Private Sector-owned Mini-grids and Rural Electrification: A Case Study of Wind-power in Kenya's Tea Industry

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Highlights

- Kenyan tea factories could act as a demand anchor extending rural electricity access
- Cost allocation to different consumers impacts on whether full benefits are attained
- Cost sharing rules can be designed where all actors benefit and would participate
- Without incentives, tea factories may prefer to exclude other rural consumers
- Regulation should consider mini-grid and national electricity pricing interactions

Abstract

We use a discounted cash flow model to explore the impact of electricity pricing and cost sharing rules on the economics of a small wind-powered mini-grid project in Kenya, designed around local tea factories as a demand anchor and connected to the national grid. The results show that including rural domestic and small business consumers in the project increases the overall economic benefit, illustrating the potential gains from using the tea factories as a demand anchor. However, the results also demonstrate that how costs are allocated to different consumer types impacts on participation and on whether the full benefits could be attained. If all consumers must pay towards the infrastructure they use according to their consumption, domestic consumers with low energy demands would not join the mini-grid. Cost sharing rules can be designed where tea factories, small businesses and domestic consumers all individually benefit and would therefore have incentives to participate. However, when the mini-grid is owned by the tea factories there are also possible outcomes where they might prefer to exclude domestic consumers. The results emphasise the need for policy makers to consider appropriate mini-grid tariffing regulation and how these tariffs interact with any existing national electricity pricing systems.

1.   Introduction

In Sub-Saharan Africa (SSA) 62.5% of the population do not have access to energy (IEA and World Bank, 2017), a factor that poses a significant obstacle to sustainable socio-economic development in the region. Government electrification strategies often follow a twin track approach; electrification occurs through national grid extension - typically built by a state-owned company - and via decentralized mini-grids developed by local communities and/or private investors. While electrification through national grid extension has had limited success in SSA (Bhattacharyya, 2012), decentralized renewable energy mini-grids may provide an alternative solution particularly for rural electrification (Deichmann *et al*., 2011; Abdul-Salam and Phimister, 2016). It has, however, been argued that insufficient attention has been given to how the two approaches might be coordinated (Tenenbaum *et al*., 2014). Of particular importance to private investors is what happens to the isolated (rural) mini-grid after the national grid arrives, as this uncertainty has the potential to undermine their business models (Tenenbaum *et al.*, 2014; IRENA, 2016; Bhattacharyya and Palit, 2016).

The tariff that operators are allowed to charge is a key consideration in the economics of decentralized mini-grids. Grid-based electricity generation, distribution and retail have traditionally been dominated by wholly or partially state-owned power companies. Consequently, electricity pricing tends to have been tightly controlled by governments. Many SSA governments are trying to encourage a growth in both small, renewable energy Independent Power Producers (IPPs) and Distributors (IPDs) by offering a range of incentives, e.g. FiTs in Kenya (MoE, 2012, 2015). However, the emergence of privately funded IPPs and IPDs raises policy issues with regards to how tariffs within new mini-grids should be set and the extent to which they should be regulated. As is the case for all distribution networks, such firms have local market power which they may exploit to the detriment of (often poor) consumers. At the same time, flexible tariff pricing rules are needed to provide private firms with sufficient incentives to invest. However, while flexibility may be accepted in principle, there are also often political considerations and pressure for equity across consumers may require providers to charge the same tariffs as the national grid, particularly if the national utility is also the mini-grid operator, e.g. TANESCO in Tanzania (Tenenbaum *et al*., 2014). Despite this, some SSA governments have introduced regulation to allow IPDs to charge cost-reflective tariffs which may be significantly higher

than the rates charged by the national grid (Kapika and Eberhard, 2013; Tenenbaum *et al*., 2014). For example in Kenya, although the retail prices of the national utility responsible for the transmission and distribution of grid electricity are regulated to "ensure efficiency pricing and a fair return on investments" (Kapika and Eberhard, 2013, p 39, para. 1), the Kenyan Government does allow flexibility in setting private sector operated mini-grid tariffs to reflect costs (Tenebaum *et al*., 2014; IRENA, 2016).

Mini-grid projects are not always developed as isolated from the main grid. Rather they exist in a variety of configurations and include those in which the mini-grids export/import power from the main grid and serve local retail customers (Tenenbaum *et al.*, 2014). Even when grid connection is available mini-grids may still be established due to main grid service reliability issues, for example supply shortfalls or unanticipated demand may lead to "load-shedding" by national utilities (Global Lighting, 2018). In addition, with the development of renewable energy technologies, the traditional model of electricity supply based around a small number of large power plants has changed to one where production is naturally more decentralised and spatially distributed (Cossent *et al.*, 2009). However, the development of community and private sector-operated mini-grids in rural areas can be affected by insufficient funding and unstable demand (Yadoo and Cruickshank, 2012; Bhattacharyya and Palit, 2016). One solution may be to design mini-grids around a rural commercial 'anchor load', a local consumer whose base electricity demand is large, to reduce investment risk (WEF-PwC, 2013; Bhattacharyya and Palit, 2016). Large commercial customers may also be able to finance such investments from their own resources and thus facilitate investments which might not be fundable from other sources. Connecting such mini-grids to the national transmission network could then further lower demand risk and stabilize the service if electricity import/export is permitted (Tenenbaum *et al*., 2014). These *connected mini-grids* could offer insights into the challenge of ensuring that incentives to invest in isolated mini-grids are not undermined by the arrival of the main grid, as well as provide an opportunity to explore how tariff structures in the mini-grid and wider national grid interact.

The rural tea-growing regions in Central and Western Kenya provide a good example of areas where connected mini-grids have potential. The Kenyan tea industry is an important contributor to the country's economy and accounts for ~20% of income from exports (FAO,

2016; KNBS, 2016). The tea-growing regions are, however, energy-poor and existing electricity distribution systems are not sufficient to supply the local population (IED, 2008; SWERA, 2008; Nordman, 2014). The tea industry has a high demand for electricity. Harvested green leaf tea is processed in tea factories, large rural energy consumers that are distributed across the tea-growing region (IED, 2008). Several tea factories have already invested in small own-use renewable energy plants, some of which are connected to the national grid (ERC, 2015b). Small hydro-power is an inexpensive energy source in the tea-growing region (IED, 2008), but it is spatially restrictive and climatically sensitive. Nordman (2014) demonstrated that wind-power may provide a viable alternative energy source for the tea industry.

