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Electrification and productive use among micro- and small-enterprises in rural North India☆

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ABSTRACT

The reported effects of electrification on rural entrepreneurship are mixed, with recent studies describing heterogeneity in outcomes and methodological challenges in attributing causal effects. Furthermore, the debate largely focuses on performance outcomes, rather than supply- and demand-side barriers to productive electricity use itself. In this paper, we contribute new evidence describing electricity use among micro- and small-enterprises (MSEs) in rural northern India. Puzzlingly, 34% of the 2,004 MSEs surveyed have no grid-connection despite almost complete village grid electrification. We exploit variation in grid supply hours at village level, finding no conclusive link with this and MSE connection likelihoods. Rather, connection likelihood appears to be more closely related to wealth characteristics. Supporting this hypothesis, the reported electricity consumption appears equally unrelated to supply quality and quite low overall: 75% of grid-connected MSEs consume less than 1 kW-hour per day, powering only lighting and fans. These results are notable given the positive bias we expect due to the likely endogeneity between grid supply quality and broader development trends, as noted in recent literature. Our work follows others in arguing that supply side improvements must occur in concert with demand side initiatives to unlock rural MSE electricity consumption. At the same time, the role of off-grid technologies in meeting nascent MSE electricity needs deserves further study.

1. Introduction

Access to electricity is broadly recognised as an important factor in enterprise development as it unlocks a variety of energy services that can increase productivity and enable provision of new goods and services, linking Sustainable Development Goal (SDG) 7 - *Energy access for all* with SDG 8 - *Decent work and economic growth* (McCollum et al., 2018). Examples of such energy services include lighting, fans, digital technologies, mechanisation and product cooling (Bhatia and Angelou, 2015; Jeuland et al., 2021). Although access to these energy services is generally seen as positively associated with enterprise performance, the literature points toward heterogeneity in outcomes across different enterprise types and in different contexts (Riva et al., 2018; Hamburger et al., 2019; Blimpo and Cosgrove-Davies, 2019; Bayer et al., 2020; Jeuland et al., 2021).

Contemporary Indian energy access policy and literature has focused on household electrification, exemplified by the recent *Saubhagya* electrification program. In contrast, the electrification status and evolving electricity needs of micro, small and medium sized enterprises (MSMEs) has seen comparatively less research and policy intervention (Palit and Bandyopadhyay, 2017; Jeuland et al., 2021). While MSME revenues represent a small share of the broader Indian economy, they employ approximately one fifth of the rural working population (NSSO, 2017, 2019). Their perceived importance is thus perhaps limited in terms of their contribution to the gross domestic product, but nevertheless significant for the livelihoods of rural households across India. In this work, we consider the smaller segment of this group, specifically micro- and small enterprises (MSEs) that are typically owner-operated

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and engage in retail or services provision such as grocery shops, tailors, and cycle repair centres.

We conduct our analysis using the SPI-ISEP REDI dataset, consisting of detailed enterprise-level surveys (N = 2,004) from 200 similar revenue villages across rural areas of Bihar, Odisha, Uttar Pradesh and Rajasthan. We ask three related questions under the umbrella of rural electricity policy reform and productive electricity use: Is grid supply quality related to rural MSEs' propensity to connect to the national grid? For grid-connected MSEs, is the supply quality related to their electricity consumption and likelihood to acquire off-grid backups? How do grid-connected and off-grid MSEs actually use their electricity supply?

Using a linear probability model with state and enterprise category fixed-effects, we find no statistically significant relationship between revenue village grid electricity supply duration and the likelihood of grid connection, or off-grid backup supply. Rather, the regression coefficients and descriptive statistics suggest that MSE wealth characteristics are important covariates related to grid-electricity take-up and use across the villages studied. In interpreting these outcomes, we draw on literature which cautions that grid supply quality and economic development may be endogenous, such that better infrastructure is built in areas with rapid economic growth. Our work suggests that in spite of the expected endogeneity between MSE performance and grid supply quality, even when grid supply is adequate, some MSEs opt out of a grid connection and those connected may still consume very little electricity. It is evident, therefore, that barriers to MSE productive energy use beyond electricity supply quality deserve more attention.

Strengthening the case for exploring barriers beyond supply quality, our work also shows that energy services utilisation among both grid-connected and off-grid rural MSEs is low, with 75% of grid-connected MSEs consuming less than 30 kWh per month, and the same proportion of off-grid MSEs consuming less than 15 kWh per month, both of which are within the lifeline residential tariff block. We also find that only a minority of grid-connected MSEs (42%) use appliances beyond lighting and fans, dropping to just 18% among off-grid MSEs. This is not likely to be related to supply capacity constraints, as the grid is available. Rather, we speculate that wealth constraints and enterprise scale, as indicated in the earlier regression analyses, remain the main drivers for low productive electricity utilisation.

Overall, the evidence provided suggests that MSE electricity consumption is more related to demand than supply constraints across the villages studied. Efforts to increase productive electricity use among rural MSEs in northern India must address these concerns, both in terms of supply affordability and demand stimulation. Ignoring the affordability concerns and low level of electricity consumption among rural MSEs runs the risk of poor rural electricity distribution company health in the mid-term with the potential to affect supply reliability in the long-term.

2. Background

Broadly speaking, there is a clear call for further investigation into the effects and modifiers of reliable, affordable and modern electricity access, especially in the context of productive electricity use and smaller enterprises (Peters and Sievert, 2016; Bos et al., 2018; Riva et al., 2018; Hamburger et al., 2019; Bayer et al., 2020; Lee et al., 2020 a; Jeuland et al., 2021).

Literature investigating the impacts of rural electricity access on productivity is mixed and weighted towards household-level outcomes. Access to electricity has been linked with increased incidence of rural household non-farm entrepreneurship in diverse contexts (Cabraal et al., 2005; Deininger et al., 2007; Gibson and Olivia, 2010; Kooijman-van Dijk and Clancy, 2010; Rao, 2013). At the same time, the literature reports modest and in some cases null effects on rural employment outcomes (van de Walle et al., 2015; Burlig and Preonas, 2016; Salmon and Tanguy, 2016; Samad and Zhang, 2017). Reviews synthesising these debates suggest that contextual barriers such as market access, gender bias, local capacities and access to capital (see Peters and Sievert (2016); Bos et al. (2018); Riva et al. (2018); Pueyo and Maestre (2019)), play an important role in modifying the effects that rural electrification may have on household-level productivity and economic development.

