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# Can Time-of-Use Tariffs Increase the Financial Viability of Mini-Grids?

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## Executive Summary

Declining solar and battery costs and increased operational efficiency have helped expand community-scale mini-grids, especially in sub-Saharan Africa and South Asia, where they now meet the power needs of over 47 million people.[1] However, mini-grid system economics must continue to improve to be a reliable power solution for a significant share of the nearly 800 million people still lacking access. For rural, low-income communities with generally small power loads and significant demand variations, it can be challenging to align supply and demand while maintaining affordable rates and recovering investment costs.

Time-of-use (ToU) tariffs—a rate structure where the tariff varies by the time of day that electricity is consumed—could represent one piece of the solution. ToU tariffs can be designed to encourage customers to shift their consumption to times of day that typically see lower energy demand coupled with high renewable energy generation. Properly implemented, this can reduce costs for a mini-grid provider and lower electricity costs for customers. Additionally, lower daytime tariffs under a ToU rate may carry the added benefit of increasing demand if productive users see an opportunity to increase production and energy consumption at lower daytime electricity rates.

A model was developed to estimate the effects of a ToU tariff on average costs and revenues using data from Energicity, a solar mini-grid operator in Sierra Leone, and demand elasticity data from

other mini-grid customers in sub-Saharan Africa. Our analysis found that the cost of delivering power using batteries at night and in the early morning—when solar panels are not producing electricity—increased overall power supply costs by roughly 60% over the system's life.[2] While ToU tariffs can be a tool for driving down that cost increase, the extent of that savings is determined by community-specific service needs and the ability to shift energy demand to off-peak periods during the day. For example, energy demand from lighting—the leading source of electricity demand for most rural households—will not shift to daytime hours through ToU incentives. Lighting is an example of a nonsubstitutable service, and consumers are more price-inelastic when consuming energy for lighting.[3] However, higher shares of community power demand from freezers, grain mills, irrigation pumps, and other small appliances present a more feasible case for load shifting and increase the likelihood of cost reductions and higher revenue returns through ToU tariffs.

Based on these modeled results, ToU tariffs—a 15% reduction in the daytime off-peak hour rate and a 15% increase in the evening peak hour rate—can reduce per unit energy cost and present an opportunity for mini-grid operators to increase their profit compared to the existent fixed tariff structure. When a ToU tariff shifts consumers' energy load and total energy demand remains constant, a mini-grid operator can gain a 3.9% increase in revenue. However, the degree and existence of a revenue increase depend upon consumers' price elasticity of demand—a change in energy demand in proportion to the change in energy price. Site-specific pilots can be used to measure customers' response to a ToU tariff intervention and evaluate efficacy.

Based on this analysis, we offer the following recommendations for regulators, developers, and funders:

- **Pilot ToU pricing and daytime tariff subsidies.** Piloting different ToU tariff approaches and/or daytime tariff subsidies can allow mini-grid operators and regulators to assess the economic and social benefits of alternative tariff designs. Providing a subsidy for daytime energy use—ensuring that customers are aware of and have bought into the program—can be an effective means to create a price differential between daytime and nighttime energy prices and subsequently monitor energy usage and related benefits.
- **Consider mini-grid tariff subsidies in the proper context.** Regulators and system planners should consider daytime subsidies and associated economic benefits against the costs and benefits of extending grid service. Mini-grid tariff subsidies that generate additional local economic benefits and mobilize private investment will be a lower-cost approach for governments than extending the grid in many cases.
- **Build an evidence base.** Building a greater repertoire of research on ToU tariff structures and daytime rate subsidies will support business decision making and inform tariff policy making. More granular data on the impacts of ToU tariffs and their application in the off-grid context could greatly inform tariff design and economic development programming. Integrating regulators in pilot efforts and sharing lessons learned across communities and countries will be essential to adopting ToU tariffs.
- **Protect vulnerable consumers.** ToU tariffs can be regressive when rates for already low-consuming customers are increased and households have little or no ability to shift demand. Tariff policies should incorporate "lifeline" tariffs or other mechanisms to ensure low-income households are not priced out of lighting, phone charging, and other basic electricity services.

