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Working Paper: Is walk-though energy auditing effective for micro and small enterprises? Evidence from a randomised experiment in Addis Ababa

This paper provides the results of a randomised control trial (RCT) that was conducted to understand the impact of walk-through energy audits on the energy consumption of micro and small-sized firms in Addis Ababa, Ethiopia.

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Is walk-though energy auditing effective for micro and small enterprises? Evidence from a randomised experiment in Addis Ababa

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Abstract

Information problems may limit firms' adoption of energy-efficient production processes and technologies. Such problems can potentially be reduced via energy audit programmes. In this study, walk-through energy audits were randomly assigned to and carried out in 400 out of 1,000 micro and small enterprises in Addis Ababa, Ethiopia, to assess their effects on energy consumption. Six months after the audit, half of the audited firms were revisited to conduct visual checks regarding implementation of the audit recommendations. Energy auditing was found to reduce electricity consumption by 10% and energy auditing plus a revisit resulted in a 2% additional reduction. Audited and revisited firms were also 14% and 22% more likely to be using energy star appliances at end line than non-audited firms. Overall, the measured savings, compared to the total cost of production and firms' profit, are not economically significant from the firm perspective, though they may provide benefits to the grid system as a whole.

Key words: Energy audit, Ethiopia, Addis Ababa, randomised trial, electricity consumption.

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1 Introduction

Energy is an essential factor of production and its inefficient use can reduce firms' competitiveness. Studies have shown that micro and small enterprises are less energy efficient than large enterprises, perhaps due to lower awareness of the energy intensity of their behaviour, as well as lower pressure to conserve electricity from policymakers and other stakeholders (Mulugetta, 2008; Cagno *et al*., 2010; Bazilian *et al*., 2011). The most commonly cited barriers to improved energy efficiency relate to market failures caused by high information and transaction costs, hidden costs, financial and technological risks, capital market restrictions, split incentives, and organisational and behavioural constraints (Brown, 2001; Eyre, 1997; Howarth and Andersson, 1993; Jaffe and Stavins, 1994a,b; Sorrel et al., 2004; Stern, 1986; Kalantzis and Revoltella, 2019).

Among the problems listed above, informational market failures[1] are often considered a major reason for firms' lack of adoption of seemingly profitable energy-efficient technologies. Energy audit programmes, which are now common in many countries, address this issue directly by providing enterprises with highly specific information on ways to be more energy efficient and to conserve electricity (e.g. the European member states' energy audit programmes for small and medium-sized enterprises (SMEs)).[2] In general terms, an energy audit is a process that analyses energy consumption within a facility (i.e. estimates how much energy is lost/used and tries to identify the main reasons for those losses) and then provides the energy consumer with a menu of potential interventions to reduce consumption. One very simple energy audit is a walk-through inspection, during which a trained inspector visits a specific facility to identify maintenance, operational, or equipment issues that are deficient, and to potentially highlight areas that warrant further investigation or evaluation. This type of inspection does not attempt to make major changes in the structure of the audited firm, and all changes made by a participating facility are voluntary (Leonardo Energy, 2021).[3]

Although energy audit programmes are now well-established and commonplace in Europe and the US, they are still very new in many low-income countries. In Ethiopia, for example, the only institution that provides an energy auditing service is the government regulator, the Ethiopian Energy Authority (EEA), and this service is mainly provided to large manufacturing firms that consume very substantial amounts of electricity. The EEA recently developed an Energy Efficiency Programme and Activity Plan (EEA, 2020), within which energy auditing of industries and buildings form key components. Participation by industries has thus far been voluntary, and the agency has established voluntary agreements with a number of major industries. However, in the long run the EEA is considering mandating such audits (EEA, 2020). In addition, micro and small manufacturing enterprises have thus far not been included, despite the fact that these enterprises constitute more than 50% of all firms in Ethiopia and consume about one-third of the country's electricity supply (Hassen *et al*., 2018).

Given the significance of these neglected firms in terms of electricity consumption, this study aimed to understand the impacts of a simple energy auditing programme on micro and small enterprises in Addis Ababa, the capital city of Ethiopia. We consider the effects of a walk-through energy auditing programme on micro and small enterprises' adoption of energy efficiency measures and on electricity consumption.

A growing number of studies have analysed the impacts of energy audit programmes, but nearly all such studies have taken place in industrialised countries (e.g. Harris *et al*., 2000; Kalantzis and Revoltella, 2019; Kontokosta *et al*., 2020). For example, Harris *et al*. (2000) found that about 80% of Australian firms were willing to adopt energy-efficiency measures after taking part in a subsidised energy audit programme. Anderson and Newell (2004) found that rates of adoption of measures suggested by energy audits were close to 50% in the US. Energy audit programmes among SMEs and non-energy-intensive industries in Germany (Schleich, 2004; Fleiter *et al*., 2012; Schleich and Fleiter, 2017) and in Sweden (Thollander, 2007) were also considered successful, with estimated implementation rates for suggested improvements of 77% and 40%, respectively. To the best of our knowledge, there are no similar studies from low-income countries.

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[1] In general, information market failure is a type of market failure whereby individuals or firms have a lack of information about economic decisions. This includes information asymmetries – where one party has access to information that another party does not, lack of education/awareness, failure to disclose information (i.e. agents may not make full disclosure), moral hazard (i.e. individuals alter their behaviour because of certain guarantees) (for details click here). In this particular case, the term is referring to a lack of education/awareness.

