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Energy Intensity and Manufacturing Firm Characteristics in Sub-Saharan African countries

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1. Introduction

The increase in global production of manufacturing goods over the past decades has—not surprisingly—required a rising consumption of energy by the manufacturing industry. However, total energy consumption by the manufacturing industry did not increase as much as global production. Whereas global production of manufacturing goods (in terms of manufacturing value added) increased by 70% over the period of 1990–2010, total energy consumption by the manufacturing industry increased by only 34% over the same period. Such a difference in trends is commonly denoted as "relative decoupling". Over the shorter and more recent sub-period of 2005–2010, however, manufacturing production and energy consumption increased by 12% and 14%, respectively, showing no evidence for relative decoupling (UNIDO, 2015; IEA, 2015).

When focusing on the region of Sub-Saharan Africa (SSA), a different picture is observed. Between 1990 and 2010, the manufacturing industry increased its production remarkably by 81%, and its energy consumption increased likewise by 77%, indicating only slight relative decoupling. Over the more recent period of 2005–2010, however, manufacturing production increased by 28%, while the associated energy consumption increased by only 13%, indicating considerable relative decoupling. Hence, SSA's manufacturing sector differs from the global average with virtually no relative decoupling over the 20-year period of 1990–2010 and significant decoupling over the more recent five-year period of 2005–2010. This suggests that the SSA region has recently started catching up with other regions in reducing the energy intensity of its manufacturing sector (UNIDO, 2015; IEA, 2015).[1] Still, countries in Africa are still far below the global energy efficiency frontier.[2]

A common way to gain more understanding about such patterns of manufacturing production and energy consumption is to employ decomposition methods at the country level. The recent study by Voigt et al. (2014) finds that reductions in energy intensity are largely attributable to technological change rather than to structural change, a finding consistent with earlier studies. Only a small number of studies, however, focus on the manufacturing industry, and most of these studies draw on data from high- or middle-income countries. This implies a lack of knowledge about energy use on the firm-level in low-income countries, especially in SSA.

Fortunately, there are now detailed data available on energy use by 1,450 manufacturing firms in 18 SSA countries as a result of the UNIDO Africa Investor Survey that was conducted in the year 2010 (UNIDO, 2012a). The energy use data along with other data from this survey allow us to calculate energy intensity (i.e. energy used per unit of sales) at the level of individual firms, and to investigate

[1] Alternatively, these observations could be a statistical anomaly, reflecting the fact that data on energy consumption are only available for 22 of the 47 SSA countries, and that the manufacturing data have been revised by several SSA countries in the past ten years (Luken and Meinert, 2016).
[2] As of 2013, the African region manufacturing energy intensity was 0.64 ktoe per thousand US$, compared to global manufacturing energy intensity of 0.24. It was 0.32 for the Asian region and 0.12 for the European region (UNECA, 2016).

its relation with firm-specific characteristics. The availability of this unique dataset constitutes a major step forward for the understanding of energy use and energy intensity of manufacturing production in SSA.

In the next section, we review the existing literature on the role of internal factors (i.e. firm characteristics) and external factors (i.e. government policies and market structures) on energy intensity in the manufacturing sector, particularly in African countries. The third section describes the database we use in our analysis. The fourth section describes our empirical methodology. The fifth section presents the results of our analysis on the relationship beween firm-level characteristics and energy intensity in 18 SSA countries. The sixth and last section comprises our conclusions and policy recommendations.

2. Literature Review

Our literature review focuses on articles that examine the influence of firm characteristics on manufacturing energy use, on the adoption of resource efficient and cleaner production (RECP)[3] and on the adoption of environmentally sound technologies (EST)[4]. At the same time, we do not include articles on government policies and programmes such as national energy decoupling programmes, subsidies and tax breaks.

A holistic conceptual model is laid out in Luken et al. (2008), reflecting the view that a firm's decision to adopt EST is determined by external (i.e. contextual) factors as well as internal (i.e. firm-level) factors. Contextual factors are incentives that plants are presented with to adopt EST. Broadly speaking, incentive structures are created by policy regimes, with incentives being transmitted to firms through three types of institutions, namely governments, markets and civil society. Firm-level factors determine a plant's capacity to respond to the incentive structure, and they are comprised of ownership structure, profitability, size, technological capabilities and environmental commitment.