This paper aims to explore how interactions between mini-grid tariffs and the national grid affect the economics of a mini-grid investment and the extent to which connected mini-grids, with commercial demand anchors, can be used to extend access to electricity to smaller rural consumers. To do this we use a case study, based in Kenya's tea-growing region, in which rural tea factories serve as both the facilitator and demand anchor for a wind-powered rural electrification scheme. As is typically the case for Kenya's tea factories, the rural mini-grid also has a connection to the national electricity grid. We construct a discounted cash flow model to examine the impact of electricity pricing and cost sharing rules on the economics of the grid-connected, wind-powered IPP mini-grid project. The underlying data is drawn from a range of actual projects from East Africa (e.g. IED, 2008, 2009; Nordman, 2014). Using this model to test different cost sharing rules, we explore how local electricity pricing affects the economic benefits both of the overall project and for different types of local consumers, and consider how these benefits might (or might not) be achieved via private investment.

The remainder of the paper is structured as follows. Section 2 provides an overview of the effect of Kenya's current policy on mini-grid projects and outlines the potential for a decentralized wind energy project in the tea-growing region. Section 3 describes the financial cost-benefit models used to investigate the economic case for the wind energy plant and rural electrification scheme, the cost sharing rules assumed and how local electricity prices are determined in each case. The data and technical assumptions underpinning the

study are detailed in Section 4. Empirical results are presented and discussed in Section 5. Finally, in Section 6, key conclusions and policy implications are highlighted.

2.   Background

Around 74% of the population of Kenya live in rural areas (FAO, 2017) and, in 2015, rural electrification rates were estimated to be as low as 10% (MoE, 2015). Rural consumers are in favour of replacing existing diesel, kerosene or liquefied petroleum gas with electricity due to high fuel costs and supply uncertainties (Abdullah and Jeanty, 2011). Kenya's Rural Electrification Authority (REA) was tasked with overseeing service expansion in rural areas and many public facilities are now connected to the national grid (Parsons Brinckerhoff, 2013; Boampong and Phillips, 2016; Eberhard *et al*., 2016, Lee *et al*., 2016). Increasing demand for electricity in Kenya (MoE, 2015; Osano and Koine, 2016) could, however, place a significant burden on existing generation and transmission capacity (MoE, 2015; Boampong and Phillips, 2016).

The Kenya Tea Development Agency (KTDA), the largest co-operative of tea-growers in Kenya, is central to our case study. The KTDA produces ~60% of all Kenyan tea and has a membership of more than half a million small-scale farmers (IED, 2008; Nordman, 2014). Sixty five independently-run tea factories fall under the management of the KTDA (KTDA, 2017) and small-scale farmers both supply and hold shares in their local factory. On average, each factory serves a catchment area of ~2,000 ha and ~9,000 growers (KTDA, 2017). In a small hydropower feasibility study conducted by the IED (2008) on behalf of the East Africa Tea Trade Association (EATTA) and the 'Greening the Tea Industry in East Africa' (GTIEA) initiative, the KTDA expressed an interest in providing electricity to local communities. However, this is not currently permitted by the Kenya Government (Nordman, 2014).

2.1   Existing Policy Environment for Mini-Grid Projects

Electricity generation in Kenya is dominated by the partially privatized KenGen and the 50% state-owned national power utility, Kenya Power and Lighting Company or Kenya Power (KPLC), maintains operating control over the national transmission-distribution networks and

monopoly power in the retail sector (Parsons Brinckerhoff, 2013; ERC, 2015a; Eberhard *et al.*, 2016). But the energy market is changing. The Kenyan Government supports the growth in small renewable energy Independent Power Producers (IPPs) and Distributors (IPDs). Technology-specific feed-in-tariffs (FiTs) are available for small (0.5 to 10MW) renewable energy projects (MoE, 2012, 2015). The standard FiT is an inflation-adjusted, fixed-price tariff (in U.S. dollars) guaranteed under a Power Purchase Agreement (PPA) for a contract period of around 20 years (MoE, 2012, 2015). These FiTs were originally calculated to reflect the underlying costs for each technology. Accounting for the estimated lifetime of the plant and electricity to be generated, they were set to allow a fair rate of return on invested capital, where allowable expenses include for example plant capital expenditure, costs of connecting to the grid, and operating, maintenance and financing costs (MoE, 2012). However, there have been few adjustments for increases in the cost of generating equipment or financing since 2012 and the Kenyan Government has recognized that "to attract private investment a realistic review of the tariffs" will be required (MoE, 2015, p.65).

Additional revisions made by the Kenyan Government to the energy regulatory environment also aim to promote IPPs and IPDs (Kiplagat *et al.*, 2011; Kirubi *et al.*, 2008). Although several IPPs have entered the market since 1996 (Eberhard *et al.*, 2016), few independent companies are currently involved in managing small electricity distribution networks. Until recently, rural mini-grids in Kenya were either community-run or operated by KPLC (Yadoo and Cruickshank, 2012; IRENA, 2016). Independent companies, such as PowerGen Renewable Energy and Powerhive, have now entered the mini-grid operating market (IRENA, 2016; Aglionby, 2017). With more players in the market, electricity pricing, in particular for the rural poor, may become a key issue.

As in many developing countries, uniform national tariffs have typically been imposed on many larger mini-grids in Kenya (Tenebaum *et al.*, 2014). Rural mini-grids operated by KPLC charge national grid prices but, as these schemes are typically diesel-powered, additional subsidization is required to cover the high costs of fuel (IRENA, 2016). KPLC uses a long run marginal cost (LRMC) pricing approach to determine its national two-part electricity charges and any shortfall in revenue from its mini-grids is recovered from the Rural Electrification surcharge applied to the national electricity market (IRENA, 2016).

Although seen as a 'fair' pricing scheme, the use of national uniform tariffs for mini-grids may not lead to efficient outcomes (Tenebaum *et al*., 2014; IRENA, 2016) and tariffs may be too low to encourage investment from independent, private sector companies. To allow for cost recovery, small community-operated mini-grids may levy break-even (average cost) tariffs, often at very low discount rates, but these tariffs can be higher than main grid prices (Yadoo and Cruickshank, 2012; IRENA, 2016). To ensure project financial viability, the Kenyan Government has given Powerhive, one of the first independent mini-grid operators, the authority to charge its own rates (Tenebaum *et al*., 2014; IRENA, 2016).

2.2 Potential for Small Wind Energy Projects in Tea-growing Regions

Tea factories owned by the KTDA are large rural energy consumers, using 2-3 GWh of electricity per year (IED, 2008). Currently connected to the national grid, electricity accounts for ~50% of the energy cost per ton of 'made' tea for KTDA factories (IED, 2008). In addition, due to their 'end-of-the-line' rural location, tea factories may experience variable quality electricity supply and expensive back-up diesel generators are often employed (IED, 2008). To reduce cost, improve electricity reliability and move towards 'clean' energy sources, the KTDA has already invested in a number of own-use small hydro-electric projects through its subsidiary power company (IED, 2008; KTDA, 2017).