[2] https://leap4sme.eu/wp-content/uploads/2021/07/LEAP4SME-D2.2-Mapping-SME-energy-policies-in-Europe.pdf

[3] The targeted assessment in such audits typically pays specific attention to areas within the business that have the highest energy-saving potential. More comprehensive audits are more suitable for multiple retrofit/upgrade projects that allow for radical changes to be made in energy-consuming behaviour.

Many existing studies of the impacts of energy audits (e.g. Kalantzis and Revoltella, 2019) also suffer from methodological challenges due to reliance on observational data and threats to inference arising from unobserved differences between treated (audited) and control (unaudited) firms. These studies may also be subject to sample selection bias whereby companies participate in auditing especially when they perceive that there is value in adopting energy efficiency measures. Firms not participating may also differentially adopt high-cost energy efficiency measures that ultimately harm their relative productivity and competitiveness. If these factors are not addressed in an impact evaluation, the unobserved differences and sample selection problems are likely to deliver misleading findings on the effect of energy audits.

The rest of the paper is organised as follows. Section 2 discusses the data and the implementation of the energy audit experiment; Section 3 presents the empirical strategy of the study; Sections 4 and 5 provide the descriptive and econometric results of the study; and the last section concludes.

2 Data and description of the experiment

2.1 Data

This study leverages a panel dataset comprising pre- and post-experiment survey data. A baseline survey of micro and small manufacturing enterprises was conducted in December 2016 and May 2017 in 10 of Ethiopia's largest cities (Addis Ababa, Adama, Jimma, Bahir Dar, Gondar, Dessie, Dire Dawa, Jigjiga, Mekelle, and Hawassa), located in seven regional states of Ethiopia. The baseline survey was conducted as part of the 'Entrepreneurship and Small Business Development (ESBD) Research Programme', a project that aimed to generate data and knowledge on small business development in Ethiopia, with a focus on micro and small firms in the manufacturing sector (Gebreeyesus *et al*., 2018). The energy study was an integral part of that project.

During the baseline survey, data were collected from 8,174 micro and small enterprises located in the 10 sample cities. Since the firms were randomly selected from firms in these cities, the selected sample is representative of micro and small firms in urban Ethiopia. Of the 8,174 firms, 3,310 (40.5%) were considered microenterprises (having five or fewer employees), 4,553 (55.7%) were small enterprises (six to 30 employees), and 311 (3.8%) were enterprises in the medium-size category (31 to 100 employees) (Gebreeyesus *et al*., 2018). In selecting the original sample, micro and small enterprises were randomly selected from the list of all micro and small enterprises. Medium enterprises were not initially part of the survey; however, some of the firms had been categorised as small in the pre-survey but were found to be medium-sized during data collection.

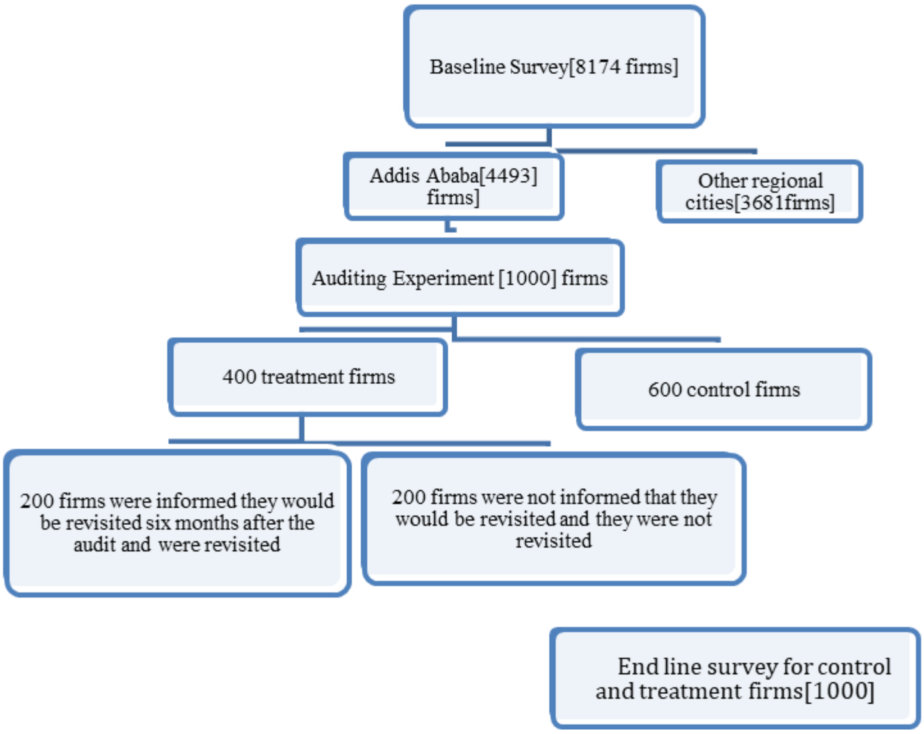
In the follow-up survey in 2020, due to resource limitations, the survey was repeated only in Addis Ababa and the sample size was reduced to 1,000 of the 4,493 original respondents. Before selecting the 1,000 firms, following the advice of energy audit experts from the EEA we decided to focus on firms with relatively high electricity consumption. Based on this advice and on the baseline data, we found that firms that engaged in metal- and wood-working activities were the groups with the highest electricity consumption. From the list of these types of firms, 1,000 were randomly selected with probability of selection proportional to firm size. Of these, 787 were micro and 213 were small, which is similar to the proportions from the baseline survey in Addis Ababa (in the baseline survey about 73% of the firms were classified as micro and about 27% were small).