Enterprise-level electrification outcomes, on the other hand, have seen comparatively less discussion, although there is evidence of recent growth in this literature as synthesised by Blimpo and Cosgrove-Davies (2019). Even within the literature on enterprise electricity use, there appears to be a focus on industrial/manufacturing productivity, rather than the services sector and smaller retail firms despite the importance of energy services for these businesses as well as their prevalence in rural and under-served areas (Jeuland et al., 2021). In our context of rural India an estimated 32.5M non-farm micro, small and medium enterprises (MSMEs) provide employment to approximately one-fifth of the working population of 266M people (NSSO, 2017, 2019). MSMEs therefore represent an important source of livelihoods within the rural Indian economy.

Literature describing MSME electricity use and performance suggests that outcomes are mixed and context-dependent (Chakravorty, Pelli, and Marchand, 2014; Falentina and Resosudarmo, 2019; Litzow et al., 2019; Sharma et al., 2020). Of direct relevance to our study, the work of Peters et al. (2011); Neelsen and Peters (2011) and Grimm et al. (2013) highlights the heterogeneity observed in outcomes among micro- and small enterprises in rural areas. Contemporary literature also warns of specific methodological challenges in isolating the relationship between grid supply quality and economic development due to the expected endogeneity between infrastructure quality and general development trends (Lee et al., 2020 a). Specific to our context of rural India, recent work has shown that even in the industrial/manufacturing sector, electrification and reliability of supply has a plurality of effects on firm performance which are endogenous to local and global factors (Allcott, Collard-Wexler, and O'Connell, 2016; Fetter and Usmani, 2020). Furthermore, notwithstanding the recognition that energy consumption among small non-manufacturing enterprises is initially modest, the actual consumption patterns and end-uses among such MSMEs has received comparatively little attention (Lenz et al., 2017; Lee et al., 2020 b; Taneja, 2018; Jeuland et al., 2021).

In this work, we specifically target the knowledge gap with respect to micro- and small enterprise (MSE) productive electricity use in rural northern India. We shed more light on whether rural MSE connection to the national grid is related to supply quality, as well as characterise their electricity utilisation in terms of typical energy services used. While we are unable to completely overcome methodological challenges posed by possible endogeneity between grid supply quality and general development trends in our analysis, our work is cognisant of this weakness and we include a discussion of the possible effects of this bias on our results.

3. Research design

Our research design centres around three related questions under the umbrella of rural electricity policy reform and productive electricity use: Is grid supply quality related to rural MSEs propensity to connect to the national grid? For grid-connected MSEs, is the supply quality related to their electricity consumption and likelihood to acquire off-grid backups? How do grid-connected and off-grid MSEs actually use their electricity supply?

3.1. Survey data

We conduct our analysis using the SPI-ISEP REDI dataset, consisting of a survey of 2,004 rural small- and micro enterprises from 200 similar rural revenue villages in Bihar, Uttar Pradesh, Rajasthan and Odisha (Agrawal et al., 2019).

200 revenue villages were selected as part of a study designed to measure rural electricity demand and understand the customer

Table 1
Descriptive statistics of the sampled revenue villages by sampling group. The group means refer to village-level means by sampling group. The connection cost values refer to enterprise-level average connection costs paid, by sampling group. BPL is an acronym for Below Poverty Line and refers to households holding a ration card.

Villages Sampled	Grid (Franchise)	Grid (Public)	Grid (Public) + Minigrid
	54	96	50
Group Means	Grid (Franchise)	Grid (Public)	Grid (Public) + Minigrid
Grid electrification: Yes	1	1	1
Households	938	937	1650
Share of BPL households	0.45	0.51	0.63
Marketplaces	1.26	1.05	1.08
Grid supply hours	19.4	14.9	13.6
All hamlets electrified	0.96	0.89	0.62
Grid Connection Cost	1656	1899	1900
Minigrid Connection Cost	–	–	696

perspective towards mini-grid electricity and grid electricity. Mini-grid revenue villages were sampled from a master list of 91 Smart Power India mini-grid intervention revenue villages across the states surveyed, where these decentralised systems co-exist in parallel to the national grid. These mini-grids range from 30 to 60 Kilowatt-Peak (kWp) in size and are operated by local energy service companies. Alongside the mini-grid interventions, the survey also explored the effects of privatisation of the national grid distribution network, and sampled from a list of revenue villages in Odisha where private distribution franchises operated the local grid.

Starting with a random sample of 50 revenue villages with a Smart Power India mini-grid intervention and 50 revenue villages being served by private franchises operating the local grid network, 100 revenue villages without mini-grids or a private grid franchise, but similar to these revenue villages, were selected from their respective sample frames. To ensure structurally similar comparisons the revenue villages were selected based on their similarity across three variables: Total revenue village population, Distance to town, and Presence of clustered shops (market). It is important to note that the surveys were not statistically representative of the states covered given the sampling design, nor were in-house enterprises covered. During enumeration, the actual distribution of revenue villages across the three groups changed slightly from the intended sample, as four of the non-franchise villages were in-fact served by a local private franchise. Further detail on the sampling design can be found within the Sampling Design document hosted on the Harvard Dataverse (Agrawal et al., 2019).

Table 1 describes the revenue villages surveyed across the three groups and Fig. 1 describes the distribution of average grid supply hours across the three groups, the colors reflect whether or not all hamlets within the revenue village jurisdiction have a grid connection, indicative of *completeness* of revenue village-level electrification. The revenue villages are comparable across our sample in terms of economic activity and wealth, though there appears to be a trend suggesting that villages with mini-grid interventions were slightly poorer and most certainly received less reliable grid supply. Here we also note that grid supply availability ranges broadly, from under 4 h–24 h across our sample with an average of betwen 14–19 h across the village groups. Enterprise-reported total grid connection costs vary from nominal amounts to just over 10,000 INR, averaging between 1600 and 1900 INR across the village groups. The reported connection fees vary mainly due to the fact that they encompass the necessary formal charges, potential informal charges due to corruption as well as in-shop wiring. Disaggregation of these costs was not possible in the data collected, and is a potential source of error in our analysis.