Located at high altitudes on the eastern and western flanks of the Great Rift Valley, Kenya's tea-growing regions experience good rainfall and wind conditions that could support both hydro and wind-energy projects (AFA TD, 2017; MoE, 2015). Hydropower is an established energy source in Kenya, but interest and capacity in the wind-power sector is growing, in particular due to the impact of climate change on water resources (IEA, 2014; Murage and Anderson, 2014; ERC, 2015a; MoE, 2015). A pre-feasibility study by Nordman (2014) estimates ~30% of Kenya's tea-growing region could have ample wind resources, based on data from the UNEP Solar and Wind Energy Resource Assessment (SWERA) project. Nordman's study showed that the potential for wind power is highest in the eastern tea-growing regions, where the density of tea plantations is lowest, while in the west where most tea plantations are located, wind potential is significantly lower. Despite this, he found that 19 tea plantations in the west (approximately 23% of all plantations) had potential for the

economic use of wind power. Clearly local, site specific wind conditions may change the economic viability of any investment in wind power projects. For example, the data used in Nordman is based on quite a "coarse spatial resolution" (25 km^2) and at sites where finer scale data is available, there is some evidence that wind resources can be substantially higher (Nordman, 2014, p.512).

The Kenyan Government also identified a lack of detailed wind regime data as a barrier to the development of wind power, and they have installed 60 wind masts and loggers across Kenya to help improve available information (MoE, 2015). Therefore, wind-power could provide a flexible, but as yet relatively unexploited, alternative energy resource in the tea-growing region, if the cost of generation is sufficiently low and if local wind speeds and densities at specific sites are sufficiently high.

3. Methodology

A discounted cash flow model is used to explore the economics of the potential wind-powered IPP-mini-grid project. The electricity price is key to project viability and rural consumer participation. To ensure cost recovery, project electricity prices are determined using an average cost/break-even pricing approach. The business case for a small wind-powered IPP and mini-grid in this study is informed by a similar hydro-powered project in Tanzania (IED, 2009), and builds upon wind-power (Nordman, 2014) and hydro-power (IED, 2008) studies linked to the tea industry in Kenya. The grid-connected IPP is assumed to supply four tea factories directly and, as the factories are already connected to the national grid, these also serve as nodes from which electricity is distributed to local rural consumers (Figure 1). To balance the intermittency of wind power, the generation-distribution system in this study makes allowance for all consumers to draw electricity from the main grid during periods of low IPP production.

Scenario 1: Power plant supplies electricity to tea factories and local rural consumers with any surplus exported to the national grid.

Scenario 2: Power plant supplies electricity to tea factories with all surplus exported to the national grid.
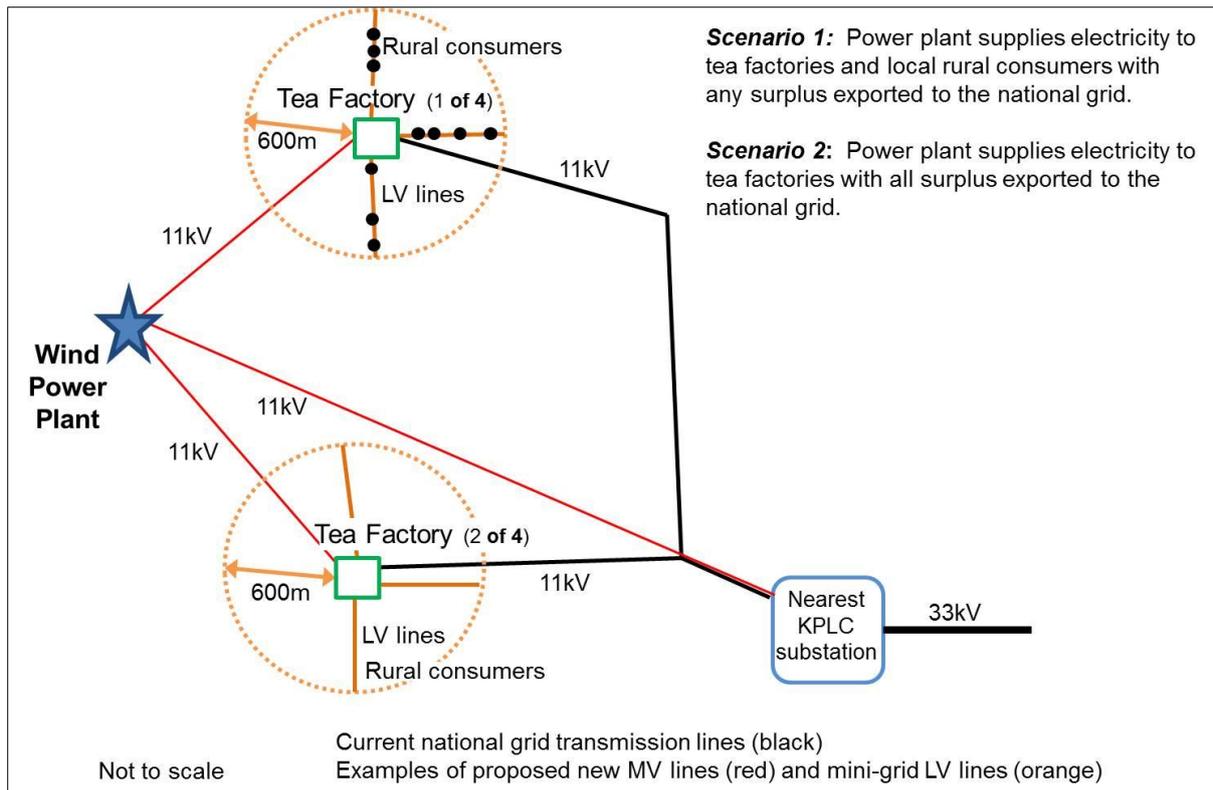
Figure 1: Proposed business case with wind power generator-supplier and potential consumers.

In the base case two main scenarios are examined. In Scenario 1 the IPP supplies tea factories and rural communities, whereas in Scenario 2 the IPP supplies only the tea factories. In both scenarios we assume that any excess electricity generated can be exported to the national grid at the feed-in-tariff. As highlighted in Section 1, how different cost allocations and pricing rules affect the results is a key element of this study. To explore this, three simple IPP electricity pricing options are used here. First the two scenarios above are considered in the base case, where project cost is allocated so that all consumers are treated as equals and pay towards the infrastructure that they use. Scenario 1 is then re-considered under two alternative cost allocation rules: where all consumers share all project costs and where rural consumers pay only the extra costs associated with the mini-grid.

