stage runs whenever the timetable changes. It steps through the 24 hours of the day and, for each hour, sets the generation from the average profile against the scheduled load and the system's standing parasitic draw. When generation exceeds demand, the surplus charges the battery; when demand exceeds generation, the battery discharges to cover the difference. Charging and discharging are bounded by the battery's power rating, by its permitted state-of-charge range, and by a round-trip efficiency, and any demand met by neither generation nor the battery is recorded as “unmet”. The state-of-charge curve and the unmet-demand flag shown in the editor are generated by this stage.

6.2. Economic outputs

The first economic figure the application produces is the levelised cost of energy (LCOE), computed once as soon as the annual generation is known, as a discounted cost per unit of energy:

$$\mathrm{LCOE} = \frac{C \cdot \mathrm{CRF} + C \cdot m}{E} \tag{2}$$

Where C is the hardware capital cost (KSh), $CRF = \mathrm{r}(1 + \mathrm{r})^{\mathrm{n}} / ((1 + \mathrm{r})^{\mathrm{n}} - 1)$ is the capital recovery factor, r the discount rate, n the system lifetime in years, m the annual operations-and-maintenance rate as a fraction of C, E the annual generation (kWh).

The lifetime used here is the physical life of the installation (25 years), deliberately longer than the financial projection horizon, and the capital cost is the hardware alone. The result is stored and reused by the rate calculators described next as the marginal cost of electricity.

Setting prices for revenue services was one of the harder parts of the co-design, so the application provides a guided rate calculator for each service type, covering cooking, water pumping, laundry, drying, ironing, lighting, and IT. Each calculator uses inputs the school can estimate locally, such as the going rate for the service, the fuel cost, the cost of consumables and labour, and the running time, together with the electricity cost taken from the LCOE. It then suggests a price per device per hour, which the user enters into the activity registry.

The Annual Calendar Planner tracks the running revenue and payback totals described in section 5. A separate monthly summary (Figure 4) aggregates revenue and energy by activity across the entire two-year horizon and compares each month against a revenue target, defined as the income needed to recover the hardware cost over the target payback period, plus annual maintenance. It reports the two-year totals, average daily and monthly revenue, the number of months above and below target, the best and worst months, a per-activity breakdown including device-hours, and a projected simple payback, calculated by dividing the hardware cost by the net annual revenue.

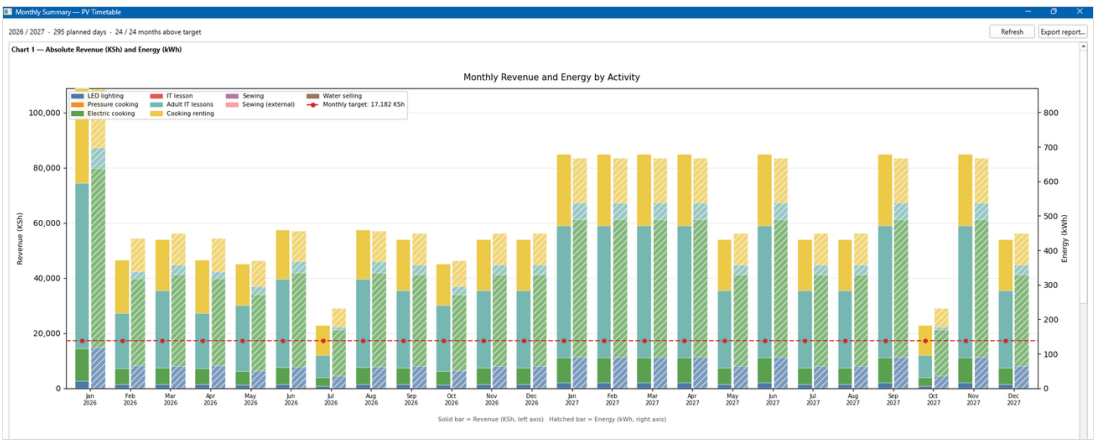

Figure 4. The monthly summary. For each of the 24 months in the two-year horizon, revenue is stacked by activity (solid bars, left axis) and set against energy use by activity (hatched bars, right axis). The horizontal dashed line marks the monthly revenue target, the income needed to recover the hardware cost over the target payback period, together with annual maintenance.

Additionally, a dedicated financial-analysis tool (Figure 5) generates a year-by-year cash flow projection over a configurable horizon (ten years by default). The capital cost is treated more completely here. For example, the hardware cost plus installation, entered as a proportion of the hardware cost, less any grants on either, gives the net capital the project must fund, which appears as an outflow in the construction year and can be partly financed by an optional annuity loan. Every following year, inflated by a default or year-by-year inflation rate, sets the revenue from external services, together with optional streams for avoided firewood and fuel costs, the value of the additional enrolment that electrification is expected to bring to the school, and monetised carbon savings, against the running costs of maintenance, personnel and other operations, the loan repayments, and, where enabled, taxes with straight-line depreciation. From the resulting net cash flow, the tool computes the net present value at the discount rate, the internal rate of return, and an interpolated payback year, and presents a year-by-year table of every line item, a cumulative-profit chart marked with the payback point, and an exportable report.