Table 2 summarises enterprise types in the survey dataset. We group enterprises by the type of goods or services offered. We see that retail enterprises are the most common with grocery stores alone representing a quarter of the sample. In contrast, the sample contains very few manufacturing or cottage industry type MSEs typically considered as 'productive' electricity consumers. This provides context to the grid connection likelihoods and types of energy services found to be utilised

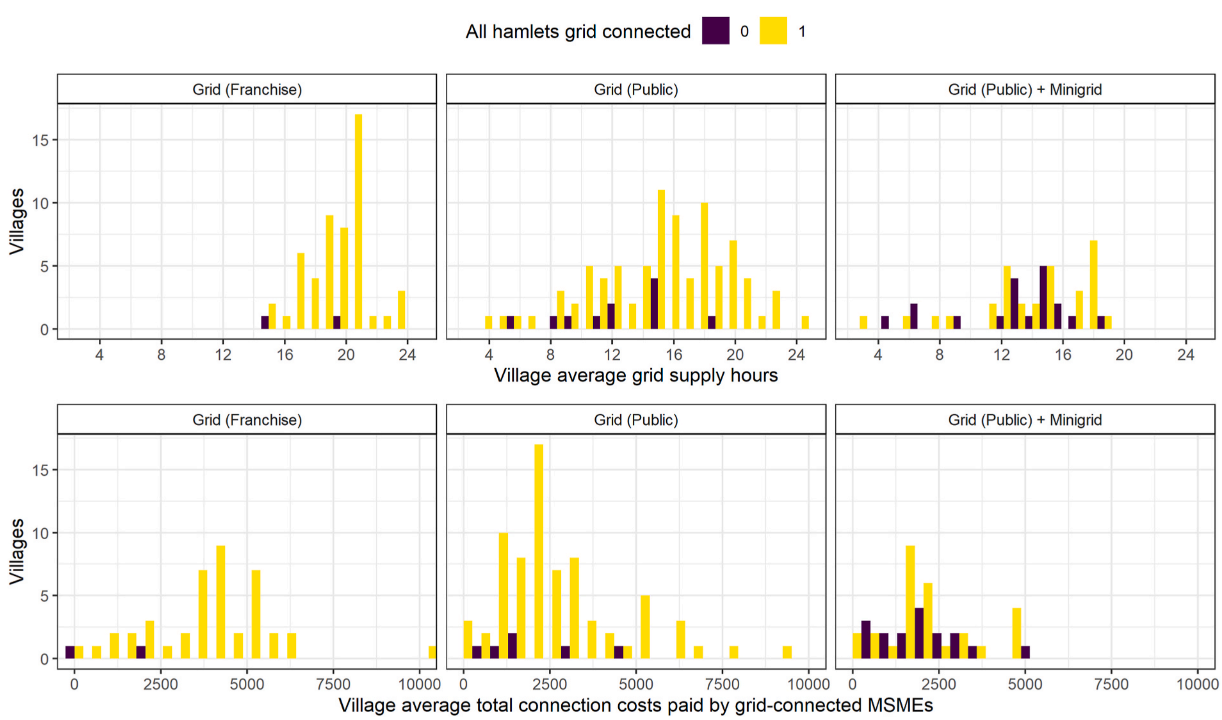

Fig. 1. Village-level grid supply hours and average connection costs paid. The colors indicate village electrification completeness, which is a binary variable indicating whether or not all hamlets in the revenue village are grid-electrified. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Summary table describing the proportion of different rural enterprises surveyed.

Category	Type	Observations	Share
Agri	ColdStorage	12	0.6%
Agri	MilkChilling	4	0.2%
Digital	CyberCafe	61	3.0%
Digital	MobileRepair	80	4.0%
Digital	Photostudio	16	0.8%
Food	Fruits	65	3.2%
Food	Groceries	484	24.2%
Food	Sweets	195	9.7%
Health	Clinic	52	2.6%
Misc	FlourOilMill	43	2.1%
Misc	Others	11	0.5%
Misc	Warehouse	11	0.5%
Retail	Agricultural	45	2.2%
Retail	Clothes	219	10.9%
Retail	Electronics	182	9.1%
Retail	Medical	123	6.1%
Trades	BeautyParlour	115	5.7%
Trades	BicycleRepair	99	4.9%
Trades	Carpentry	25	1.2%
Trades	CarScooterRepair	72	3.6%
Trades	Tailoring	90	4.5%

Table 3
Overview of the primary electricity sources across all sampled MSEs. Table (a) groups MSEs by the type of electrification into those using the grid only, off-grid only and those using both or none. Table (b) describes all sources of electrification reported by the MSEs, the proportions here sum to over 100% as MSEs can rely on multiple sources indicated by Table (a).

(a) Electrification groups		
Electricity source group	Total firms	Proportion
Grid	876	44%
Grid + Off-grid	431	22%
Off-grid	437	22%
None	260	13%
(b) All sources of electricity		
Sources used	Total firms	Proportion
Grid	1307	66%
Minigrid	176	8%
SolarHomeSystem	234	12%
Generator	107	6%
SolarLantern	87	4%
Battery	338	16%
None	260	12%

by micro- and small enterprises in the following analyses. Finally, Table 3 provides overview of electricity sources across the sampled MSEs. As MSEs may use more than one source of electricity, we aggregate these into electrification groups, as well as showing the prevalence of each form of electrification across the entire sample. Puzzlingly, despite all villages being grid connected, 34% of MSEs remain without a grid connection. Furthermore, 22% of MSEs use both the grid as well as an off-grid backup while 22% rely on off-grid sources alone.

The reported differences across the villages surveyed as well as the sampling design suggests that we should not expect large village-level effects, though potential endogeneity is nevertheless addressed as far as possible in our empirical work.

3.2. *Grid supply quality, connection and utilisation*

Does the variation in grid supply quality explain the puzzling lack of utilisation in our sample? To explore this, we link the reported average revenue village grid supply quality to MSE grid electrification likelihoods, propensity to secure off-grid backups and grid electricity consumption. The reported average revenue village grid electricity supply duration hours reflect the average of stated winter and supply duration as reported by the revenue village leaders during the community survey, and is therefore not expected to be biased by enterprise characteristics.

We use linear regression model specifications, applying both state and enterprise category fixed-effects. The motivation for the former is to address potential state-level time-invariant differences, which should be minimal given the nature of the sampling design. The motivation for the latter is to draw inference on the relationship between grid electricity quality and enterprise connection and utilisation in aggregate terms, that is, for the rural MSE sector as a whole. We specify the following model which is applied in three different cases:

$$Y_{ij} = \beta_1 \ \ revenue \ \ village \ \ grid \ \ hours_j + \beta_n X_{ij} + \nu_s + \nu_c + \varepsilon_1, \tag{1}$$

where Y_{ij} is the outcome variable for enterprise i in revenue village j, β_1 captures the relationship between typical revenue village grid supply hours and the outcome and β_n is a vector of coefficients relating the vector of controls X_{it} to the outcome. ϑ_s captures state fixed effects and ϑ_c captures enterprise category fixed effects. ϵ_{ij} is the error term and standard errors are grouped at the district level.