3.1   IPP-Mini-grid Cash Flow Model

The discounted cash flow model, constructed in real terms, is used to evaluate revenue streams for the IPP and mini-grid and find break-even electricity prices. Only financial costs and benefits of the project are considered in Net Present Value (NPV) calculations.

Externalities, such as environmental costs and benefits, are excluded. Project life is assumed to be 24 years and electricity generation and sales occur over a 20 year period in accordance with typical wind-plant lifetimes (IRENA, 2012b) and standard Kenyan PPAs (MoE, 2015). Electricity generation starts at full capacity and sales commence after a two year construction period. Total benefits are restricted to revenues obtained from the sale of electricity and total costs include capital investments (CAPEX), operations and maintenance (OPEX), and decommissioning costs (DECEX).

Capital costs (CAPEX) depend upon the type and number of consumers included in the project. Plant costs include estimates for civils works, electro-mechanical items and the turbines. A medium voltage (MV) transmission system connects the plant to the tea factories and national grid. The MV system cost is given by the cost per unit length of line, and the distances from the power plant to each tea factory and to the national grid. It is assumed that there is no national grid connection fee. Rural mini-grid costs are given by the cost per unit length of low voltage (LV) line, and the total number and maximum length of each LV distribution line extending from each tea factory. The cost of an additional transformer per tea factory is included to support the LV distribution system.

OPEX is calculated as a percentage of the power plant-MV system and the rural mini-grid CAPEX, and applied separately. DECEX is calculated as a percentage of total CAPEX. CAPEX is split 70:30 over the two-year construction period and DECEX is split 70:30 over two years following the cessation of operations. Capital equipment has no scrap value and CAPEX is depreciated along a straight-line over 20 years (after IED, 2008). Kenyan corporation tax is included in the model as we are assuming that the project is financed by private investors. All values used are in real terms.

3.2   Wind Electricity Price Determination (Base Case)

In practice, tariffs are set following a range of different principles, such as uniform pricing, avoided cost tariffs or cost-reflective tariffs. The tariff structures faced by consumers come

in a variety of types, including a simple flat rate amount, a price per unit of consumption, a combination of these, or more complex multiple block tariffs (Train, 1991; Tenenbaum *et al.*, 2014; RECP, 2016). Here, to ensure economic viability, we use cost-reflective tariffs and assume that the IPP-mini-grid price consumers face is a simple per unit rate. Specifically, power plant revenue is a function of the prices charged and quantities of electricity consumed by each consumer type.[1]

To allow for cost recovery, a simplified average cost pricing approach is used to estimate the price per unit of wind-generated electricity. The base case cost allocation rule used in this study assumes that tea factories and rural consumers contribute equally (p_{base}) to the total costs of the power plant and MV transmission system. Rural consumers pay an additional surcharge (p_{RC}) to cover the total LV-distribution system costs. Surplus electricity exported to the national grid is sold at the feed-in-tariff (p_{FiT}). Under the break-even constraint, the total cost (*TC*) of building and operating the plant, transmission and distribution systems is equal to the project's total revenue (*TR*):

$$TC = TR = p_{base} \sum_{i=1}^{i=n} q_{TF_i} + (p_{base} + p_{RC}) \sum_{j=1}^{j=m} q_{RC_j} + p_{FiT} \cdot q_{NG}$$

$i = 1,…,n$ number of tea factories ; $j = 1,….,m$ number of rural consumers

where the quantities of electricity consumed by each tea factory, each rural consumer and sold to the national grid are q_{TFi}, q_{RCj} and q_{NG}, respectively.

3.3   Financial Benefits for Tea Factories

We assume that the tea factories will invest in the IPP project only if there is if a non-negative Present Value of savings (*PV_savings*) with respect to electricity expenditure. Any additional financial benefits from improved tea quality or product 'greening' by participating in a renewable energy scheme (IED, 2008) are not considered. Without the IPP, a tea factory's total electricity cost (TC^{gd+d}) consists of national grid and backup diesel generation components (IED, 2008). Wind-generated electricity is intermittent and this model assumes that the cost of IPP electricity (TC^{IPP}) will displace only a fraction of the current national grid

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[1] For simplicity, we assume that domestic consumers and small businesses are charged the same price.

and diesel electricity costs. As diesel generators serve as a backup, a constant demand ratio of diesel and national grid electricity is assumed. Savings are calculated as:

$$\text{Savings (\textit{undiscounted})} = TC^{gd+d} - [l^{TF}.TC^{IPP} + FC^{gd} + VC^{gd+d}.(1 - l^{TF})]$$

where the fraction of electricity obtained from the IPP is l^{TF}, FC^{gd} is the fixed cost of grid electricity and VC^{gd+d} are the variable costs associated with grid electricity and diesel generation. Diesel generator maintenance costs are considered insignificant, and sunk fixed costs associated with the generator and pre-existing grid connections are excluded from this model.

3.4 Financial Benefits for Rural Consumers

Two consumer types are identified within rural communities; domestic and small businesses. For simplicity, it is assumed that *all* rural consumers wish to connect to electricity in project year 2. Financial benefits to rural consumers of joining the IPP are represented by the Present Value of savings ($PV_{savings}$) made over the duration of the project. The $PV_{savings}$ are calculated as the difference between the cost of national grid electricity (TC^{gd}) and the cost of a combination of national grid and IPP-mini-grid electricity:

$$\text{Savings (\textit{undiscounted})} = TC^{gd} - [l^{RC}.TC^{IPP} + FC^{gd} + VC^{gd}(1 - l^{RC})]$$

where the fraction of electricity obtained from the IPP is l^{RC}, TC^{IPP} is the cost of the IPP-mini-grid electricity, FC^{gd} and VC^{gd} are the fixed and variable costs associated with grid electricity.[2]

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[2] Where a household connects directly to the national grid it is assumed that they would pay the standard Kenyan grid connection fee per household (149 USD; Mwiti, 2016). Where the connection is via the mini-grid the marginal cost of connection under the IPP is assumed to be 80 USD (Lee *et al.*, 2016).