2.2 The energy audit experiment

The energy audit experiment was conducted in cooperation with the EEA, which is a government agency tasked with regulating the energy sector, improving energy efficiency and conservation, and facilitating private sector investment in the energy sector in the country. The walk-through energy audit service was conducted by experts from the EEA, as there is no private company that provides such auditing services in Ethiopia. Of the 1,000 firms randomly selected to participate in the follow-up survey, and based on the budget and human resource capacity available for conducting the audits, 400 firms were randomly assigned to receive the energy audit, with the remaining 600 in the control group.

We also split the audited group into two separate treatment groups (n=200): all 400 of these firms received the same walk-through audit, but half of the firms were also assigned to receive a second follow-up visit from the EEA inspector to assess implementation of the energy efficiency measures that had been recommended during the initial audit visit. These revisited firms were informed during the initial audit that a follow-up would be conducted after six months. The motivation for this additional treatment was three-fold. First, it allowed us to determine more definitively if the firms had actually made specific changes in response to the audits, and to understand the extent of those modifications, given that the literature suggests varying compliance with audit recommendations (Harris *et al*. 2000; Anderson and Newell, 2004). Second, it was considered that this additional visit might act as an additional nudge to firms to follow through on the recommendations, and thereby enhance the treatment effect of the audits. Third, and related to this, from a policy perspective, an important question is whether additional monitoring is needed after auditing, and whether this is cost-effective. Figure 1 summarises the experiment design.

Figure 1: Experiment design



The sample size for the experiment was informed by power calculations conducted prior to implementation of the experiment. Baseline data (from the 2016 survey) in the sample indicated that the average electricity consumption among the micro and small enterprises was about 594 kilowatt hours (kWh) per month, with a standard deviation of 120kWh. Assuming a 5% significance level, 80% power, equal standard deviations in each group, and a 10% effect size (Schleich and Fleiter, 2017), we obtained a total sample size of 726 for three groups of equal size (n=242): two treatments and one control.[4] Given the constraints on the number of audits that could be conducted (n=400), we increased our overall sample size to 1,000, by oversampling somewhat in the control group. Thus, we are slightly underpowered for measuring a 10% difference in the comparison of the two treatment groups, but we are well powered for a single treatment versus control comparison (pooling the two treatment groups), and also gain additional power for independent tests of equality of each treatment group on its own, versus the control.

During the audits, the treated units were provided with firm-specific recommendations on how to reduce their electricity consumption. The most common energy efficiency and conservation recommendations provided by the experts are summarised in Table 1.

[4] This power analysis was conducted to determine if the available survey and intervention resources would be sufficient to achieve the study's objective of estimating the expected treatment effect of the audit on energy consumption. The determination of the sample size depends on the study design (randomisation level), significance level (α) (which we assume to be 5%), power ($1-\beta$) (which we assume to be 80%), standard deviation (σ) of the control and treatment (usually assumed to be same), and anticipated effect size ($\partial = (\mu_T - \mu_C)/\sigma$ for one mean test and $\partial = (\mu_T - \mu_C)/2\sigma$ for two mean tests, where μ_T is the mean for the treatment group and μ_C is the mean for the control group).

Table 1: Energy efficiency and conservation recommendations

S.N.	Energy saving measures	Description
1	Preventive maintenance	The savings associated with the maintenance of a machine can range from 2% to 3% of total motor system energy use.
2	Methods for starting motors	Using star delta or soft starter starting methods instead of the direct on line starting[5] method for motors greater than 7.5KW.
3	Controlling motor loading	-Avoiding oversized motors, especially motors operating below a 50% rated load. Such motors have lower efficiency and should be replaced with more appropriate ones. -For variable and small-loaded motors, it is advisable to use variable speed drive (VSD).
4	Measures to make sure that motor efficiency does not change substantially after rewinding	When motors are rewound frequently, their efficiency decreases. Checking the stability of motor efficiency after rewinding helps diagnose potential problems.
5	Checking voltage imbalance	When voltage imbalance occurs, the lifetime of a motor decreases. Ensuring that voltage imbalance does not exceed 1% helps avoid potential problems.
6	Using energy star electronic appliances	Energy efficiency levels of electronic appliances are categorised as energy star level or non-energy star level. The energy star symbol is available on the packaging of appliances and was shown to firms during the audit.
6	Replacement of lamps with efficient lamps	Replacing inefficient lamps with light-emitting diodes (LED) or compact fluorescent lamp (CFL) lights can save significant amounts of energy.
7	Type of ballast used in fluorescent lamp	Replacing the magnetic ballast of T12 fluorescent lamps with electronic ballast and tube T8 fluorescent lamps can reduce energy use by 10%.
8	Natural light from transparent roof tiles and walls	Using transparent roofing and wall materials allows for natural lighting and reduced use of lamps during daytime hours.

3 Empirical strategy

The study has two primary outcome variables. The first is the adoption of the energy efficiency measures and energy conservation methods described in the above table; this outcome level is represented by binary indicators (Adopt) that are equal to 1 if the firm adopted the particular conservation and efficiency measure, and 0 otherwise. The second outcome variable is a continuous variable that measures firms' electricity consumption, which is measured in kWh. The main explanatory variable is the walk-through energy audit treatment (*Audited*), which takes a value of 1 for treatment firms (audited firms) and 0 for unaudited firms. In the treated sub-sample, half of the firms also received a second visit (as well as being informed during the walk-through that they would be revisited). Hence, a second explanatory variable, *Revisit*, takes a value of 1 for audited firms that were subject to the revisit, and 0 for control firms.