We first link average revenue village grid electricity supply duration in hours with a binary dependent variable indicating enterprise grid connection. In this specification, Y_{ij} is a binary variable indicating the usage of the grid for enterprise i in revenue village j. We conduct this analysis using the full dataset of 2,004 rural MSEs.

Next, we link average revenue village grid electricity supply with the propensity for grid-connected to use off-grid backup sources such as minigrids, SHS, batteries of generators. In this specification, Y_{ij} is a binary variable indicating the usage of a backup electricity source for enterprise i in revenue village j. We conduct this analysis on the subset of grid-connected enterprises (N = 1,307).

Finally, we link average revenue village grid electricity supply with grid-connected enterprise electricity consumption. In this specification, Y_{ij} is the estimated monthly electricity consumption in kWh for enterprise i in revenue village j. We conduct this analysis on the subset of grid-connected enterprises (N = 1,307), including an additional dummy variable indicating use of an off-grid backup solution, as this will directly influence electricity consumption.

Across all models, we adjust for revenue village-level variables including, **revenue village hamlet electrification** which is a binary variable reflecting 'completeness' of grid electrification within a revenue village, with respect to all hamlets having a grid connection, **revenue village households** which is a numeric variable indicating the total number of households in the revenue village, **revenue village marketplaces** which is a numeric variable indicating the total number of marketplaces in the revenue village, and **revenue village BPL share** which is a numeric variable indicating the share of households that have a Below Poverty Line (BPL) ration card. We do this to mitigate revenue village-level differences across our sample, though we have little reason to believe there is much variation here due to the sampling design. We also use enterprise-level control variables including **Floor area** which reflects the total square footage of the enterprise, **Salaried employees** which represents the number of salaried employees and typically excludes unpaid family members, **Building owned** which is a binary variable indicating that the entrepreneur owns the structure housing their enterprise and **Building pucca** which is a binary variable indicating that the structure housing the enterprise is permanent and of good quality. The justification for these variables is that we expect wealthier enterprises, assumed to be indicated by the floor area, number of employees, building ownership and structural quality, to be more likely to be electrified and consume more electricity.

We center and standardise our independent variables throughout our inductive work to enable a more straightforward comparison between continuous and binary variable regression coefficients. For numeric independent variables, we subtract the sample means and divide by two standard deviations. To maintain all variables on the same scale, we also

Table 4
Summary statistics tables of the variables relevant to the regression analysis.

(a) Model 1: All MSEs

	Mean	SD	Min	Max	Observations
MSE grid connected	0.66	0.48	0	1	2, 004
MSE uses OG backup	0.43	0.50	0	1	2, 004
MSE monthly kWh	32.30	140	0	2, 980	2, 004
Village grid supply hours	15.79	4.33	2.50	24	2, 004
Village households	1, 115	802	180	5, 750	2, 004
Village share of BPL households	0.52	0.33	0	1.65	1, 994
Village marketplaces	1.11	0.41	1	4	2, 004
Village hamlets electrified	0.84	0.37	0	1	2, 004
MSE floor area	142.42	246	9	7, 200	2, 004
MSE salaried employees	0.16	0.61	0	10	2, 004
MSE building pucca	0.69	0.46	0	1	2, 004
MSE building owned	0.62	0.49	0	1	2, 004

(b) Models 2 & 3: Grid-connected MSEs

	Mean	SD	Min	Max	Observations
MSE grid connected	1	0	1	1	1, 307
MSE uses OG backup	0.33	0.47	0	1	1, 307
MSE monthly kWh	42.9	137.1	0.10	2, 350	1, 307
Village grid supply hours	16.95	3.96	2.50	24	1, 307
Village households	1, 057	708	180	5, 750	1, 307
Village share of BPL households	0.48	0.29	0	1.65	1, 299
Village marketplaces	1.14	0.46	1	4	1, 307
Village hamlets electrified	0.90	0.30	0	1	1, 307
MSE floor area	151.19	282.39	16	7, 200	1, 307
MSE salaried employees	0.21	0.71	0	10	1, 307
MSE building pucca	0.74	0.44	0	1	1, 307
MSE building owned	0.66	0.47	0	1	1, 307

center the binary independent variables to have a mean of 0. This procedure enables a comparison of the effect of a binary variable being present with the equivalent effect of a two standard deviation increase in a numeric variable as proposed by Gelman (2008). Summary statistics for outcome and explanatory variables are shown in Table 4 for all model specifications. Two standard deviations remain within the plausible domain of all numeric variables. Finally, robustness checks are provided in the Appendix Section A1 including i) identical model specifications but limiting the sample to villages that are fully grid-electrified and do not contain any minigrid or private-franchise interventions, and ii) linearity checks for the linear regression model. The reported results hold against the robustness tests and satisfy assumptions made in our model specification.

3.3. Understanding productive electricity use

How do grid-connected and off-grid MSEs use their electricity connections? We calculate the estimated monthly electricity consumption based on the reported total hourly usage of each appliance type, multiplied by the reported average hourly power requirements of the appliance. Table 5 describes the energy services categories, typical corresponding appliances and the reported peak power requirement. For the minority of enterprises using atypical appliances with high peak power requirements and intermittent usage, such as drills, grinders or welding machines, the reported power requirement is multiplied by a utilisation factor of 0.25 to estimate average hourly electricity consumption corresponding to 15 min of peak power drawn in every hour of usage. For enterprises using appliances with medium power requirements and cyclical or standby usage patterns such as fridges, printers and computers the reported power requirement was replaced

Table 5
Energy services, typical corresponding appliances and average hourly power requirement summary statistics. Reported power requirements vary due to differences in appliance sizes for lights, televisions, ceiling fans and air coolers. The remaining appliance power requirements reflect ex-post assigned average hourly power consumption as per the multi-tier framework guidelines, which do not vary.

Service	Appliance	Mean Wattage	Minimum Wattage	Maximum Wattage
Light	Bulb	103	15	200
Light	CFL bulb	18	2	100
Light	Led	8	2	40
Light	Tubelight	30	5	70
Fans	Ceiling fan	69	20	120
Fans	Table fan	50	50	50
Fans	Cooler	188	60	550
ICT	TV	50	15	237
ICT	Computer	50	50	50
ICT	Printer	45	45	45
Mechanical	Sewing Machine	50	50	50
Mechanical	Weighing Scale	5	5	5
Refrigeration	Fridge	75	75	75

with average hourly power requirements described by the multi-tier measurement framework guidelines (Bhatia and Angelou, 2015).