3.5 Cost Allocation Rules

After assessing the two main scenarios under the base case cost allocation rule two further cost allocation mechanisms are considered. Under the base case cost allocation (Option 1, equation 1), consumers are treated as equals and pay towards the infrastructure *that they use*, according to their consumption. The second cost allocation option (Option 2, equation 2) assumes that all consumers share all project costs, proportional to their consumption. The third cost allocation option trialled (Option 3, equation 3) assumes that rural consumers pay only the excess, or costs associated with the mini-grid, while all other costs of the IPP project are paid by the tea factories. Equations expressing these three pricing options are given below and for completeness the base case is repeated:

$$TC_s = TR_s = p_{base}.q_{TF} + (p_{base} + p_{RC}).q_{RC} + p_{FIT}.q_{NG} \qquad (1)$$

$$TC_s = TR_s = p_{all}.(q_{TF} + q_{RC}) + p_{FIT}.q_{NG} \qquad (2)$$

$$TC_s = TR_s = p_{TF}.q_{TF} + p_{RC}.q_{RC} + p_{FIT}.q_{NG} \qquad (3)$$

where TC_s = total cost of supply, TR_s = total revenue, p_{base} = price covering IPP and MV line costs (paid by all consumers, Option 1), p_{RC} = price covering LV mini-grid costs (paid by rural consumers only, Option 1), p_{all} = price covering all costs (paid by all consumers, Option 2), p_{TF} = price covering all costs for the IPP and MV lines (paid by tea factories only, Option 3), p_{RC} = price covering LV mini-grid costs (paid by rural consumers only, Option 3), q_{TF} = tea factories' consumption, q_{RC} = rural consumers' consumption, $p_{FIT}.q_{NG}$ = revenue from the national grid at the feed-in-tariff.

4. Technical Assumptions and Data

The design and costing of the power plant and mini-grid is informed by the wind power pre-feasibility study of Nordman (2014) and the hydro-power feasibility studies of IED (2008, 2009). Additional legal and technical regulatory requirements for the operation of the grid and power plant are beyond the scope of this study. Key model input data is presented in Table 1 and technical assumptions are given below.

Cash Flow Model	Input Parameters		Assumption	Source
All	Discount rate		10%	*Pueyo et al. (2014)*
Independent	Wind FiT[a]		0.11 USD	*MoE (2012)*
Power	**Total Costs**[b]			
Plant	CAPEX	Civils, other	845k USD	*Nordman (2014)*
		Wind Turbine	422k USD	*Nordman (2014)*
		Transmission line (11kV)	14k USD/km	*IED (2008)*
		Transmission line (LV)	8.5k USD/km	*Authors' estimate; after IED (2009), Lee et al. (2016)*
		No. of LV lines	7 per tea factory	*Authors' estimate*
		Transformer (MV-LV)	6,2k USD	*Authors' estimate; after IED (2009)*
	OPEX	IPP	3 % of IPP CAPEX	*Authors' estimate; after IRENA (2012b)*
		Transmission line (LV)	2 % of LV CAPEX	*Authors' estimate*
	Exchange Rate	USD:KSh	1:103	January 2017 rate
	Corporation tax rate		30%	*Pueyo et al., 2016; IED, 2008*
Rural Consumers	No. of consumers	Domestic households	30	*Authors' estimate*
	per LV line	Small businesses	5	*Authors' estimate*

[a] *FiT originally calculated by Kenyan Ministry of Energy to provide a fair return on investment after including costs for capital, operating and maintenance, connection to grid, economic lifetime and estimated electricity output (MoE, 2012).*
[b]*Feasibility studies excluded. Costs (in U.S. dollars) from the literature were adjusted to January 2017 values using U.S. inflation rates (World Bank, 2017b).*

Table 1: Base case cost assumptions for the Independent Power Plant cash-flow model.

4.1 Power Generation and Rural Mini-grid

IPP annual electricity generation capacity is calculated here using total turbine capacity and a wind power capacity factor. Due to discrepancies between SWERA and ground observed wind data (Nordman, 2014), we assume a capacity factor of 33% based on the average annual generation of the 5.1MW Ng'ong Hills Wind Farm (KenGen, 2017). Cost estimates follow Nordman (2014) and assume Goldwind S48 750 kW turbines are a suitable option. An annual degradation factor of 1.6% (Staffell and Green, 2014) is applied to turbine generation capacity. To explore the efficient level of local production, i.e. how much of the local electricity demand should be met by the project, we examine the overall economics of investing in three, four or five turbines.

Cost estimates for the medium voltage (MV) transmission system are based on 11 kV lines. IED (2008) demonstrated the technical viability of a single 35km 11kV line supplying four tea factories, linked in tandem. For simplicity, voltage losses along the lines are considered negligible. It is assumed that an MV line from the plant can connect to the national grid through an existing regional substation (IED, 2008). Provision is made for one additional transformer per tea factory to convert MV current to low voltages (LV) for distribution to rural consumers (ECA, 2014; Tenenbaum *et al.*, 2014). A maximum of 600m is allowed for

each LV line in the rural mini-grid, in accordance with Kenyan regulations (Parsons Brinckerhoff, 2013; Lee *et al*., 2016). The installation of transmission and distribution lines is assumed to be optimized to reach the maximum number of consumers.

4.2   Electricity Demand

Although tea factories have year-round electricity requirements, electricity demand is primarily a function of the quantity of tea processed. The mean processing capacity, estimated across thirty-three KTDA tea factories, is 15 million kilograms of green leaf (KTDA, 2017) and approximately 0.067kWh is required to process 1kg of green leaf (IED, 2008). These values are used to evaluate the annual demands of our four 'average capacity' tea factories.

Rural domestic and small business electricity requirements are more challenging to quantify. As a domestic household density of around 210 households per km^2 is assumed, we use the electricity usage estimate of 45kWh/month per household from Parshall *et al*. (2009) for lower density areas (<256 people per km^2) in the base case. Small rural businesses can have highly variable electricity demands (e.g. IED, 2009; Parshall *et al*., 2009; Lee *et al*., 2016). Here we assume thirty-five small businesses surround each tea factory, each with an electricity usage of 125kWh/month in the base case (estimated after IED, 2009).