## INTRODUCTION: HOW TIME-OF-USE TARIFFS CAN INCREASE DEMAND, IMPROVE RELIABILITY, AND EXPAND ACCESS

The World Bank estimates that mini-grids could represent a cost-effective option for electrifying roughly 41% of people without access to electricity globally by 2030.[4] Mini-grid systems operate under various business models and integrate with the grid's incumbent utilities through multiple approaches.[5] However, to reach the scale that least-cost models have suggested, the economic viability of mini-grids will need to continue to improve, and key hurdles to expansion must be addressed.

Shifting mini-grid electricity demand to daytime hours through ToU tariffs can improve system performance and economics by stimulating daytime productive power use and increasing total demand. This can improve reliability and willingness to pay for power while increasing revenue and reducing costs for the mini-grid operator.

Batteries are often the largest capital expense for solar hybrid mini-grid operators, and they need to be replaced every three to eight years, depending on the technology. Our analysis found that providing power through battery storage represents a roughly 60% increase in power supply costs over the system's life, compared to providing power only during the daytime.[6] This is because of the added cost of capital for batteries as well as their ongoing operation and maintenance costs. If customers were to shift their demand to daytime hours, less battery storage would be required to meet demand.

ToU tariffs can be designed to shift customers' energy use away from peak evening periods, which reduces heavy reliance on battery storage. Small businesses and consumers that use energy to run freezers, grain mills, irrigation pumps, and other small appliances are best positioned to shift some of their energy usage to the daytime off-peak periods under a ToU tariff. Lower daytime tariffs may carry the added benefit of increasing demand if productive users see an opportunity to increase production—and energy consumption—at a lower cost per unit of energy. However, households that use electricity predominantly for lighting and phone charging will be unable to shift much, if any, of their energy consumption to daytime hours. Ultimately, customers' ability to shift their energy consumption to the daytime off-peak period depends largely on their use of productive use loads.

Shifting evening loads to daytime hours could also improve energy service reliability and quality. The amount of installed battery capacity determines the amount of electricity that can be sold during nondaylight hours.[7] If evening energy loads exceed the available storage capacity, outages result. Incentivizing customers to shift some of their nighttime energy load to the daytime could reduce the amount of power lost in the conversion and storage process, increase the amount of total sellable power, and reduce the duration and frequency of late-night outages. Recent evidence from Ethiopia suggests that customers are willing to increase their monthly electricity bill by 16% to get three hours of additional evening power supply per month—equivalent to a mere 2% increase in the total hours of evening supply.[8] A study conducted in Ghana also found that households are willing to pay 50% more for improved service reliability and fewer unplanned outages.[9] The availability of reliable power affects customers' willingness to pay, and increasing the reliability of the power supply may warrant a mini-grid operator to offer a ToU tariff with higher rates during peak periods.

## IMPLEMENTING TOU TARIFFS IN THE OFF-GRID CONTEXT

To take advantage of these benefits, mini-grid operators in the off-grid context are increasingly open to implementing ToU tariffs. In some regions of sub-Saharan Africa, ToU tariffs are already being used, according to a survey conducted by the Mini-Grids Partnership—a consortium of mini-grid operators operating in sub-Saharan Africa and South Asia. One survey of group members found that 40% of developers had tried using a ToU tariff to better align consumption with generation.[10] Prior to the Tanzanian government levying a uniform tariff to override various mini-grid tariff levels and approaches in July 2020, several mini-grid operators had offered a ToU tariff.[11] A mini-grid operator in the Lake Victoria region reported that the introduction of a ToU tariff led farmers to use irrigation systems more during the day, when the price of electricity was lower.[12]