A similar view is reflected in the conceptual model of Del Rio and Tarancon (2005), where the decision to adopt EST results from the interaction of contextual factors, firm characteristics and environmental technologies. In this regard, external factors include environmental regulation, markets, equipment suppliers and communities, while firm-level characteristics include organizational and environmental strategy, technological competencies, financial position and size.

[3] RECP denotes techniques and technology changes within a firm that reduce the input of all resource inputs and discharge of pollutants. UNIDO (2012b) provides an overview on EST interventions in 43 firms in three North African countries. Approximately 50% of the monetary benefits of these interventions were energy savings.
[4] EST consist of techniques and technology changes within a firm plus pollution control technology external to production process.

An overview of several aspects of industrial energy efficiency found in many developing countries is provided in the UNIDO Industrial Development Report 2011. Although the Report's focus is on barriers such as market failures and limitations of human decision-making in form of bounded rationality (also see Sorrell, 2011), it lists several firm-level characteristics that influence energy efficiency, namely size, age of equipment, technical skills of employees and technology of production.

A number of empirical studies assess the relation between firm-level characteristics and external factors on energy use. Fisher-Vanden et al. (2004) investigate the effect of firm-level characteristics and technological innovation activities on energy productivity of 2,500 Chinese firms over the period 1997–1999. They find that two particular characteristics—ownership and research and development (R&D expenditures—and several external factors—primarily rising energy prices—imply lower levels of energy intensity, aside from overall shifts in the industrial structure. It is worthwhile to note that the internal ability to improve the technology of production seems to have a greater influence on energy intensity than technology imported from abroad.

Cantore (2011) investigates the relative importance of various factors in decisions of 116 plants in four developing countries to adopt or not adopt energy efficient technology. For increasing the likelihood of investing in energy efficiency, the internal organization of firms seems to matter more than broad macroeconomic factors, with commitment of the top management being reported as the most important factor. Moreover, firms that have previously invested in energy efficiency are more likely to do it again in the future.

Covering Indian manufacturing firms over the period 2000–2008, Sahu and Narayanan (2011) report a non-linear relationship between energy intensity and firm size, implying that both very large and very small firms tend to be more energy intensive than medium-sized firms. Moreover, they find that foreign-owned firms are less energy intensive than domestically owned firms, and that young firms are less energy intensive than old firms.

Several studies focus on the particular roles of economic openness and trade. Zheng et al. (2011) investigate the impact of exporting on industrial energy intensity in China on a sectoral level, using data on 20 industrial sectors over 1999–2007. In contrast to expectations, their findings imply that exporting increases rather than decreases sectoral energy intensity. Furthermore, they report great divergences in the impact of increased exports on energy intensity across sectors. Also covering China, albeit on a provincial level and over the period 1985–2008, Herrerias et al. (2013) investigate whether openness and foreign ownership influence the uptake of energy saving technologies. They find that increases in foreign direct investment play a leading role in the decline of industrial energy intensity.

Using firm-level Irish data over the period 1991–2007, Batrakova and Davies (2012) find that high energy intensive exporting firms adopt energy efficient technologies that are made profitable because of expanded market size. Using Indonesian firm-level data over the period 2001–2007, Roy and Yasar (2015) find that exporting reduces the use of fuels relative to the use of electricity. Thus, exporting can be viewed as environmentally beneficial. On the country- rather than the firm-level, Keho (2016) uses data from 12 African countries and finds that FDI and imports reduce per capita energy consumption, although the effects vary drastically by country, both in terms of magnitude and sign. In contrast, Adom and Amuakwa-Mensah (2016) use data from 13 East African countries and find that FDI increases energy intensity while trade openness decreases it, although their results also vary drastically by country.