Electricity demand of the tea factories and rural communities will vary over short (e.g. hourly) and long (e.g. annual) timescales. For example the Kenyan tea industry experiences up to two harvests per year, with highest electricity demand falling between July and September (Figure 2) (IED, 2008; Azapagic *et al*., 2016; KTDA, 2017). Although electricity demand is not specifically modelled here, the percentage of tea factory and rural consumer annual electricity requirements that could be fulfilled by the wind plant is estimated using the monthly frequency data of winds >5.4m.s^{-1} at Ng'ong Hills (Figure 2) (Meteoblue, 2017). Average wind strengths of >5.5m.s^{-1} are typically considered acceptable for generation (SWERA, 2008; Nordman, 2014).
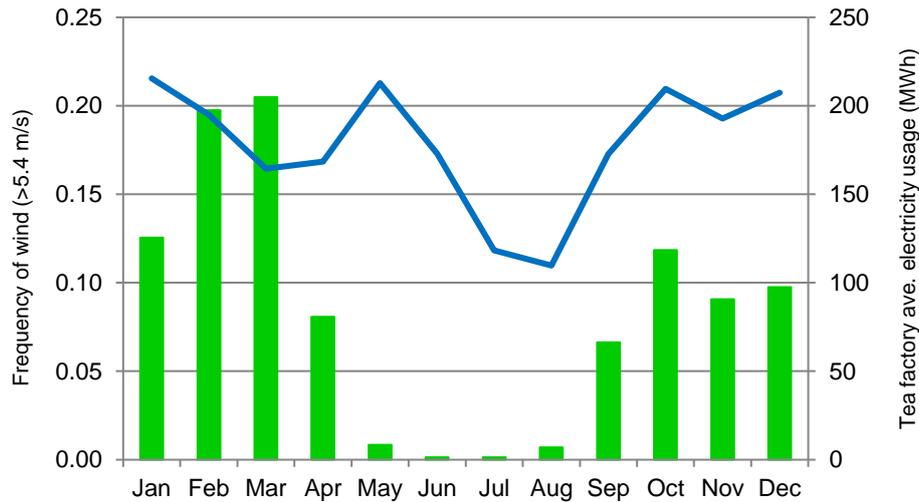
Figure 2: Monthly frequency of winds of greater than ~5.4m.s^{-1} (green) at Ng'ong (Meteoblue, 2017) and averaged recorded monthly electricity usage of four tea factories (blue) (IED, 2008).

4.3 Current Cost of Electricity (without IPP-mini-grid project)

The electricity prices that all consumers would pay if they were connected to the national grid are presented in Table 2 (for tea factories this allows for the unreliability of the grid and the need for diesel backup). Monthly national grid electricity charges are calculated for all consumers following World Bank (2017a). Grid electricity charges consist of a fixed 'access' and variable 'usage' components. The usage component for small businesses (Small Commercial cost band) and domestic consumers is limited to a consumption charge. Domestic consumers face an inverted block tariff with a lower lifeline (subsidized) tariff for the first 50kWh consumed, paid for by increased tariffs for those consuming higher quantities of electricity (Kapika and Eberhard, 2016). Access to even limited quantities of electricity can have positive impacts on livelihoods of the poor and marginalized groups via budget, health and productivity effects (Abdul-Salam and Phimister, 2019). This type of in-kind benefit is often used in developing countries as a pro-poor policy, although evidence suggests that its benefits are not necessarily well targeted on the poor and marginalized groups (Komives *et al*, 2007; Angel and Wodon, 2007). In addition to a consumption charge, larger commercial users also pay a demand charge that is determined by their peak electricity demand. Tea factories are treated as Commercial/Industrial CI2 electricity users and a peak electricity demand of 550 kVA is assumed (IED, 2008). Tea factory electricity prices also include a diesel-generator component at a ratio of diesel generation to national grid electricity of 1:50 (IED, 2008). We assume a diesel price of 0.77 USD/kWh.

Consumers	No. of consumers	Monthly consumption[a]	Imputed price[b]
Tea Factory	4	146,041 kWh	0.18 USD/kWh
Rural Domestic	840	45 kWh	0.12 USD/kWh
Rural Small Business	140	125 kWh	0.23 USD/kWh

[a]Average assumed per consumer.
[b]Price per unit paid by consumers if connected to the national grid. To compensate for grid unreliability, the price paid by the tea factories includes a diesel generation component.

Table 2: Imputed average electricity prices for all consumers if connected to the national grid.

5. Results and Discussion

5.1 Project viability under the Base Case Pricing Assumption

As discussed in Section 3, the base case allocation rule sets break-even prices so that the tea factories and rural consumers contribute equally to the total project costs. These results are presented under Scenario 1 in Tables 3 and 4 for three, four and five turbine IPP projects. In addition, to explore whether the tea factories would have incentives to invest in an own-use wind-power plant, we report the results for the project without the mini-grid extension to the rural consumers. These results are presented under Scenario 2. For the IPP-mini grid project to be viable, the wind electricity price must be sufficiently low to reduce tea factory operating costs. Similarly, rural consumers will only participate in the project if the cost of electricity with the IPP-mini-grid is no more than that with national grid electricity only. In Table 4, the overall results are therefore disaggregated for each type of consumer.

The Table 3 results indicate the level of electricity generation, export to the national grid, the overall level of CAPEX and the break-even electricity prices under the various project sizes and scenarios. In Scenario 1, rural consumers and tea factories contribute equally to the costs of the IPP and MV systems, with excess electricity exported to the national grid at the feed-in-tariff. The higher NPV CAPEX in Scenario 1 is due to the costs of the rural mini-grid, but this cost is borne solely by rural consumers. In Scenario 2, without the rural consumers, more electricity is exported to the national grid at the wind feed-in-tariff.

Scenario[a], Rural Consumers	3 Turbines		4 Turbines		5 Turbines	
	Scenario 1, Inclusive	Scenario 2, Exclusive	Scenario 1, Inclusive	Scenario 2, Exclusive	Scenario 1, Inclusive	Scenario 2, Exclusive
Electricity Generated (in Year 2)	6,504,300 kWh		8,672,400 kWh		10,840,500 kWh	
Electricity Export (in Year 22)	129,512 kWh	328,592 kWh	1,249,766 kWh	1,640,009 kWh	2,904,353 kWh	3,174,847 kWh
NPV CAPEX	4,238,841 USD	4,179,854 USD	5,471,475 USD	5,412,488 USD	6,694,195 USD	6,645,122 USD
Simple Payback Period	9 years	9 years	9 years	9 years	9 years	9 years
Electricity Price per kWh *(Post tax NPV=0)*	**0.145 USD**	**0.147 USD**	**0.147 USD**	**0.150 USD**	**0.151 USD**	**0.154 USD**
Rural Community surcharge / differential price (per kWh)	**0.054 USD**		**0.027 USD**		**0.027 USD**	

[a]*Under the base case allocation rule break-even prices imply tea factories and rural consumers contribute equally to total costs. Scenario 1 results include rural consumers. Scenario 2 results are for an own-use IPP for the tea factories alone. In all cases, surplus electricity is exported to the national grid at the feed-in-tariff (0.11 USD/kWh) throughout project life.*

Table 3: Key results of wind-power project with three, four and five turbines under the base case cost allocation rule.

By calculating the Present Value (PV) of savings (Table 4), the benefits, both overall and for each different type of individual consumer, can be evaluated. The Table 4 results show that the overall project economics benefit from the inclusion of rural consumers under the base case cost allocation rule. For example, acting on their own (Scenario 2) the tea factories generate economic savings of 388.5 thousand U.S. dollars for the four turbine case, whereas if the project is extended to supply electricity to other local customers the overall economic value increases to 406.5 thousand U.S. dollars.