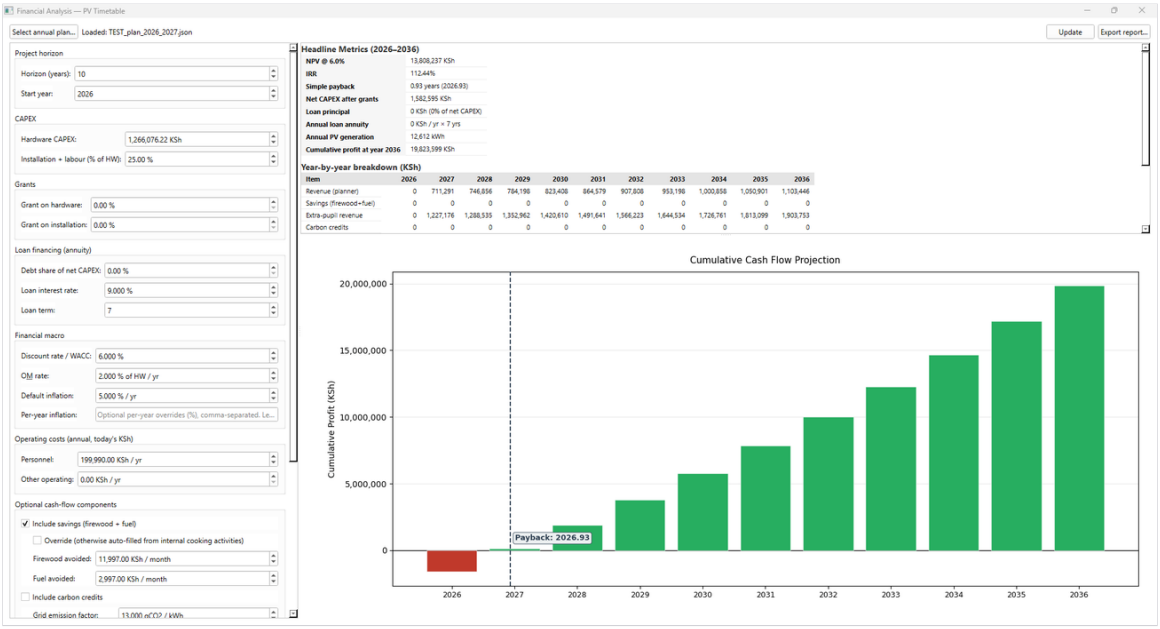

Figure 5. The financial-analysis tool. The input panel on the left sets the horizon, capital cost, grants, loan terms and the optional cash-flow components; the results on the right comprise the headline metrics (net present value, internal rate of return, payback and net capital cost after grants), the year-by-year cash-flow table, and the cumulative-profit chart with its payback marker.

The avoided-cost savings are handled through the same mechanism as revenue. An internal cooking activity earns no external revenue, so its avoided firewood and fuel cost is entered either as a rate on that activity, set with the cooking calculator, or as an explicit monthly override in the financial-analysis tool.

7. Field deployment and validation

E-Ratiba will be deployed to all eight schools by July 2026, and the plans built in the application will then be checked against measured performance over the remainder of the project. The purpose of this stage is to find out how closely those plans match what the installations actually do, and to use any differences to improve the tool, the plans, or the way the services are run.

The comparison will be supported by three streams of measured data. Whole-system generation and consumption will be read from the inverter manufacturer's online monitoring service, which reports the total energy the system produces and uses, to test the energy model directly. Consumption by individual activity will be measured through per-circuit sub-metering, with each activity wired to its own circuit and monitored separately. Revenue by activity will be derived from mobile-money records used to pay for community services, since payments in these informal settlements are made almost entirely electronically through M-Pesa (Mbiti and Weil 2011). For each school, the plan that the administrative staff built in E-Ratiba, including predicted demand, peak load, energy use, and revenue for each activity, will be compared against these measurements, activity by activity. The comparison will be made often at first and less often as the installation settles, beginning every 15 days, then every 30, then every 60. Where prediction and measurement do not align, possible causes and solutions will be considered, and outcomes include the model needing correction, the plan resting on an inaccurate assumption, or an activity being run differently than scheduled. Each finding will feed back into the application, the plan, or day-to-day practice, and the cycle will repeat until the end of the project (Figure 6).