Information on electricity consumption in both the baseline and follow-up surveys was collected based on the firms' electricity bills. The dependent variable for the electricity consumption variable is log-transformed to ease interpretation.

[5] A star delta starter is a type of reduced voltage starter. It is used to reduce the starting current of a motor without using any external device or apparatus. When the motor reaches about 80% of its full load speed, it will begin to run in a delta connected stator winding. In contrast, direct on line (DOL) motor starting is when a motor is started at full load, with full line voltage applied to motor terminals. This causes the motor to draw a large amount of current (for details click here).

We apply a fixed effects regression model to estimate the effect of the walk-through energy audit and revisit treatments on adoption and electricity consumption, as shown in the equations below:

$$logCElec_{it} = \alpha + \beta_{10}Audit_{it} + \beta_{12}Post_t + \delta_1 X_{it} + \varepsilon_{it} \quad (1)$$

$$logCElec_{it} = \alpha_2 + \beta_{21}Revisit_{it} + \beta_{22}Post_t + \delta_2 X_{it} + \varepsilon_{it} \quad (2)$$

$$logAdopt_{it} = \alpha_3 + \beta_{31}Audit_{it} + \beta_{32}Post_t + \delta_3 X_{it} + \varepsilon_{it} \quad (3)$$

Where $logCElec_{it}$ is the logarithm of electricity consumption in kWh for year *t*, *Audit* is the indicator representing whether the firm is audited or not, *Post* is an indicator for the post-intervention time period (or follow-up survey), *Adopt* is the binary indicator that is equal to 1 if the firm adopted any of the recommendations, *Revisit* is a binary variable that takes a value of 1 if the audited firm was subject to a second visit, and 0 for control-. The subscripts *I* and *t* represent each firm and time of the survey (2016[6] and 2020), respectively, and the variable X represents time-varying firm characteristics.

The effect of energy audit interventions is measured by the coefficient β_{10} (for electricity consumption) and β_{31} (for adoption) in equations (1) and (3) above. In addition to the energy audit treatment, the audited firms are differentiated by revisits. Thus, we also estimate the effect of revisits on the adoption of the energy efficiency and conservation measures.

$$Adopt_{it} = \alpha_4 + \beta_{41}Revisit_{it} + \beta_{42}Post_t + \delta_4 X_{it} + \varepsilon_{it} \quad (4)$$

Where the coefficient β_{41} measures the effect of this additional treatment (*Revisit*) on the use of any of the energy efficiency and conservation activities.

4 Descriptive statistics and basic results

As stated in Section 2 above, only 1,000 firms were randomly selected for the 2020 follow-up survey. For the follow-up survey, only metal- and wood-working firms were purposively selected for the energy audit intervention. As a result, about 54% and 43% of the sample firms engage in wood- and metal-work activities, respectively, while in the original baseline survey these firms in Addis Ababa constituted about 24% and 21% of the total sample, respectively. Although all firms were initially selected because they were wood- and metal-work firms, in the follow-up survey, about 3% firms were found to be engaged in food and leather production activities.

Table 2: Economic activities of sample firms from Addis Ababa

Firm type	2016 sample (4,493 firms)	2020 sample (1,000 firms)
Wood-work	24%	53.89%
Metalwork	21%	43.21%
Food and beverages	25%	2%
Garments	14.36%	0%
Leather and leather products	2.92%	0.89%
Other	15.55%	0%
Total	**100.00%**	**100.00%**

Table 3 shows the mean revenue and mean costs of the sample firms in 2016 and 2020. As shown in Table 3, the sample firms made about 17% profit (profit to cost ratio) in 2016 and only 4% in 2020. The decline in profit could be related to the overall

[6] Note that the baseline was conducted between 2016 and 2017, which means that it stared at the end of 2016 and ended in early 2017. Here, we simplify the terminology to 2016 to represent the baseline.

economic slowdown in the country. Labour and material costs constituted about 96% of the total cost in 2016 and about 78% in 2020. Electricity costs account for less than 1% of the total cost of production of the firms.

Table 3: Revenue and costs of firms

	2016	2020
Annual average revenue in ETB[7]	960,783.2	946,522.3
Annual average cost in ETB	819,022.9	908,232.1
Annual average profit8 in ETB	141,760.3	38,290.2
Profit percent ((profit/cost) x 100)	17%	4%
Share electricity in the total cost	0.3%	0.4%
Share other utilities in the total cost	0.8%	0.7%
Share of labour cost in the total	20.0%	22.1%
Share of material cost in the total	75.7%	57.6%

Figure 2 shows the average electricity consumption measured in kWh and electricity cost of the non-audited firms in 2016 and 2020, the latter measured in ETB. This chart shows that the average electricity consumption of the non-audited firms increased by about 10% over the period, while the electricity cost increased by more than 100%. Although the electricity cost increased by more than 100%, this does not significantly change the share of electricity in the total cost (Table 3) as the firms' electricity consumption is generally low and the tariff was increased from a very low base.