Regarding the empirical investigation of drivers and barriers of adopting energy efficient technologies, studies exist for high-income countries such as Germany (Trianni et al., 2013), Italy (Cagno and Trianni, 2013) and Spain (Del Rio and Tarancon, 2005) as well as for Sub-Saharan African countries such as Zambia (Siaminwe et al., 2005), Ghana (Apeaning and Thollander, 2013) and Uganda (Never, 2016). The study by Luken and Van Rompaey (2008) covers a set of nine developing countries, including Kenya and Zimbabwe. Although these studies are conceptually different from ours, a common feature is the consideration of the role of size, pressure from the foreign parent company, skilled personnel, technological capabilities and the presence of a quality management programme.

All in all, the literature in this field suggests that a wide range of relevant firm-level characteristics and contextual factor matters for energy intensity. The dominant characteristics that correspond to lower energy intensity seem to be size, foreign ownership and export orientation, followed by management commitment, technical skills and in-house R&D.

3. Data

Our empirical analysis draws on UNIDO's Africa Investor Survey 2010, which was conducted in 19 countries in SSA, namely Burkina Faso, Burundi, Cameroon, Cape Verde, Ethiopia, Ghana, Kenya, Lesotho, Madagascar, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, Senegal, Tanzania, Uganda, and Zambia. The survey population consisted of a harmonized business directory of about 60,000 formal firms with at least 10 employees, active in all economic sectors.[5] The survey sample was drawn by stratifying the survey population by size (below 50, 50–99, 100 and more employees), ownership (domestic or foreign[6]), and sector (2-digit level of ISIC[7] Rev. 3.1) in each of the 19

[5] Exceptions are Cape Verde and Burundi, where firms with 5 to 10 employees were also included.
[6] A firm is defined as foreign-owned if a direct investor that is resident of another economy has 10 percent or more of the ordinary shares or voting power or the equivalent (IMF and OECD, 2003).
[7] ISIC stands for International Standard of Industrial Classification.

surveyed countries, and selecting companies randomly within each stratum. Eventually, about 6,000 firms were interviewed (UNIDO, 2012a).

In our analysis, we only consider firms that are active in the manufacturing sector, because the role of energy as a production input in manufacturing is likely to differ systematically from firms in the agriculture and service sectors, and thus should be analyzed separately.[8] More specifically, the dataset we use comprises 1,450 firms in ISIC sectors 15, 17, 24, 25, 26 and 28 that reported non-zero values for the core variables of interest. These sectors were chosen because they are the five largest manufacturing sectors in the dataset. Tables 1 and 2 report the number of firms by sector and by country. Note that we only use 18 out of the 19 countries that originally participated in the UNIDO Survey, as we exclude Lesotho due to its small number of observations.

Table 1: Number of firms in dataset, by country

Country	Number of firms	Share in all firms (%)
Burkina Faso	14	0.97
Burundi	14	0.97
Cameroon	45	3.1
Cape Verde	45	3.1
Ethiopia	207	14.28
Ghana	116	8
Kenya	199	13.72
Madagascar	42	2.9
Malawi	20	1.38
Mali	86	5.93
Mozambique	67	4.62
Niger	8	0.55
Nigeria	176	12.14
Rwanda	27	1.86
Senegal	35	2.41
Tanzania	100	6.9
Uganda	177	12.21
Zambia	72	4.97

Table 2: Number of firms in dataset, by sector

Sector (ISIC Rev 3.1 2-digit)		Number of firms	Share in all firms (%)
15	Manufacture of food products and beverages	512	35.31
17	Manufacture of textiles	95	6.55
24	Manufacture of chemicals and chemical products	228	15.72
25	Manufacture of rubber and plastic products	225	15.52
26	Manufacture of other non-metallic mineral products	127	8.76
28	Manufacture of fabricated metal products, except machinery and equipment	263	18.14

[8] See Foster-McGregor et al. (2015) for an analysis of the relation between importing, exporting and productivity for services firms using the same data set.

Our main variable is energy intensity, calculated as each firm's total energy use divided by the value of its total sales during the last financial year, and measured in kilojoule per US$ (kJ/US$).[9] Total energy use comprises all forms of energy purchased by a firm during the last financial year, either in form of electricity from grid or in form of fuels. In this context, "fuels" can stand for (i) liquid fuels (for direct use in production or to run a generator), (ii) liquefied petroleum gas, (iii) natural gas, and (iv) coal. In fact, it is not uncommon for firm in our dataset to purchase a different forms of energy in parallel.