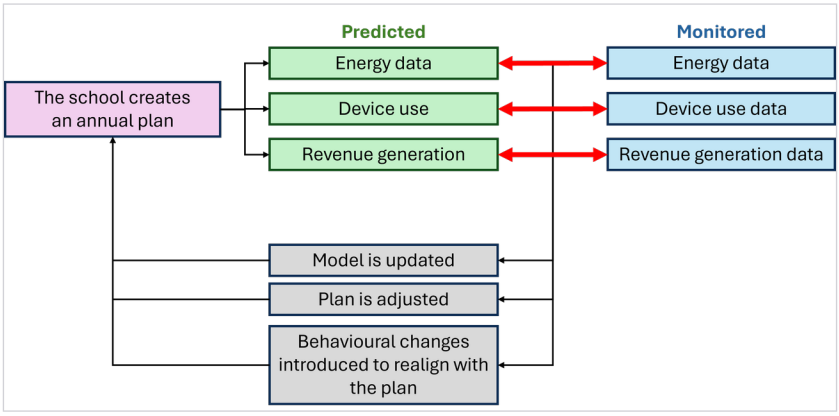

Figure 6. The field-validation cycle. A plan built in E-Ratiba provides predicted demand, energy use, and revenue for each activity. These are compared, activity by activity, against three measured streams: whole-system generation and consumption from the inverter's monitoring service, per-activity consumption from per-circuit sub-metering, and per-activity revenue from mobile-money records. Each divergence is diagnosed as a model, plan, or behaviour issue; the relevant ones are corrected, and the cycle repeats at longer intervals (15, then 30, then 60 days) until the end of the project.

Along with serving as a check on the energy and financial models, this plan is also a test of the business model on which the wider African SCENe project depends: whether the income from community services covers enough of the system's costs for the installation and financing to be viable for the school. In this way, it links E-Ratiba back to the central aim of the African SCENe project described in section 2, in which the school serves as both the anchor for a solar installation and the provider of services that help pay for it.

8. Discussion and limitations

E-Ratiba brings together two things that are usually handled separately: a physically based model of a school's solar installation and a plan for the revenue-generating services meant to pay for it. It puts both in front of the people who run the school, in a form they can use without technical training, a network connection or special preparation. The need for it follows from a change in the schools' circumstances. While a school either had no access to electricity or drew on an unreliable or informal grid connection, energy at the point of use behaved as though it was unmanageable whether it could met needs or not, and there was little to plan; a sized solar-and-battery installation is finite, so for the first time, the available energy has to be shared deliberately between the school's own activities and any services it wants to sell. E-Ratiba allows staff to plan lessons and the working day as before, but now alongside everything else, while the energy and revenue consequences are automatically accounted for. In doing so, it puts the productive-use-of-energy approach into the school's hands. As community services are productive uses, their income is meant to cover the cost of the system, and a tool that lets a school plan and price them is a step towards the investment becoming financially self-sustaining once the project's support has ended.

The co-creation described in section 3 shaped much of what the tool became. Most of what the school staff members suggested was accommodated, in particular the shape and colours of the interface, the ability to export schedules and figures to hand to the people running each service, and the format of those exports. The first version of the application looked very different and lacked most of its auxiliary functions. It is worth being clear about where that influence stopped. Co-creation shaped how the tool communicates its results, not the formulas behind the solar generation or the financial considerations, which the staff were not in a position to judge. This is a reasonable boundary rather than a shortcoming, but it does mean that the people the tool is designed for shaped the way it speaks to them, nor the model that drives it. The process also ran in both directions as it surfaced needs the team had not anticipated and then adopted itself. One example is the request for

clear monthly reports that became a feature likely to prove as useful to the wider project as to the schools.

The financial outputs are considered in two places. For the school, they offer a reasonable overview of expected daily revenue generation, and specifically whether the installation and the school business can hold up once the two-year pilot project ends. For the project, they are more significant as evidence presented to future funders proving that the model works. That suggests a limitation, as the tool has no internal guard against overly optimistic cases. It will reproduce whatever its inputs imply. Therefore, reliability rests on the person who sets the inputs, not on the tool. However, this flexibility is also a strength, as it lets the project team run the application through many different scenarios across schools and contexts that differ from one another, which is the purpose of the variable parameters and is one of the reasons one tool can serve them all. The configurability cuts both ways, and the figures it produces, particularly those meant for funders, should be read with that in mind.

A planning tool works only if its plan changes what people do, and the operations will run whether or not the plan is followed. To face this, some strategies are in place: the school commits to a schedule it helped to create, the exported reports tell whoever is responsible for each service exactly when and for how long to run it, and regular communication and checks hold the school to the agreement. Because the plan is co-created rather than imposed, it carries a measure of agreement that an externally set schedule would not. Whether that agreement translates into day-to-day adherence is, however, one of the questions the wider project is designed to answer, and section 7 treats any divergence between the schedule and what actually happens as something to be measured and diagnosed rather than assumed away.