### ToU Tariffs Applied in Jharkhand, India

In India, mini-grid operators that do not receive government subsidies are permitted to charge cost-reflective tariffs, including tariffs with a ToU option. Under this scheme, Mlinda, a mini-grid operator with over 50 mini-grids in Jharkhand, offers a two-block ToU tariff. During the day (6 a.m.–6 p.m.), the price of electricity costs, on average, $0.32/kWh; during the evening (6 p.m.–6 a.m.), the price is double, $0.64/kWh.[13] One of their primary motives for offering this ToU rate is to incentivize daytime productive use loads. In addition to their energy service business, Mlinda has an economic development mandate in which they seek to create additional income opportunities for local businesses through powering productive use appliances like grain mills and irrigation pumps.[14] Mlinda has a designated field technician at every site to ensure robust system operation. Staff work directly with commercial users to utilize equipment primarily during daytime hours and manage larger energy loads, reserving battery storage capacity for smaller residential loads.

The price of power during the evening, while higher than the daytime energy prices, is less than the price of kerosene or the total cost of owning and operating a diesel generator, which was how households met evening energy needs before the arrival of Mlinda's mini-grids. Mlinda has specific capacity development targets because part of their funding comes from performance-based grants. They help households procure LED lights and efficient domestic appliances to achieve these development goals, enabling households to conserve energy and pay less. By working in close collaboration with the community, Mlinda is able to communicate the benefit of ToU tariffs to users and has helped customers utilize energy in a manner that maximizes household benefits.[15]

There is some evidence that ToU tariffs reduce peak energy consumption in the US and other advanced economy contexts. However, despite the anecdotal evidence mentioned previously, there is very little data on how effective ToU tariffs are in the rural off-grid context, where many low- and middle-income countries envision mini-grids might be most appropriate.[16] More granular data on how ToU tariffs have been implemented and applied to the off-grid context would greatly inform mini-grid regulation and tariff design going forward.

## CASE STUDY: ENERGICITY

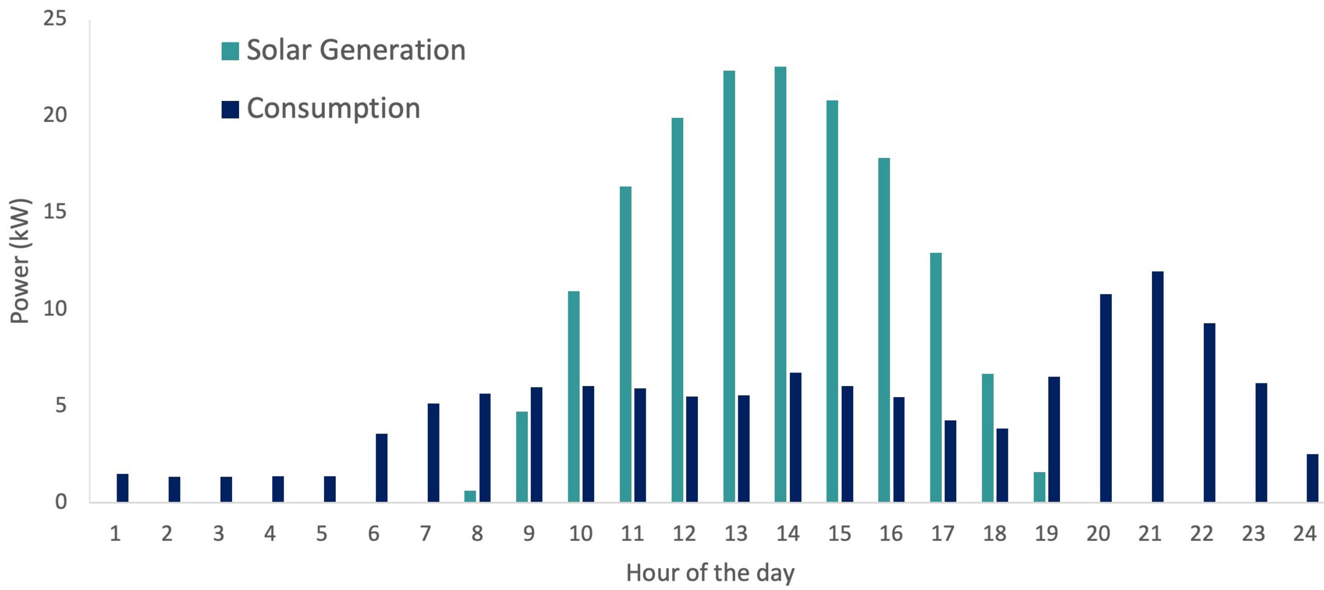
Across Energicity's more than 30 mini-grids in Sierra Leone, daily solar generation and power demand are misaligned. As seen in Figure 1, peak demand is generally double the average daytime demand. Peak demand occurs from 8 p.m. to 10 p.m., a period when solar panels are producing no power, and demand must be met by discharging batteries. Given the mismatch between energy generation and demand and the added cost of serving off-peak demand, the system would perform better and at a lower cost if some evening demand could be shifted to daytime.