Several steps were necessary to obtain each firm's total energy use (in kJ) during the last financial year as a single and consistent variable. Regarding energy purchased in the form of electricity from grid, firms reported either the amount (in kilowatt hours or megawatt hours) or the cost (in national currency or US$) of purchased electricity, and many firms actually provided both. Our default approach was to use the amount of electricity whenever available and to transform it into kilojoules. In cases where a firm reported only the cost of purchased electricity but not its quantity, we imputed the corresponding quantity by applying the average price of electricity faced by other firms in that country. This approach was possible because—as already mentioned above—many firms provided both the cost and the quantity of purchased electricity, allowing us to calculate country-specific average prices by taking the trimmed mean[10] of firms' cost-quantity-ratios (Table 3, column 1). To check robustness, we also applied electricity prices reported in IMF (2013), although these prices only refer to residential use (Table 3, column 2). Despite the difference in average price levels, the regression results are qualitatively similar. We therefore focus our discussion on results from the first approach, while alternative results using prices from IMF (2013) are presented in Annex Tables A.2 and A.3.

Regarding energy purchased in the form of fuels, firms reported a physical quantity (such as tonnes, kg, etc.). We transformed each reported amount into kilojoules by applying the fuel-specific calorific value (Table A.1). Each firm's total energy use is then the sum of purchased electricity and purchased fuels in kilojoules, and further dividing it by the value of each firm's sales (in US$) gives us—as already stated above—the firm's level of energy intensity in kJ/US$.

[9] Note that energy intensity (i.e. primary energy use per unit of economic output) is generally not a good indicator of energy efficiency (i.e. primary energy use per unit of physical output). Energy intensity is nevertheless often used as a proxy for energy efficiency, especially in the absence of better data (IEA, 2013).
[10] We trimmed the top 5% and bottom 5% of cost-quantity ratios within each country to increase robustness against extreme values.

Table 3: Price of electricity from grid, by country

Country	Implicit average electricity price reported by firms (US$ per kWh)	Electricity price from IMF (2013) (US$ per kWh)
Burkina Faso	0.22	0.30
Burundi	0.14	0.30
Cameroon	0.17	0.14
Cape Verde	0.34	0.25
Ethiopia	0.09	0.04
Ghana	0.15	0.08
Kenya	0.20	0.15
Madagascar	0.33	0.25
Malawi	[a]	0.20
Mali	0.28	0.20
Mozambique	0.14	0.065
Niger	0.17	0.14
Nigeria	0.09	0.17
Rwanda	0.71	0.14
Senegal	0.36	0.155
Tanzania	0.11	0.085
Uganda	0.17	0.22
Zambia	0.10	0.05

Notes:
[a] In Malawi, no firm reported both electricity cost and quantity, hence no average electricity price can be calculated

Tables 4 and 5 show summary statistics of energy intensity by country and by sector. respectively.[11] The country with the highest mean level of energy intensity is Nigeria, followed by Uganda and Mali. The lowest mean levels of energy intensity are found in Burundi, Kenya and Burkina Faso. When looking at 2-digit ISIC sectors, firms in sector 26 (manufacture of other non-metallic mineral products) have the highest average level of energy intensity, while firms in sector 24 (manufacture of chemicals and chemical products) have the lowest average level.

Table 4: Summary statistics of energy intensity (in kJ/$), by country

Country	Mean	Median	Min	Max
Burkina Faso	1,691.17	640.05	98.40	7,668.93
Burundi	1,307.97	667.67	68.12	5,228.28
Cameroon	2,245.25	754.73	46.16	26,747.33
Cape Verde	2,478.15	359.69	56.22	30,101.44
Ethiopia	1,981.46	819.06	53.39	31,685.86
Ghana	2,984.21	901.67	48.66	25,657.75
Kenya	1,609.73	373.35	44.30	35,124.71
Madagascar	1,349.67	379.83	55.37	11,665.95
Malawi	645.22	216.37	45.00	3,061.37
Mali	1,596.31	586.35	43.22	19,032.07
Mozambique	2,327.78	1,505.36	68.15	11,738.13
Niger	2,871.34	1,471.19	306.80	8,864.64
Nigeria	5,084.72	2,542.55	62.67	36,950.65
Rwanda	2,029.30	949.77	60.46	13,533.78

[11] The largest 5% and smallest 5% of observations were excluded when calculating the summary statistics.