	Scenario[a]	PV of Savings		Total Savings[b]
5 Turbines	**Scenario 1**	PV Savings for Tea Factory	87,598 USD	
		PV Savings for Rural Consumers		
		Domestic: *(per household)*	**-181 USD**	
		Small Business: *(per property)*	307 USD	**241,332 USD**
	Scenario 2	PV Savings for Tea Factory	55,584 USD	222,336 USD
4 Turbines	**Scenario 1**	PV Savings for Tea Factory	125,258 USD	
		PV Savings for Rural Consumers		
		Domestic: *(per household)*	**-167 USD**	
		Small Business: *(per property)*	327 USD	**406,532 USD**
	Scenario 2	PV Savings for Tea Factory	97,132 USD	388,528 USD
3 Turbines	**Scenario 1**	PV Savings for Tea Factory	130,346 USD	
		PV Savings for Rural Consumers		
		Domestic: *(per household)*	**-83 USD**	
		Small Business: *(per property)*	113 USD	**467,484 USD**
	Scenario 2	PV Savings for Tea Factory	116,532 USD	466,128 USD

[a]*Base case allocation rule breakeven prices imply tea factories and rural consumers contribute equally to total costs. Scenario 1 results include rural consumers. Scenario 2 results are for tea factories alone. Tea factories and rural consumers pay a 'base price' and share the CAPEX, OPEX and DECEX for the plant and MV lines. A surcharge for rural electrification is paid by rural consumers (see equation 1).*
[b]*Total of the PV of savings made by all actors in each scenario.*

Table 4: PV of savings per consumer under base case cost allocation rule.

The individual impacts on different consumers within the model are also important as these indicate whether each type of consumer would have an incentive to buy electricity from the IPP. The wind plant produces savings for the tea factories under all scenarios. Tea factories make the greatest savings under Scenario 1, which includes small business and domestic consumers, with either a three turbine (130,346 USD) or a four turbine (125,258 USD) plant. Small businesses have the greatest PV of savings (327 USD) with a four turbine plant. However, the base case cost allocation rule produces an IPP electricity price that is too high for our domestic consumers whatever the number of turbines in the project. Hence, these consumers would be better off using the grid alone. Without intervention the full economic value of the project could, therefore, not be achieved.

Under the base case cost allocation rule, the PV of savings differ for rural domestic and small business consumers depending upon their respective electricity demands (Figure 3). As we use fixed per unit pricing for the IPP electricity, the observed differences are explained by the national grid pricing structure. Small businesses make a positive PV of savings by connecting to the IPP across all tested demand levels. As the national grid usage fee for small businesses increases at a fixed rate with increasing consumption, the amount of savings gained by joining the IPP project also increases with increasing consumption.

The impact on domestic consumers is more complicated due to the inverted block tariff (with lifeline tariff) that they face when using the national grid. Consistent with the simple welfare analysis of multi-part tariffs by Train (1991), if the inverted block tariff faced by the consumer is replaced by a single unit price with the IPP, those consuming at or below the maximum quantity attracting the lifeline tariff will lose consumer surplus (assuming the single unit price is above the lifeline tariff). When the single IPP unit price lies below national block tariff, consumers will gain from every unit of extra consumption so that the losses on low consumption will eventually be offset. This is reflected in Figure 3. Assuming negligible price effects, the modelling shows that domestic consumers with high electricity usage (>100kWh per month) make a positive PV of savings with the IPP, whereas consumers with a usage of between 45 and 55kWh/month make the greatest losses.
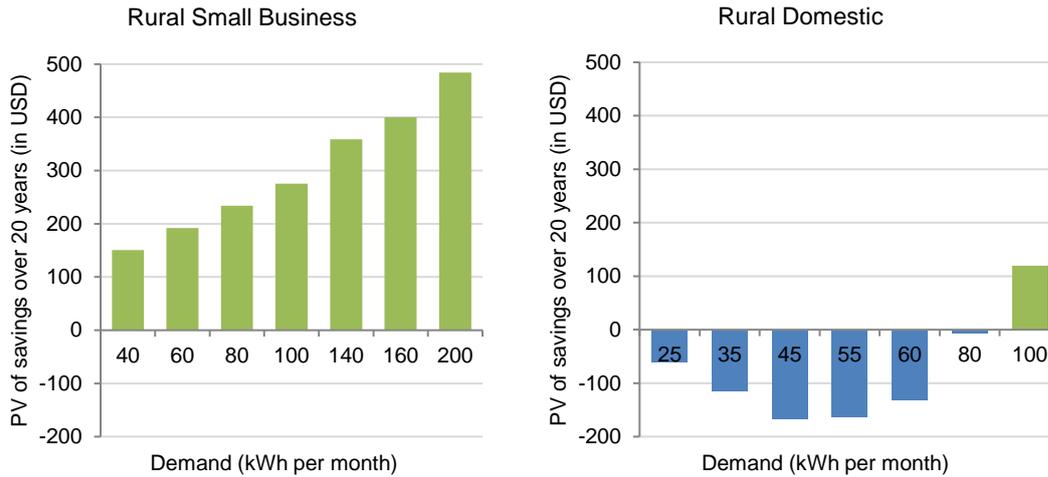
Figure 3: PV of savings sensitivity for rural consumers under the base case cost allocation rule.

The results in Table 4 also appear to show that the three turbine configuration provides the overall largest economic surplus. However, this ignores the economic value associated with the increased reliability arising from an increase in local electricity supply. Although we can see from Table 3 that a three turbine wind farm provides the lowest base IPP electricity price (p_{base} = 0.145 USD/kWh) for tea factories, by project year 22 the plant is capacity constrained. In our model, with three turbines there is sufficient electricity to cover 63% of tea factory and just 30% of local rural consumer annual demand. As less electricity is sold to rural consumers, a higher rural surcharge (p_{RC} = 0.054 USD/kWh) is needed to cover the mini-grid costs. The four and five turbine plants produce sufficient electricity to meet 66% and 67% of the tea factories', and 59% and 60% of local rural consumers' annual requirements, respectively. The IPP base electricity price is, however, 0.004 USD/kWh cheaper for a four turbine plant under both Scenarios 1 and 2. With increased sales to rural consumers, the mini-grid surcharge is also lower at 0.027 USD/kWh. Hence arguably, the four turbine wind farm will provide a better trade-off between local capacity, potential reliability and electricity price, if the difference in the overall value is less than the value of extra reliability to local consumers.

5.2 Evaluation of Different Cost Allocation Strategies

As the previous results showed (Section 5.1, Table 4), the full potential economic benefits are unlikely to be realised with the base case cost allocation because the associated pricing means

that rural domestic consumers have no incentive to participate and buy electricity from the IPP. In this section we consider whether alternative cost allocation mechanisms, and their associated prices, could lead to a situation in which all consumers would have positive incentives to participate and buy from the IPP. In addition to the base case, two further cost allocation mechanisms are now considered.