We then explore *how* both grid-connected and off-grid MSEs actually use their electricity connection. To do so, we aggregate all appliances into five electrical energy service categories. These include **Lights** - referring to lighting services, **Fans** - referring to primary to ventilation through fans and in a minority of cases standing air coolers, **ICTs** - referring to digital information and communication technologies, **Mechanical** - referring primarily to mechanical loads but also includes some thermal loads for a small minority of enterprises who indicate usage of equipment such as soldering irons, welding machines and hot-air guns, and finally **Refrigeration** - referring to enterprises using fridges. All other atypical equipment types manually entered during data collection (such as welding machines) have been assigned to the corresponding service categories described above.

4. Results

4.1. Grid supply quality, connection and utilisation

We first look at the association between grid supply reliability and rural MSE propensity to connect to the grid. Table 6 shows that revenue village typical grid supply hours has a positive but statistically insignificant relationship with enterprise grid connection likelihoods. Similarly, completeness of electrification in terms of connection of all revenue village hamlets appears to have a positive but statistically insignificant relationship to the likelihood of rural enterprise grid connection. Due to the wide confidence bands of these point estimates, a general trend indicating that better supply reliability is associated with higher incidence of enterprise grid connection as indicated by the literature cannot be explicitly inferred and suggests instead that this relationship is modified by the wealth and scale of enterprise, among other factors. A review of the stated reasons for not connecting to the national grid, shown in Fig. 2, supports this hypothesis. It is evident that the main two reasons for not connecting have nothing to do with supply quality, rather these are directly linked to wealth constraints and a perception of poor affordability.

It appears that MSE wealth and supply affordability, rather than grid supply quality are important covariates of MSE propensity to connect to the national grid. Next, we consider the fact that a substantial sub-set of grid-connected MSEs also rely on off-grid supply technologies. Is the variation in grid supply quality related to the propensity for grid-connected MSEs to secure off-grid backup supply? The regression

Table 6
Results from the linear probability models linking the likelihood of enterprise grid connection with revenue village grid supply reliability. Coefficients indicate the estimated percentage change in likelihood (β_x*100) of enterprise grid connection given a two-standard deviation increase in the numeric explanatory variable or the equivalent presence of a dummy variable. The relevant standard deviation data can be found in Table 4. Robust standard errors are clustered at district level.

Dependent Variable:	Grid connected		
Model:	(1)	(2)	(3)
Variables			
Village typical grid hours	0.112*	0.105*	0.087
	(0.060)	(0.057)	(0.055)
Village households		−0.028	−0.033
		(0.035)	(0.032)
Village marketplaces		0.0006	−0.001
		(0.024)	(0.022)
All hamlets grid connected		0.104	0.087
		(0.068)	(0.068)
Village share BPL households		−0.055**	−0.040
		(0.026)	(0.026)
Floor area			0.056**
			(0.023)
Salaried employees			0.060***
			(0.020)
Building owned			0.049*
			(0.026)
Building pucca			0.242***
			(0.041)
Fixed-effects			
State (4)	Yes	Yes	Yes
Enterprise Category (7)			Yes
Fit statistics			
Observations	2,004	1,994	1,994
R^2	0.23481	0.24578	0.31869
Within R^2	0.01049	0.02359	0.09996

One-way (District) standard-errors in parentheses.
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

coefficients shown in Table 7 suggest otherwise, indicating that, once again no conclusive relationship between grid supply characteristics and MSE propensity to secure off-grid backup supply. This naturally does not imply that supply reliability is adequate for all MSEs, nor does this imply that off-grid backup supply prevalence is exogenous to grid supply reliability, as we can see by the sign of the coefficients. In-fact, less than 5% of the sampled villages report supply of greater than 20 h per day on average, suggesting a broad need for backup solutions to secure reliable supply. Rather, this result suggests once again that MSE wealth is a crucial factor in describing needs for and capacity to acquire back-up solutions. Fig. 3 describes MSE characteristics across electrification group. Here we note that MSEs using both the grid and an off-grid

Table 7
Results from the linear probability models linking the likelihood of grid-connected enterprises securing off-grid backup supply with revenue village grid supply reliability. Coefficients indicate the estimated percentage change in likelihood (β_x*100) of enterprise off-grid backup supply given a two-standard deviation increase in the numeric explanatory variable or the equivalent presence of a dummy variable. The relevant standard deviation data can be found in Table 4. Robust standard errors are clustered at district level.

Dependent Variable:	OG backup		
Model:	(1)	(2)	(3)
Variables			
Village typical grid hours	−0.026	−0.012	−0.018
	(0.050)	(0.048)	(0.043)
Village households		0.049	0.034
		(0.032)	(0.030)
Village marketplaces		−0.048*	−0.045*
		(0.024)	(0.025)
All hamlets grid connected		−0.129	−0.136*
		(0.080)	(0.073)
Village share BPL households		−0.053	−0.052
		(0.046)	(0.044)
Floor area			0.054**
			(0.022)
Salaried employees			0.110***
			(0.030)
Building owned			0.037
			(0.038)
Building pucca			0.048
			(0.038)
Fixed-effects			
State (4)	Yes	Yes	Yes
Enterprise Category (7)			Yes
Fit statistics			
Observations	1,307	1,299	1,299
R^2	0.08534	0.09663	0.15739
Within R^2	0.00051	0.01416	0.03832

One-way (District) standard-errors in parentheses.
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

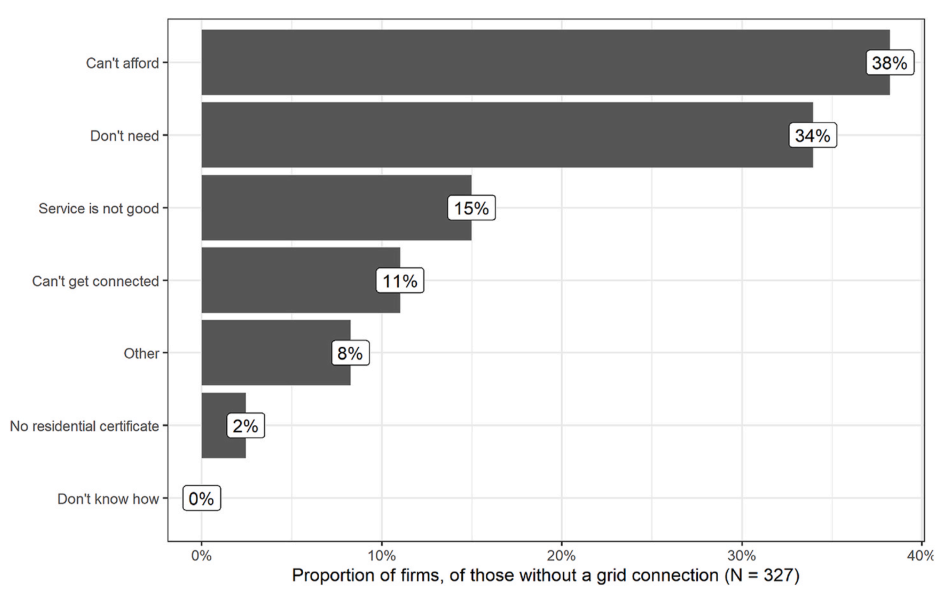

Fig. 2. Stated reason for not connecting to the national grid. This visualisation only reflects those firms in villages which do not have a minigrid and are fully grid electrified across all hamlets (N = 327). The proportions can sum to over 100% as firms could select multiple reasons.