Implementing a ToU tariff could incentivize users to switch to mini-grid power from diesel generators, the predominant alternative fuel source. The cost of fueling diesel generators in Sierra Leone nearly doubled from $0.30/kWh to over $0.60/kWh over the course of 2022.[a] This price rise is evidence that fossil fuel is highly susceptible to price spikes and that reliance on mini-grid power subjects users to less price volatility. Further, reducing the daytime energy price of mini-grid power through a ToU tariff may attract diesel users to make the switch to mini-grids. Diesel generators are also subject to a handful of reliability issues based on fuel supply and maintenance. Therefore, even a marginal reduction in the daytime tariff might be enough to entice some commercial users to switch to using mini-grid power during the day.

Lowering the daytime price could also increase demand from commercial users. Currently, commercial users represent 95% of daytime energy demand within Energicity's mini-grids.[b] In Sierra Leone, these productive use

[a] The price per kWh was based on average assumed diesel generator set efficiencies.
[b] The differing load segments for Energicity were derived through detailed customer analysis; commercial users were classified as those customers that utilize more than 0.5 kWh/day.

**Figure 1. Typical hour-by-hour daily energy generation versus average daily energy consumption.**




Note: This load profile represents the average weekday hourly demand and generation at a 36 kW capacity site within Energicity's portfolio.

loads are commonly ice makers, grinders, general stores, cold storage, welders, and rice mills. The connectivity rate of commercial users varies between communities, but many of these small businesses are already mini-grid customers. Businesses with larger demand, such as telecommunications and cold storage operators, tend to rely more on diesel.[17] Lowering the daytime energy price would present a more attractive economic case for these consumers to utilize mini-grid power.

## *Addressing Consumer Price Elasticity*

Understanding customers' price elasticity of demand for electricity—customers' responses to price changes—is critical to forecasting how much power an operator can expect to sell and how demand may fluctuate based on the tariff charged. However, customers' reactions to price changes may be highly localized based on their awareness of price differentials, energy reliability perceptions, and income differences. It can also differ greatly across customer segments. Additionally, customers' price elasticity is dependent on what appliances customers use and when, so customer price elasticity will not be perfectly linear.[18] This means that customers' response to a decrease in daytime prices may not be the same as an increase in evening prices under a ToU tariff. A symmetric demand response occurs when a customer's percent increase in daytime energy use is the same as their percent reduction in nighttime energy use. An asymmetric response is unequal, meaning the customer's percent increase in daytime energy usage did not match their percent reduction in nighttime energy usage. Given that most Energicity customers utilize energy during the evening peak periods for lighting and phone charging, it is unlikely that they would be willing or able to shift this load considerably. Thus, customers would likely have an asymmetric demand response to ToU tariffs.