The most important limitation is that the tool's predictions have not yet been formally tested against measured performance. The validation programme described in section 7 has not yet taken place. Hence, the authors report the tool's design and rationale, rather than evidence that its forecasts are accurate. Field data will be needed to establish that, and is already being collected.

Some of the modelling assumptions aimed for speed and simplicity at the expense of some accuracy. The energy model represents a year of generation as a single average day rather than following day-to-day weather, and it dispatches a typical day rather than the hardest day of a season; the load model approximates how a device's demand varies within a slot using only two parameters. These choices keep the tool responsive enough to use interactively, but they set a limit on how closely its figures can match reality, which the field measurements will quantify.

Other limitations follow from the design. The hardware and cost parameters are fixed for each school and cannot be changed through the interface, which suits settings with limited connectivity and little specialist support, but ties an installed copy to its original configuration. The tool is designed around informal settlement schools in Nairobi and a particular way of earning service revenue, so using it elsewhere may require adaptation. Its English-only interface can be a barrier where English is not the first language, though a Swahili version is planned.

9. Conclusion and future work

The authors have presented E-Ratiba, a desktop application that lets the staff of solar-powered schools in Nairobi plan their energy use and the community services to pay for the installation and see the combined energy and revenue consequences of those choices. The application pairs a physically based model of the photovoltaic and battery system with a familiar timetable interface and a set of economic tools, all running offline and configured for each school. It was co-created with the schools it serves and built through vibe coding, with the author working as the reviewer and tester of the generated code. By giving a school a way to plan and price the productive uses of its electricity, E-Ratiba is intended to support the wider aim of the African SCENe project: that a school's solar installation can pay for itself through the services it provides.

In presenting E-Ratiba, this paper has shown that energy planning for a finite solar installation demand and the business case a school depends on can be brought together in a single tool that non-technical staff can use. Three things make that possible: an activity-based model that lets a school describe its energy use in its own terms rather than as a technical load profile, a physically grounded simulation that turns those choices into demand, peak load and a battery state of charge, and a set of economic tools that express the same choices as revenue, levelised cost and payback. Co-creation with the schools shaped how the tool communicates rather than the models beneath it, and the result is a tool that makes the consequences of a plan visible at the point where decisions are actually made. Its predictions remain to be tested, but as a design, it shows that energy planning and revenue planning, usually handled separately and by specialists, can be placed in the same hands.

The next step is testing through the field deployment and validation set out in section 7, which will compare what the tool predicts against how the installations actually perform, and so establish whether the models and the business case behind them hold up in practice.

Beyond validation, the main direction for future work is to move the tool from planning towards anticipation. At present, E-Ratiba plans against a typical day and does not warn a school when the coming days are likely to fall short. The intention is to add short-term forecasting of solar generation, drawing on weather forecasts, together with periodic alerts that flag a predicted shortfall before it arrives. When such a case is expected, the tool would help the school choose a response from a combination of measures: giving priority to essential loads and shedding others, rescheduling activities to better-supplied days, holding back a reserve in the battery, and alerting the people responsible. Which combination of these works best is itself an open question, and one that the project intends to answer by trialling them in the field. Further improvements to the application could be made by adding a language feature that allows users to properly plan school activities in a language most comfortable for them (such as Swahili in our case). Taken together, the validation and these extensions will test whether a planning tool of this kind can help a school's solar installation become and remain self-sustaining.

Declarations

Author contributions. Vincenzo Rossi: Investigation, Formal analysis, Data curation, Writing (original draft), Writing (review and editing), Visualization, Validation, Methodology. Charles Bradshaw-Smith: Conceptualization, Methodology, Writing (review and editing), Supervision, Funding acquisition, Investigation. Jordan Blanchard Lafayette: Writing (review and editing), Investigation. Lorna Kiamba: Writing (review and editing), Funding acquisition, Investigation. George W. Foden: Writing (review and editing), Investigation. Mark Gillott: Conceptualization, Funding acquisition, Supervision. Michelle Stirk: Writing (review and editing). Hafez Abdo: Writing (review and editing). Churchill Saoke: Writing (review and editing). Izael Da Silva: Funding acquisition. Lucelia Rodrigues: Conceptualization, Methodology, Writing (review and editing), Supervision, Project administration, Resources, Software, Funding acquisition, Investigation.

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Conflicts of interest. The authors declare no competing interests.

Data availability. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics. This work acquired ethics clearance from the University of Nottingham ethics committee.

Editorial independence. Lucelia Rodrigues is in the scientific committee but not involved in reviewing this work.

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