Figure 2: Average electricity consumption (in kWh) and cost of non-audited firms

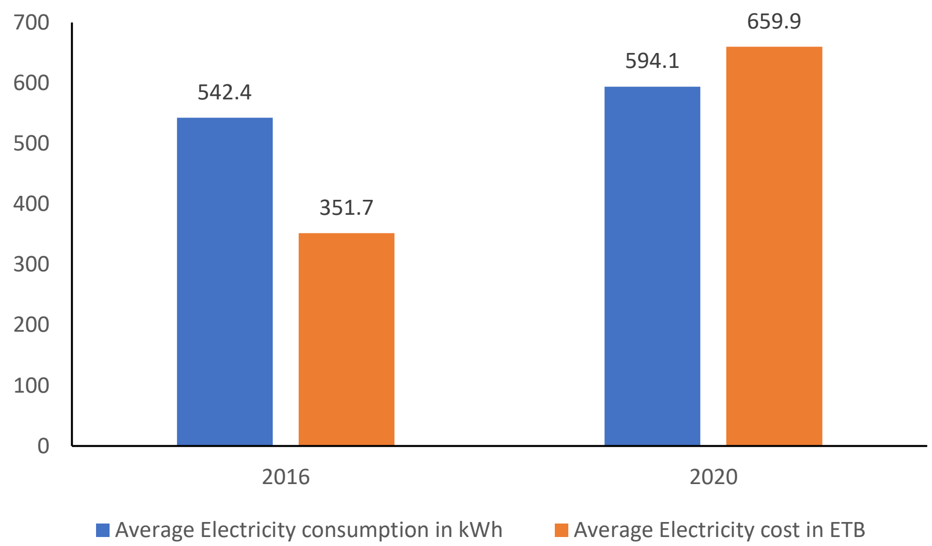
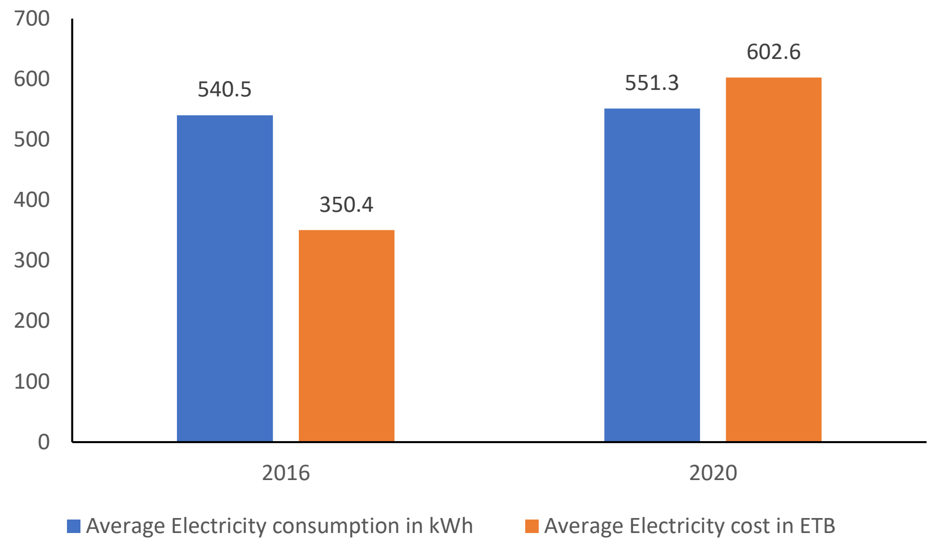


Figure 3 shows the electricity consumption and expenditure of the audited firms. The chart shows that the electricity consumption of the audited firms also increased in 2020, but only by about 2%, while the electricity cost similarly increased by more than 100%.

[7] ETB refers to Ethiopian Birr; the exchange rate was 1 US$ to ETB 39.3 at the time the survey was conducted in 2020. In 2016, on average, One USD was exchanged for 21.3ETB

[8] The profit is the pre-tax profit and does not take into account depreciation.

Figure 3: Average electricity consumption (in kWh) and cost of non-audited firms



The large increase in electricity costs for both audited and non-audited firms is due to a tariff reform that was implemented starting in 2018, which substantially increased electricity tariffs in an attempt to improve cost recovery for the Ethiopian Electric Utility Company. Comparing the two charts, we can also observe that the electricity consumption of both groups of firms increased in 2020, perhaps due to increased economic activity. At baseline, both audited and non-audited firms had nearly identical electricity consumption and costs. By 2020, however, the electricity consumption of non-audited firms was about 7% higher than that of the audited firms. Mean comparison tests for the year 2020, shown in Table 4, indicate that this difference is statistically significant at a 1% level of significance.

Table 4: Mean difference test of electricity consumption of audited and non-audited firms in 2020

Variable	Observations	Mean	Std. err.	Mean diff.	Std. err.
Audited firms	367	551.3	11.9	-42.8***	12.9
Non-audited firms	494	594.1	12.8		

In terms of cost, the above difference in electricity consumption means a reduction in electricity cost of ETB 42 per month, or ETB 504 per year, per firm in 2020. In terms of total cost of production, this constitutes about 0.06% of firms' total cost of production and 1.3% of their annual profit. Thus, a cost saving of less than 1% may not be economically significant. This may imply that the walk-through energy audit system, which is the simplest form of auditing, and relatively low-cost, while reducing electricity consumption, may not be economically significant for micro and small enterprises, whose electricity consumption is very low. Moreover, the tariff rate after the tariff reform remains quite low. Hence, it does not change firms' total costs significantly. Nonetheless, the results show that energy auditing has the potential to reduce electricity consumption, and the aggregate effect may have implications for the whole grid system in terms of reducing power overloads and power outages, from which Ethiopia suffers.