Our model uses findings from a demand response study in Tanzania to estimate the annualized average price elasticity of demand.[19] Because the study focused on mini-grid customers within a periurban community in Tanzania, it is broadly representative of Energicity's customer base in terms of customer income level and the number of customers for whom these mini-grid sites provide power. Customers were then categorized based on their average daily energy demand to approximate the price elasticity of demand for Energicity's customer base.

### *Modeling the Effects of a ToU Tariff for Energicity*

Four primary factors drive Energicity's costs and revenues: (1) energy demand, (2) the number of connections, (3) equipment costs, and (4) tariffs. To conduct the analysis, tariff and cost data were obtained from Energicity directly, and energy consumption data were collected from customer meters at 15-minute intervals. Based on this information, a model was created to assess how a ToU tariff—a 15% reduction in the daytime off-peak hour rate and a 15% increase in the evening peak hour rate—compared to the existent fixed tariff structure.[c]

Given this analysis could not predict Energicity's customer price elasticity and energy demand to a ToU tariff intervention with certainty, we modeled several scenarios to assess how variations in customers' price elasticity of demand, and cumulative energy consumption affect revenue generation (Table 1).

- Scenario 1 represents a symmetric demand response to a ToU tariff intervention where the percent change in daytime energy demand matches the percent change in nighttime energy demand, leading to a 7% curtailment in total energy usage. Under the existent tariff structure, customers use more energy during evening peak hours.
- Scenario 2 models an asymmetric demand response where the absolute percent change in response to ToU tariff is greater during the daytime off-peak hours and consumers are less responsive to a ToU price change during peak hours. This scenario also assumes total energy use remains constant.
- Scenario 3 depicts an asymmetric demand response but assumes only a portion of customers are eligible for a ToU tariff; low-usage consumers receive a fixed lifeline tariff.

ToU tariffs can reduce the operator's per-unit energy cost and present additional revenue generation opportunities. Higher shares of community power demand from loads like freezers, grain mills, irrigation pumps, and other small appliances increase the likelihood of load shifting and the potential for an increase in daytime energy usage. When a ToU tariff successfully shifts customers' energy load and total power sales remain constant, an operator can incur an additional 3.9% increase in revenue. Revenue generation under a ToU tariff is dependent on consumers' demand response to ToU tariffs. Therefore, if customers have a symmetric demand response and curtail a portion of their total energy usage, as shown in Scenario 1, a decline in revenue can occur. Nonetheless, ToU tariffs can reduce battery servicing costs and a sustained peak load shift can allow operators to reduce the quantity of onsite storage. Our analysis finds that a sustained peak load shift through a ToU tariff can allow mini-grid operators to reduce the quantity of onsite storage and increase the operating margin by up to 3% compared to a fixed tariff structure.

**Table 1. Findings from three scenarios**

| Customer Demand Response Scenario | Daytime Energy Use, %[i] | Nighttime Energy Use, %[i] | Change in Revenue, %[ii] | Change in Costs, %[ii] | Operating Margin, %[ii] |
|---|---|---|---|---|---|
| 1. Symmetric demand response | 15.4 | –15.4 | –1.6 | –2.4 | 23.9 |
| 2. Asymmetric demand response | 15.4 | –5.1 | 3.9 | –0.4 | 26.1 |
| 3. ToU tariffs applied to a fixed customer segment and an asymmetric demand response[iii] | 15.4 | –7.2 | 0.8 | –0.2 | 24.0 |

Note: A negative cost value is a reduction in costs, while a positive revenue value is an increase in revenue. All scenarios were compared against the existing fixed tariff structure, which generates a 23.0% operating margin.

[i] Calculated from the derived customer average price elasticity of demand.

[ii] Operating margin is the ratio of operating profit to the total revenues; it considers the revenue from total energy sold and operating expenses in a given year.[20]

[iii] The ToU tariff is applied to consumers that use more than 0.5kwh/day; customers using less than this quantity receive a fixed tariff with a modest rate reduction as a form of a lifeline tariff.