backup solution are broadly wealthier, own higher power appliances, and consume more electricity than those using the grid alone. Taken together, this suggests that poorer and smaller MSEs in our sample are less likely to be able to afford an off-grid backup solution, and may not (yet) require 24 h electricity supply for their operations.

Finally, we explore whether grid supply quality is associated with grid electricity consumption. Table 8 shows that rural MSE electricity consumption is once again less related to grid supply reliability and more linked to wealth constraints and other unobserved factors. This aligns with the covariates of grid connection and propensity to secure off-grid backup supply described above, suggesting once more that grid supply reliability is not the primary constraint hindering grid connection and utilisation across our sample of rural MSEs.

4.2. Understanding productive electricity use

The effective exclusion of revenue village grid supply reliability as a determinant of rural MSE grid connection and utilisation in our sample provides a starting point into understanding electricity needs and growth constraints of micro- and small non-farm enterprises in rural northern India. We now explore how both grid-connected and off-grid MSEs consume electricity in order to gain a clearer picture of their needs and how this may relate to our regression results. We first focus on MSEs using electricity in some way (N = 1,744), categorised into two groups, those that use the grid (including those with off-grid backups), and those only using off-grid solutions.

Fig. 4 describes the extensive and intensive margins of energy services use and electricity consumption across grid-connected and off-grid MSEs. It is evident that both grid- and off-grid productive electricity use among our sample of MSEs is typically very low. Only 42% of grid-connected MSEs use appliances beyond lighting and fans which drops to just 18% among off-grid MSEs. 75% of grid-connected firms own less than 200 Watts of appliances, consuming on average just over 30 kWh per month. Utilisation is lower among off-grid firms, where 75% own less than 80 Watts of appliance, consuming less than 15 kWh per month.

We know from our earlier regression analysis that supply quality is unlikely to determine MSE grid-connection, nor the propensity to consume electricity for grid-connected firms. It follows that the energy service utilisation shown here is a reflection of MSE needs and capabilities, rather than constraints imposed by grid- or off-grid supply characteristics. That is, firms that are currently off-grid would not necessary consume any more electricity were they to be grid connected.

Table 8
Results from the linear regression models linking grid-connected enterprise electricity consumption (log transformed) with revenue village grid supply reliability. The coefficients presented are approximate estimates for a percentage change in monthly kWh consumed given a two-standard deviation increase in the numeric explanatory variable or the equivalent presence of a dummy variable. The relevant standard deviation data can be found in Table 4. Robust standard errors are clustered at district level.

Dependent Variable:	Log Monthly kWh		
Model:	(1)	(2)	(3)
Variables			
Village typical grid hours	0.138	0.135	0.117
	(0.103)	(0.104)	(0.089)
Village households		−0.034	−0.061
		(0.068)	(0.068)
Village marketplaces		−0.054	−0.055
		(0.051)	(0.054)
All hamlets grid connected		0.048	0.056
		(0.129)	(0.123)
Village share BPL households		−0.049	−0.025
		(0.088)	(0.076)
Floor area			0.151
			(0.094)
Salaried employees			0.247***
			(0.066)
Building owned			0.059
			(0.057)
Building pucca			0.369***
			(0.077)
Uses OG Backup			0.199***
			(0.047)
Fixed-effects			
State (4)	Yes	Yes	Yes
Enterprise Category (7)			Yes
Fit statistics			
Observations	1,307	1,299	1,299
R^2	0.04290	0.04597	0.25827
Within R^2	0.00254	0.00425	0.06878

*One-way (*District*) standard-errors in parentheses.*
Signif. Codes: ***: 0.01, **: 0.05, *: 0.1.

Do we observe any distinct utilisation trends across firm categories? We take the same sample of firms as that described above and restrict this to enterprise categories where we have recorded at least 20

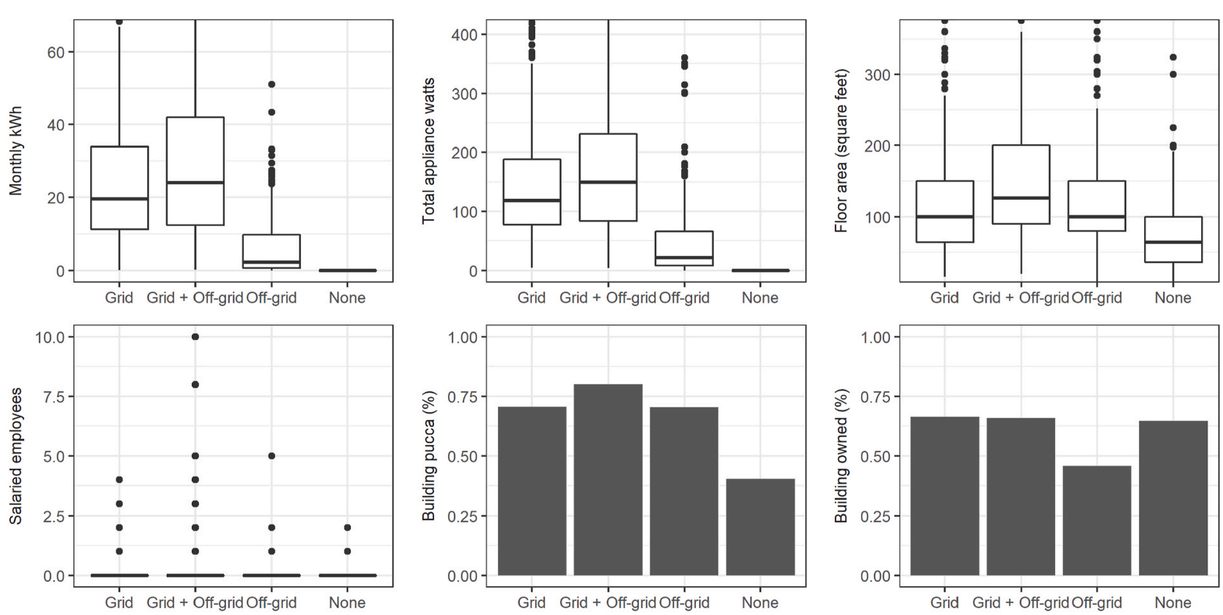

Fig. 3. Boxplots describing MSE characteristics by electrification group. Building ownership and quality (pucca) are shown using group-level means.