The follow-up survey was conducted six months after the 2020 audit (intervention). During the follow-up survey, the firms were asked if they had implemented the energy efficiency and conservation activities proposed in the prior 2020 audit. Table 5 shows the efficiency and conservation activities of control and treatment firms. As can be seen from this table, most of the treatment and control firms use energy-efficient light bulbs and regularly clean their machinery. However, about 5% and 9% more audited firms use energy-efficient light bulbs and clean their machinery, respectively, compared to non-audited firms. There is also a significant difference between audited and non-audited firms in terms of the use of energy star electronic appliances. No significant difference between the control and treatment firms is observed with respect to the use of translucent roofs, opening windows during daytime, the use of solar-based machinery,[9] or the use of energy-inefficient appliances.

An additional result not shown in the table is that 99% of control firms and 85% of treatment firms have been using the above efficiency and conservation measures for more than six months. The control firms also implement such activities independently of the energy audits. Nevertheless, auditing can motivate firms to implement such activities, by giving them direction on the most important efficiency and conservation activities they can undertake. About 15% the audited firms implemented the less costly efficiency and conservation activities within the six months (e.g. use of energy-efficient light bulbs, cleaning machinery).

[9] This was not initially included in the list of recommendations from the EEA. Later, the researchers provided suggestions to the EEA advisers and they agreed on the inclusion of this method in the survey questions. However, not many firms use such machinery.

Table 5: Energy efficiency and conservation measures taken by control (non-audited) and treatment firms (audited firms)

Variable	Control firms			Treatment firms			Mean diff.
	Observation ~	Mean	Std. dev.	Observation	Mean	Std. dev.	
Use of energy-efficient bulbs	598	86.45%	0.34	400	91.1%	0.29	4.65**%
Regularly cleaning machinery and compressors	598	83.28%	0.37	400	91.8%	0.27	8.52***%
Replaced machinery/compressor with new and energy-efficient one in the past 12 months	598	37.79%	0.49	400	42.3%	0.49	4.51%
Use of translucent roof	598	21.07%	0.41	400	22.3%	0.42	1.23%
Open windows during daytime to get natural light	598	18.81%	0.50	400	19.56%	0.50	5.70%
Use of energy star electronic appliances	551	33.21%	0.47	380	47.4%	0.50	14.19***%
Use of energy-inefficient appliances	598	33.2%	0.44	400	25.92%	0.47	0.75%
Use of solar-based machinery	598	0.33%	0.06	400	0.2%	0.05	-0.13%
How often does the firm rewind the machine?							
Every two weeks	411	0.00%	0.00		34.0%	0.00	34.00***%
Every month	411	1.70%	0.14	298	2.3%	0.15	0.60%
Every six months	411	25.30%	0.41	298	17.1%	0.38	-8.20***%
Every year	411	12.65%	0.35	298	17.4%	0.38	4.75%
More than a year	411	60.34%	0.49	298	62.8%	0.48	2.46%

The observation column in this table indicates the number of data points from the follow-up survey. The efficiency and conservation questions were not part of the baseline survey (2016 survey). These questions were asked in the 2020 survey. The data points include yes and no, where yes takes a value of 1 and no takes a value of 0. For example, for energy-efficient light bulbs, we only have responses from 598 control firms (two did not respond) and 400 treatment firms. Of the 598 firms, about 86% responded yes and the rest responded no.

Table 6 shows the descriptive statistics for the variables which are used as control variables in the regressions. As can be seen from this table, a large proportion of the firms are either partnerships or sole private ownership companies. In 2020, about 67% of the firms were located in industrial parks and about 79% were classified as micro enterprises, based on their numbers of employees.

Table 6: Summary statistics for firm characteristics

Variables	Base year [2016]			Follow-up [2020]		
	Observations	Mean	SD	Observations	Mean	SD
Location of the firm [in industrial park=1, Outside park=0]	1,000	0.44	0.50	1,000	0.67	0.47
Age of the manager [years]	1,000	39.15	9.34	1,000	41.90	9.33
Gender of the manager [1=male, 0= female]	1,000	0.94	0.24	1,000	0.94	0.24
Log of education level of the manager [number of years of education]	999	10.14	5.07	998	10.41	5.31
If the firm uses energy star appliances [1= yes, 0=no]	950	0.26	0.44	931	0.39	0.49
Separate meter [1= yes, 0=no]	998	1.21	0.41	997	1.23	0.42
Size of the firm [1= micro and 0=small]	1,000	0.73	0.44	1,000	0.79	0.41
Ownership of the firm						
Publicly owned [1= yes, 0=no]	1,000	0.00	0.00	1	0.00	0.03
Privately owned [1= yes, 0=no]	1,000	0.00	0.00	1,000	0.12	0.32
Share company [1= yes, 0=no]	1,000	0.05	0.23	1,000	0.05	0.23
Partnership [1= yes, 0=no]	1,000	0.34	0.42	1,000	0.40	0.49
Sole proprietorships [1= yes, 0=no]	1,000	0.47	0.50	1,000	0.42	0.49
Cooperative [1= yes, 0=no]	1,000	0.14	0.35	1,000	0.01	0.08
Other [1= yes, 0=no]	1,000	0.00	0.00	1,000	0.00	0.03

One of the requirements of the randomised trial experiment was that the treatment and control firms were selected randomly. Whether this was the case can be checked using the mean difference between the control and treatment variables with respect to the selected variables. The Stata software code *iebaltab* was used to calculate the mean differences between audited and non-audited firms for multiple outcome variables simultaneously. The results show that there was no significant difference between the audited and non-audited firms with respect to the selected characteristics at baseline, with the exception of the locations of the firms. In particular, there was no significant difference in the consumption of electricity between the audited and non-audited firms at baseline.