[c] A ToU tariff is a rate structure that varies based on the time power is consumed. For modeling purposes, a two-part tariff structure was used, where rates were lowered during the off-peak periods, increased during peak periods, and compared with the existent fixed tariff.

### *Estimating the Cost Recovery from ToU Tariffs*

The minimum retail electricity tariff to recover project costs was calculated by deriving the load factor from the modeled analysis.[d] Our analysis found that by increasing the amount of energy sold, Energicity can reduce its levelized cost of energy (LCOE). The LCOE measures a system's lifetime breakeven costs, including capital and operating costs, and is expressed as an average cost per unit of energy. The LCOE was derived from calculating the amortized capital costs, including the cost of capital, along with Energicity's maintenance and operating costs across all of Energicity's assets at the time of the study. Based on this method, we expect a ToU tariff to lower the LCOE by 5 cents, from $0.54/kWh to $0.49/kWh, as a ToU tariff can help increase the systems load factor and increase energy use during off-peak hours.

Analysis by the World Bank supports these findings and outlines how increasing off-peak loads and expanding the use of efficient income-generating machines and equipment can be the most effective way to increase off-peak loads and could improve a mini-grid system's LCOE by more than 25%.[e] Increasing the energy consumed while not increasing peak load is precisely the effect that a ToU tariff would be structured to accomplish.

Of course, ToU tariffs are most effective when customers are aware of the tariff schedule and are informed of how changes to their energy consumption habits will result in cost savings. Socializing ToU tariffs with customers and helping ensure consumers are aware of the price differential will be critical for ToU tariffs to be an effective price structure for mini-grid operators and their consumer bases. One relatively straightforward way of communicating the rate for electricity at a given time is by notifying customers via lights on smart meters. For example, each of Energicity's mini-grid customers has a meter with programable lights that could be programmed to change colors to indicate how much power costs at any given time. This feature, along with consumer awareness campaigns, can help ensure that customers are informed of the changing ToU rates for electricity.

### *Considering Equity and the Energy Usage Patterns of Low-Income Customers*

Any proposed ToU tariff structure should consider how price adjustments affect households with low energy use. We assessed the impacts of a ToU tariff on customers who primarily rely on electricity for phone charging and lighting. If these customers did not shift their energy load to match the ToU time blocks, a ToU tariff would result in a 7% to 11% increase in their energy expenses. However, ToU tariffs can be designed to protect these customer groups from rate increases. Scenario 3, outlined in Table 1, depicts how a ToU tariff structure can result in a net positive operating margin for the mini-grid operator when a ToU tariff is applied only to consumers who use more than 0.5 kWh/day, with low-usage consumers receiving a lifeline tariff.

## RECOMMENDATIONS

This research provides a look at how ToU tariffs could improve the economic viability of solar mini-grids. To effectively implement a ToU tariff and assure regulators that this type of tariff structure can be implemented equitably, additional data is needed to assess how a ToU tariff might affect cost recovery, customer behavior, and monthly energy fees.

### *Recommendation 1: Pilot ToU Pricing*

Piloting different ToU tariff approaches would enable mini-grid operators to assess the economic and social benefits of ToU tariff implementation and build confidence within regulatory bodies. Pilot projects that publicize

[d] In this analysis, the load factor is a measure of energy utilization and is the ratio of average energy load over peak energy load over the course of one year. System losses that happen when charging and discharging batteries are accounted for when deriving the peak load that the mini-grid system can produce. This definition of load factor aligns with the World Bank's definition and the Hybrid Optimization of Multiple Energy Resources (HOMER) model: World Bank, Mini-Grids for Half a Billion People: Market Outlook Report (Washington, DC: The International Bank for Reconstruction and Development/The World Bank Group, 2019), https://openknowledge.worldbank.org/handle/10986/31926.

[e] LCOE measures a system's capital and operational costs over the amount of energy generated by the system and is highly dependent on load factor; it is used to compare prices between different types of energy generation systems.

key data and insights would deepen the understanding of the price sensitivity of different customer groups and their ability and willingness to shift their energy load in response to ToU pricing. It would also enable mini-grid operators and regulators to more fully assess how ToU tariffs can be designed to meet both system and customer needs.