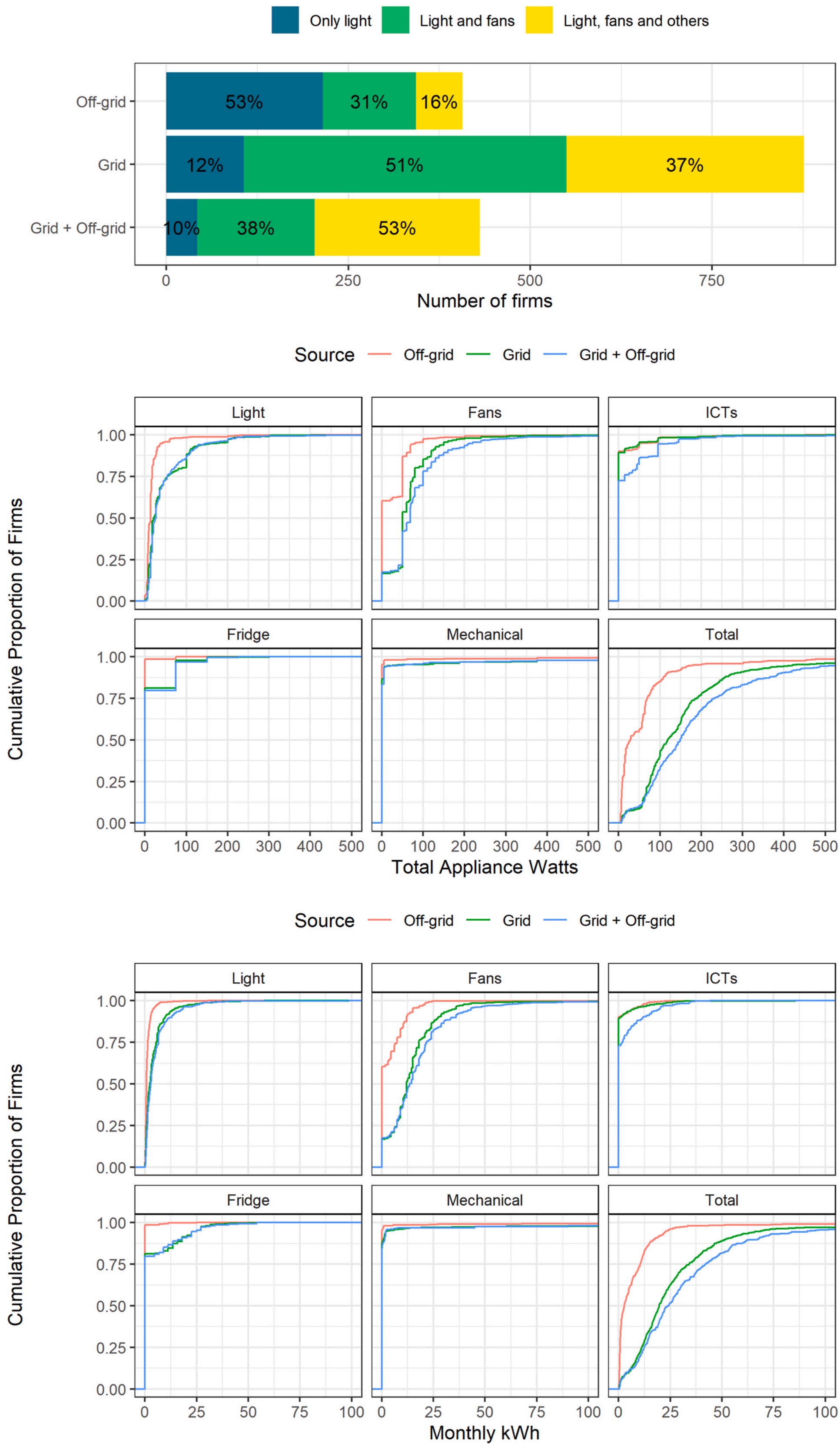

Fig. 4. Grid-connected and off-grid enterprise energy service utilisation and corresponding electricity consumption. Top: The number and proportion of enterprises using different groups of energy services. Bottom: Empirical cumulative distribution function plots of the total appliance-watts owned and monthly electricity consumption across energy services groups.

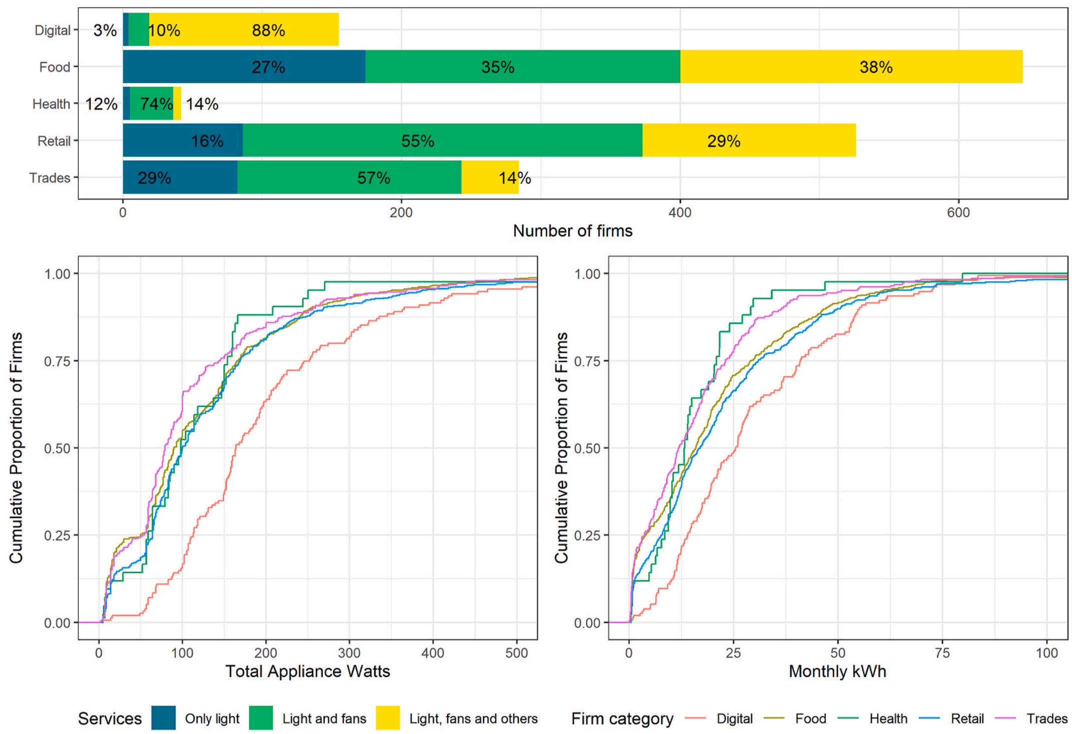

Fig. 5. Enterprise energy service utilisation and corresponding electricity consumption by enterprise category. Top: The number and proportion of enterprises using different groups of energy services. Bottom: Empirical cumulative distribution function plots of the total appliance-watts owned and monthly electricity consumption.