The base case, or cost allocation Option 1 (equation 1), is as before where consumers are treated as equals and pay towards the infrastructure that they use, according to their consumption. In Option 2 (equation 2): Share All Costs, all consumers share all project costs proportional to their consumption. In Option 3 (equation 3): Rural Pay Excess Only, it is assumed that rural consumers pay only the excess or costs associated with the mini-grid, while all other costs of the IPP project are paid by the tea factories. Tea factories therefore partially subsidize the rural consumers in Option 3. As, by definition, the IPP achieves cost recovery in all of these cost allocation options, the differences in savings across the options are most easily interpreted as the transfer of economic rent across the consumer groups.

The PV of savings for each consumer type under the three cost allocation rules are presented in Table 5. Rural small businesses achieve a positive PV of savings with all cost allocation options, irrespective of the number of turbines in the IPP. Tea factories maximize their savings with Option 1 and make the least savings with Option 3. Options 1 and 2 could not be sustained without, for example, direct subsidy as rural domestic consumers otherwise face negative PV of savings under these options and would not buy from the IPP. Cost allocation Option 3, on the other hand, does provide a positive surplus to rural domestic consumers, and all other actors, and would therefore be sustainable. Although overall economic value is reduced in Option 3 relative to Option 1 for the three turbine plant, this is not the case if the higher level of local electricity supply of the four turbine plant is preferred.

		3 Turbines	4 Turbines	5 Turbines
1. Base Case	PV Savings for Tea Factory	130,346 USD	125,258 USD	87,598 USD
	PV Savings for Rural Consumers			
	Domestic: *(per household)*	**-83 USD**	**-167 USD**	**-181 USD**
	Small Business: *(per property)*	113 USD	327 USD	307 USD
	Total Savings^a	467,484 USD	406,532 USD	241,332 USD
2. Share all costs	PV Savings for Tea Factory	107,116 USD	104,321 USD	68,348 USD
	PV Savings for Rural Consumers			
	Domestic: *(per household)*	**-19 USD**	**-105 USD**	**-119 USD**
	Small Business: *(per property)*	293 USD	501 USD	481 USD
	Total Savings^a	453,524 USD	399,224 USD	240,772 USD
3. Rural pay only excess	PV Savings for Tea Factory	72,661 USD	13,094 USD	**-32,769 USD**
	PV Savings for Rural Consumers			
	Domestic: *(per household)*	101 USD	202 USD	202 USD
	Small Business: *(per property)*	625 USD	1,373 USD	1,373 USD
	Total Savings^a	462,984 USD	414,276 USD	230,824 USD

[a] *Total of the PV of savings made by all actors in each scenario.*

Table 5: PV of savings per consumer under three Cost Allocation Rules.

Both the Table 4 and Table 5 results suggest that the ownership of the IPP-mini-grid may play a role in determining whether all of the potential economic benefits are likely to be realised or whether the tea factories would have incentives to simply 'go-it-alone'. The Table 5 results indicate that while Option 3 is the only cost allocation which provides incentives for the domestic consumers to join the IPP, the gains to the tea factories in this case are rather small. If the tea factories finance the project, by excluding the rural consumers and choosing a three turbine plant they could maximise their PV of savings (Scenario 2, Table 4). This would suggest that if the IPP-mini-grid project was to be financed by the tea factories, the factories would have few incentives to act as a demand anchor for other local consumers, and are likely to require additional incentives and subsidy from the government in order to invest both for themselves and for wider the rural community.

6. Conclusions and Policy Implications

This paper shows that including local rural domestic and small business consumers could increase the net economic benefit from small wind-powered projects in Kenya's tea-growing region, and provide increased access to locally produced electricity among rural households. However, how project costs are allocated to different consumer types has a significant impact on participation. If all consumers must pay towards the infrastructure they use according to their consumption, it is not financially beneficial for domestic consumers with low energy demands (<100 kWh/month) to join the wind-power project compared to the national grid. This is, in part, due to the increasing block structure, with a lifeline tariff, of the KPLC national electricity tariffs.

A cost allocation rule can be found that provides benefits (and positive incentives to participate) for all consumers. Under this rule, cost is allocated so that rural consumers pay only the extra costs associated with the mini-grid, while the tea factories cover all other project costs. Rural domestic and small business consumers benefit most from a four turbine plant because greater rent is transferred to them from the tea factories. Tea factories may not, however, have an incentive to provide electricity to rural consumers under such a cost allocation scheme as they would benefit more from a less capital intensive, three turbine, own-use plant.

Although the wind-power project recovers all of its costs under all scenarios and cost allocation rules examined, ownership issues could lead to exploitive IPP electricity pricing. For example, if the tea factories own shares in the IPP-mini-grid, there may be incentives to extract rent from rural domestic and small business consumers. Additional incentives and/or regulations, such as tariff caps (IRENA, 2016), may therefore be needed to promote this type of rural electrification project and encourage equitable pricing and distributive efficiency.

Such regulations may also be desirable to ensure that the cross-subsidization of poor and marginal consumers is achieved in the mini-grid. As discussed, the national lifeline tariff impacts significantly on the net benefits of the IPP for domestic consumers, with low quantity

consumers losing in the base case cost allocation rule. On the national grid, more affluent consumers cross-subsidize the lifeline tariff for poorer consumers. Hence mini-grids may be at a relative disadvantage as the lower number of rural consumers able to pay higher tariffs limits this type of cross-subsidy.[3] Where this is the only source of cross-subsidization available to fund a lifeline tariff, it may mean that the national grid should remain the first-choice provider of electricity for domestic customers. However, the different cost-allocation rules presented here, e.g. where domestic consumers only pay extra costs associated with the mini-grid, effectively provide alternative methods of cross-subsidizing a lifeline tariff.

The results presented here emphasise that while there are potential gains from using local tea factories as demand anchors for the mini-grid project, there is no guarantee that private investors will invest to a scale which will lead to maximum potential social net benefit. There is therefore a role for government in supporting such initiatives. The case discussed here focusses on wind as the renewable investment and, in reality, the project economics will depend on a range of site-specific characteristics, including wind speed and density, which may not make some investments attractive. The appropriate regulation of pricing in mini-grids, how local prices interact with any existing national electricity pricing system, the role of feed-in tariffs and the impact on overall investment incentives is, however, relevant for a wide range of renewable technologies. In the Kenyan context, for example, the structure of the problem would be similar for the other technologies supported by Feed-in Tariffs, such as hydro or biomass.

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[3] We thank one of the referees for highlighting this point.

Acknowledgements

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