More granular data on the implementation of ToU tariffs and their application in the off-grid context would greatly inform tariff design. For ToU tariffs to have an impact, customers need to adjust their energy consumption habits in response to the ToU price signals. Piloting ToU interventions is key to better understanding customer behavior responses and substantiating the business impact of ToU tariffs. Mini-grid operators and regulatory entities need access to data and case studies to thoroughly assess the effects of ToU tariffs and their usefulness in shifting energy demand and reducing costs and fees for mini-grid operators and customers.

### *Recommendation 2: Consider Mini-Grid Tariff Subsidies in the Proper Context*

Regulators and system planners should consider daytime subsidies and associated economic benefits against the costs and benefits of extending grid service. Exploring applications where mini-grid tariff subsidies can generate additional local economic activity and mobilize private investment can be more cost-effective than expanding the grid.

Subsidizing daytime energy tariffs can be a way to trial alternative tariff interventions and assess customers' price elasticity without increasing prices outright. This approach would create a price differential between daytime and nighttime energy prices, enabling mini-grid operators and researchers to measure customers' demand response.

### *Recommendation 3: Build an Evidence Base*

Building a greater repertoire of research on the implementation of ToU tariff structures will support business decision making and inform policy making regarding tariffs. As demonstrated by this report a ToU tariff can effectively reduce storage costs and increase revenue based on modeled results, but this data was based on a single case study. As developers trial new models to improve service and cost recovery, documenting what works and the specific context will be key to scaling up mini-grids in time to reach last-mile communities before 2030. Integrating regulators in pilot efforts and sharing lessons learned across communities and countries will be essential to adopting ToU and daytime rate subsidies.

When regulating tariffs, policy makers often need to balance customer affordability while allowing mini-grid operators to recoup costs.[21] Low-income rural mini-grid customers paying higher tariffs than wealthier urban customers served by the utility—which is often heavily subsidized—can trigger equity concerns and undermine critical political support for decentralized renewables.[22] ToU tariffs do not solve this problem, but they can provide additional options, allowing customers to save money by shifting energy use to times when it is cheaper to supply power while also lowering total system costs.

Most countries require mini-grid operators to obtain a license to sell electricity. Typically, to receive a license, operators need to adhere to tariff regulations. For example, Sierra Leone has adopted a licensing system that allows developers to generate, distribute, and sell power to any site within their concessional district, but requires flat tariff rates.[23] Additionally, there is no single standard mini-grid tariff structure. Some countries adopt a uniform approach mandating a specific flat tariff amount, often linked to the grid tariff. This approach typically requires considerable capital subsidy for mini-grid providers to cover their capital and operating costs. Other countries, like Sierra Leone, have adopted a more bottom-up management strategy where the mini-grid developers select sites to develop and establish a cost-reflective tariff to recoup investment costs.[24] Regulators should consider how flexibility measures like a ToU tariff fit into their existing licensing and regulatory approaches. ToU tariffs may be a means for regulators and power operators to strike a workable balance between cost recovery and affordable electricity rates.

### *Recommendation 4: Protect Vulnerable Consumers*

Low-income customers use a disproportionate percentage of their income for electricity compared to other customer segments. Deliberate tariff design is critical to ensure ToU tariffs are not regressive. One way to ensure a ToU tariff does not burden low-income and low-usage customer groups is by enacting a lifeline tariff as part of any proposed tariff revisions. A lifeline tariff could be subsidized by the government and can be structured to ensure that low-usage customers pay a fixed cost for energy. Most sub-Saharan African utilities subsidize tariffs to ensure consumers pay low prices. As the market stands today, mini-grids receive far fewer subsidies than grid utilities by comparison and implementing a lifeline tariff can help improve the affordability of mini-grid power, particularly for low-usage and low-income groups.

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