observations, thus excluding the *Misc* and *Agri* categories and leaving 1,653 firms (see Table 2 for a summary of enterprise categories and counts). Fig. 5 shows that Digital firms, such as cyber cafes and photo-studios are intuitively more likely to consume a more diverse set of energy services and therefore own more appliance-watts and consume more electricity overall. This is followed by Retail and Food categories, which present similar distributions of electricity consumption, and finally Trades and Health categories which consume slightly less electricity on average. The main intuition we derive here is, that the categories of MSEs in our sample face similar wealth constraints modifying their electricity needs and capabilities. That is, while we note some differences in utilisation driven by category such as that between Digital and Trades MSEs, it remains quite low across the board, barely exceeding 1 unit per day for 75% of firms in any category. This points once more towards our wealth hypothesis, which remains the most likely determinant of utilisation across the factors we consider within our sample of MSEs in rural northern India.

5. Conclusion and policy implications

In this paper, we describe the relationship between rural micro- and small-enterprise (MSE) productive electricity use and grid electricity supply using survey data gathered from 200 rural revenue villages across selected districts in Bihar, Rajasthan, Uttar Pradesh and Odisha.

Despite all surveyed revenue villages being grid connected, 34% of the 2,004 enterprises sampled do not have a grid connection. Using a linear probability model with state and enterprise-category fixed effects, we find no conclusive relationship between grid supply hours and enterprise grid connection likelihoods. Rather, enterprise wealth characteristics appear to be more directly linked. This is an especially notable result as the literature warns of methodological challenges in cross-sectional analysis due to endogeneity between grid electricity quality and general development trends that may also drive firm performance outcomes, resulting in spurious correlations (Lee et al., 2020 a). In spite of these expected spurious correlations, we find only a weak albeit positive relationship between supply reliability and MSE grid connection, suggesting indeed that other barriers to connection are evident. In interpreting the policy implications of this result, we must acknowledge that the policy question of whether to extend the grid out into rural areas in India is now mute, nevertheless, it is relevant to take stock of the evidence indicating that grid-connection among MSEs in rural areas remains low not due to supply reliability constraints, but rather due to wealth constraints and a perception of poor affordability.

Rural MSEs that do decide to connect to the national grid nevertheless consume very little electricity. Indeed only a minority of the surveyed grid-connected MSEs (42%) use energy services beyond lighting and fans. 75% of grid-connected firms consume less than 30 kWh per month, the same share of off-grid firms consume less than 15 kWh per month. These results support the hypothesis of a wealth barrier to productive electricity consumption. The policy implications of these findings are two-fold. First low consumption and corresponding revenues may weaken to rural distribution companies' ability to maintain the expanded rural electricity distribution network following the recent electricity policy reforms. Second, the anticipated development impacts of expansive rural grid electrification policies may not materialise, at least with respect to rural MSEs in the states we assess in the short term.

Our work indicates that these consumption trends are unlikely to be related with grid supply reliability constraints. The distribution of enterprise types in our sample hints at this broader challenge, in that manufacturing enterprises, typically associated with productive electricity use, remain in the minority relative to retail sector enterprises. This strongly suggests that other barriers to productive electricity use beyond supply reliability deserve far more attention in rural areas of the states in question. Examples of such barriers to growth requiring policy intervention could include inefficient or lack of distribution chains to larger markets (pull) or the availability of working capital for smaller potentially unbanked MSEs to expand operations (push). Both of these aspects are likely to intersect in rural areas, resulting in the prevalence of local demand serving enterprises with limited growth potential, such as the retail sector observed in our sample. Policy interventions addressing credit barriers are already taking shape following calls for increasing support to the MSME sector in response to the devastation caused by the

COVID-19 pandemic around India, most prominently under the Government's *Self-reliant India* Campaign announced on May 17, 2020, as well as more recent efforts to incentivise MSMEs to integrate into the formal banking system in order to access more affordable credit streams lead by the Reserve Bank of India (RBI, 2021). Such interventions could also be complemented through better supply chain integration around strategic industrial clusters in tier 2 cities, creating the market pull forces necessary for MSME growth (see Fetter and Usmani (2020)) and corresponding increases in productive electricity consumption.

Future policy intervention should also address barriers related to the provision of low-cost decentralised renewables as electricity supply solutions for smaller firms. These systems can enable provision of basic energy services at lower cost than the true cost of grid-connection, and satisfy MSE energy service needs until these increase sufficiently to warrant the latter. Our analysis shows that an impressive share of MSEs in our sample (44%) already seek out off-grid solutions as a backup or when the grid is perceived as too costly. Nevertheless, these technologies still remain out of reach for fledgling MSEs without the capital or access to credit necessary to pay the upfront costs. The argument for the formal integration of off-grid systems as complementary electrification solutions in lower income and rural regions is growing (see Blimpo and Cosgrove-Davies (2019); Grimm et al. (2020); Sievert and Steinbuks (2020); Lee et al. (2020 *a*)), our findings support this argument from the perspective of productive electricity use among rural MSEs in North India.

Overall, more work is necessary to understand what complementary infrastructure needs and reform preferences look like among rural MSEs in rural northern India, and to monitor their development over time. The evidence we present indicates that India's progressive electrification policy driving rapid rural grid expansion may not have the desired growth impacts among rural MSEs in the absence of other complementary infrastructure and initiatives to ease wealth constraints, at least in the short term.

CRediT authorship contribution statement

Setu Pelz: Conceptualization, Methodology, Formal analysis, Visualization, Validation, Writing – original draft, Writing – review & editing. **Michaël Aklin:** Supervision, Conceptualization, Methodology, Writing – review & editing. **Johannes Urpelainen:** Supervision, Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2021.112401.

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