Table 7: Balance test using selected characteristics of firms at baseline

Variable	Control			Treatment		Yes	Difference
	N	Mean	SE	N	Mean	SE	(control)-(treatment)
Electricity consumption (kWh)	312	542.4	32.9	277	540.5	21.4	1.90
If the firm uses energy star appliances [1= yes, 0=no]	566	0.3	0.0	384	0.3	0.0	0.01
Location of the firm [in industrial park=1, 0= outside park]	598	0.4	0.0	400	0.5	0.0	-0.06**
Log of education level of the manager [number of years of education]	597	2.2	0.0	400	2.2	0.0	0.03
Separate meter [1= yes, 0=no]	595	0.8	0.0	400	0.8	0.0	-0.01
Ownership of the firm	598	4.5	0.0	400	4.5	0.1	-0.03

The values displayed for t-tests are the differences in the means across the groups.

***, **, and * indicate significance at the 1%, 5%, and 10% critical level.

5 Econometric results

Table 8 shows the results of the fixed effects regression estimations of the impact of the walk-through energy audits on firms' electricity consumption, which includes the effect of the audit and the revisit. Both electricity consumption data and information on the use of energy star appliances were collected in the baseline and follow-up surveys. Electricity consumption data were collected based on firms' electricity bills for the last month, where last month refers to the latest month's electricity bill during the time of the two surveys. As all of the firms are micro and small enterprises, their machinery is generally fairly basic, but certain appliances and lights may have energy star labels.

The results in Table 8 show that the walk-through energy audits resulted in a 10% reduction in electricity consumption relative to the non-audited group, controlling for the year and other characteristics listed in the table. A 10% reduction in electricity consumption represents about ETB 54 per month, relative to baseline consumption, though, as noted in the prior section, electricity consumption across the firms in the sample is increasing over time. In terms of economic significance, given the current depreciation of the Ethiopian Birr, the cost saving is equivalent to about one dollar per month, and this may not be economically significant given the small share of electricity cost in firms' cost of production. In particular, such modest savings may not be large enough to persuade firms to voluntarily invest in market-based energy audits, and to implement the recommendations of such procedures. The costs of auditing, which are equivalent to half a day's fee for an expert (at least ETB 1,000), and implementation, which may involve buying new items (e.g. light bulbs and chemicals for cleaning machinery), are expected to be much higher than the benefits of auditing (i.e. ETB 54 per month or ETB 648 per year).

Table 8: Fixed effect regression of the effect of auditing and revisiting on firms' energy consumption

Variables	Audited		Revisited	
	Coef.	Se.	Coef.	Se.
Audited firms [=1 if firm is audited and =0 if not audited]	-0.10**	0.05		
Revisited firms [=1 if firm is revisited and =0 if not audited]			-0.12**	0.06
If the firm uses energy star appliances [Yes=1, No=0]	0.11***	0.04	0.11***	0.04
Separate meter [Yes=1, No=0]	-0.00	0.02	-0.00	0.02
Ownership of the firm [=1 sole /partnership/share, 0=cooperative]	-0.04	0.05	-0.05	0.05
Time (=1 for post-intervention, 0= before intervention)	0.04***	0.01	0.05***	0.01
Constant	-77.78***	16.84	-67.35***	14.03
Observations	1,347		1,347	
R-squared	0.07		0.07	
Number of observations	858		858	

One recommendation from the walk-through energy audit was to undertake energy-efficient and conservation activities. The results in Tables 9 and 10 show that audited firms are 14% more likely to use energy star appliances than non-audited firms. Likewise, firms that were revisited are 22% more likely to use energy star appliances than non-audited firms. As a result, the electricity consumption of both audited and revisited firms is 11% lower than that of non-audited firms (Table 8). Further, audited and revisited firms are 8% more likely to use energy-efficient light bulbs compared to non-audited firms. In addition, the revisited firms are 7% more likely to open windows and to use natural light compared to control firms.

Table 9: Impact of energy auditing on efficiency and conservation measures [ordinary least squares (OLS) regression using follow-up data]

Variables	Energy star		Efficient bulbs		Machine replacement		Translucent roofs		Open windows		Energy-inefficient appliances	
	coef	se	Coef	se	coef	Se	coef	se	coef	se	coef	se
Audited firms [=1 if firm is audited and =0 if not audited]	0.14***	0.03	0.08***	0.02	0.03	0.03	0.01	0.03	0.05	0.03	-0.07**	0.03
Firm size [1= micro and 0=small]	0.06	0.04	-0.05*	0.03	-0.06	0.04	-0.14***	0.03	-0.13***	0.04	-0.01	0.04
Location of the firm [clustered=1, non-clustered=0]	0.01	0.04	0.01	0.02	0.05	0.03	-0.10***	0.03	0.04	0.04	-0.01	0.03
Log of education level of the manager [log of number of years of education]	-0.00	0.03	0.03	0.02	0.02	0.03	-0.01	0.03	0.01	0.03	0.01	0.03
Separate meter [1=yes, 0=no]	-0.05	0.04	-0.08***	0.03	-0.18***	0.04	-0.17***	0.03	-0.06	0.04	-0.11***	0.04
Ownership of the firm [=1 sole /partnership/share, 0=cooperative]	-0.02	0.02	-0.01	0.01	0.04***	0.02	-0.01	0.01	0.04**	0.02	-0.03**	0.01
Constant	0.42***	0.13	0.93***	0.08	0.39***	0.12	0.68***	0.10	0.48***	0.12	0.52***	0.11
Observations	924		994		994		994		994		994	
R-squared	0.03		0.04		0.04		0.05		0.02		0.02	

Table 10: Impact of revisiting firms on efficiency and conservation measures [OLS regression using follow-up data]

Variables	Energy star		Efficient bulbs		Machine replacement		Translucent roofs		Open windows		Energy-inefficient appliances	
	coef	se	coef	se	coef	se	coef	se	coef	se	coef	se
Revisited firms [=1 if firm is revisited and =0 if not audited]	0.22***	0.04	0.08***	0.03	0.04	0.04	0.04	0.03	0.07*	0.04	0.02	0.04
Firm size [1= micro and 0=small]	0.06	0.04	-0.05**	0.03	-0.06	0.04	-0.14***	0.03	-0.13***	0.04	-0.01	0.04
Location of the firm [clustered=1, non-clustered=0]	0.01	0.04	0.01	0.02	0.05	0.03	-0.10***	0.03	0.04	0.04	-0.00	0.03
Log of education level (number of years of education) of the manager	-0.00	0.03	0.03	0.02	0.02	0.03	-0.01	0.03	0.01	0.03	0.01	0.03
Separate meter [1=yes, 0=no]	-0.05	0.04	-0.08***	0.03	-0.18***	0.04	-0.16***	0.03	-0.06	0.04	-0.11***	0.04
Ownership of the firm [=1 sole /partnership/share, 0=cooperative]	-0.01	0.02	-0.01	0.01	0.04***	0.02	-0.01	0.01	0.04**	0.02	-0.03**	0.01
Constant	0.42***	0.13	0.95***	0.08	0.39***	0.12	0.67***	0.10	0.49***	0.12	0.54***	0.11
Observations	924		994		994		994		994		994	
R-squared	0.04		0.03		0.04		0.06		0.02		0.02	

Compared to studies in Sweden, Germany, and the US (Anderson and Newell, 2004; Schleich, 2004; Fleiter *et al*., 2012; Schleich and Fleiter, 2017; Thollander, 2007), which found an adoption rate greater than 50% after energy auditing, this study's results are relatively weak. However, firms in Ethiopia operate in a very different policy and competitive environment than those in industrialised countries. Moreover, as noted above, their electricity consumption, and therefore potential cost savings from energy efficiency, is relatively low.

Both the energy consumption and energy efficiency results show that energy audits change the behaviour of small and micro firms, reducing energy consumption by about 10% and increasing uptake of energy-efficient technology and conservation. In Ethiopia such audits are not mandatory for any type of firm, though there is an EEA plan to mandate audits for large firms (EEA, 2020). Micro and small enterprises, which comprise more than 50% of all firms in the country, are not part of these current plans. Nonetheless, the effects we estimate are modest, and the benefits of energy auditing may not be larger than the costs of auditing and the implementation of efficiency measures. If that is the case, small firms will continue to require some form of subsidy (or publicly provided audit service) if they are to participate in an energy audit programme. Subsidies could also include support for investments in efficient technology.

6 Conclusions

Energy audits consider the energy consumption of firms, and the types of energy appliances used, and assess whether energy losses due to the use of particular appliances or production processes can be reduced. Energy audits are considered to be one option for providing firms with information on how energy efficiency can be improved. Lack of information is a major barrier to the use of energy-efficient appliances.

The current study involved conducting a walk-through energy audit for 400 randomly selected firms, while 600 control forms were not audited. The energy audit service was provided by experts from the EEA, as there is no private company that provides an energy auditing service in Ethiopia. Half of the audited firms were revisited after six months to check to what extent the recommendations were implemented.

The study used both descriptive and fixed effect regression approaches to analyse the effect of energy auditing on energy consumption. Compared to non-audited firms and firms in the base year (2016), the econometric results show that the energy audits reduced electricity consumption by about 9% in 2020, and that additional revisits increased those savings to 12% in 2020. The results also show that, compared to non-audited firms, audits and revisits increased the adoption of energy-efficient appliances by 12% among audited firms and by 18% among audited and revisited firms. Although energy audits reduce electricity consumption significantly, the savings do not appear to be economically significant from the firm perspective. They equate to approximately one US dollar per month, which is unlikely to exceed the costs of auditing and the implementation of efficiency measures.

The key findings of this study are that energy auditing reduces the energy consumption of, and the use of energy-efficient appliances by, micro and small enterprises, but that the savings from their implementation appear small. To encourage firms to undertake energy auditing and improve their electricity savings, micro and small firms may need to be subsidised or be obliged to bear these costs as part of their licensing or other costs. This may be justifiable on social welfare grounds, given the environmental and health benefits from reduced emissions associated with energy consumption. Further, both the audited and non-audited firms used energy-efficient methods even before the energy auditing started and the audited firms adopted more of these methods due to the information on energy saving (auditing) than the non-audited firms. This implies that information campaigns can help firms to gain greater awareness and understanding of the most promising energy efficiency technologies.

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