Senegal	1,412.83	323.38	78.86	19,553.67
Tanzania	2,630.91	1,332.32	60.43	21,411.11
Uganda	3,986.18	1,595.10	51.66	35,444.15
Zambia	2,406.65	968.48	55.50	28,145.83

Table 5: Summary statistics of energy intensity (in kJ/$), by sector

Sector (ISIC Rev 3.1 2-digit)		Mean	Median	Min	Max
15	Manufacture of food products and beverages	2,635.98	902.16	48.42	35,444.15
17	Manufacture of textiles	2,265.40	1,288.06	43.22	9,966.87
24	Manufacture of chemicals and chemical products	1,641.74	397.02	45.00	25,309.95
25	Manufacture of rubber and plastic products	3,365.17	1,433.19	44.30	36,172.21
26	Manufacture of other non-metallic mineral products	4,011.30	1,605.59	62.52	36,950.65
28	Manufacture of fabricated metal products, except machinery and equipment	2,381.80	812.33	46.16	33,592.31

4. Methodology

The AIS dataset contains a wide set of variables, which enables us to study the relationships between energy intensity and a wide set of potential explanatory variables within a single regression model. More importantly, as the dataset got constructed by surveying individual firms, are able to analyze such relationships on the firm level as well. At the same time, we cannot directly assess the role of certain sector- or even country-level characteristics, but we are able to control for unobserved sector- and country-level effects by including a set of sector- and country-level dummy variables in the regression model. Unfortunately, the dataset does not include a time dimension, hence we are unable control for unobserved variation on the level of firms by using panel data methods, neither are we able to draw strong conclusions about causality.

Our linear regression model is set up as:

$$\ln EI_{isc} = \alpha + \beta_1 Exp_{isc} + \beta_2 Foreign_{isc} + \beta_3 \ln Emp_{isc} + \beta_4 \ln Age_{isc} + \beta_5 \ln K/L_{isc} + \beta_6 Generator_{isc} + \beta_7 Fuels_{isc} + \beta_8 Comp_{isc} + \beta_9\, R\&D_{isc} + \gamma_s + \delta_c + \varepsilon_{isc} \quad (1)$$

where EI denotes energy use over sales of firm i in sector s in country c, measured in kJ/US$.

Exp is a dummy variable, equal to one if the firm is an exporter, and zero otherwise. We expect its coefficient to be negative. Compared to serving only the domestic market, serving export markets usually involves higher fixed costs at market entry and higher variable costs due to transport, insurance and customs handling (see Wagner, 2012, for an overview of recent studies). In addition, being active in several markets may trigger learning effects that lead to even higher productivity (Foster-McGregor et al., 2014). Accordingly, exporters usually use production inputs in a more effective way, which includes energy inputs. Indeed, several empirical studies have found that exporting firms are more energy efficient (Batralova and Davies, 2012; Roy and Yasar, 2015; Keho, 2016); the only exception is Zhang et al. (2011).

$Foreign$ is a dummy variable, taking the value one if the firm is partly or wholly foreign-owned, and zero otherwise.[12] We expect a negative coefficient because foreign owners are expected to bring better management skills to a firm, which includes a greater awareness of the importance of reducing energy intensity. The outcome of foreign owned firms being more energy efficient has been reported by several studies (Fisher-Vanden et al., 2004; Sahu and Narayanan, 2011; Herrerias et al., 2013; Keho, 2016). Aside from that, it could be that foreign investors are attracted by highly productive and low energy-intensive sectors, but we try limiting the bias from such a selection effect by the inclusion of country- and sector-fixed effects.

Emp denotes the number of employees, which serves as a proxy for the size of firms. We expect a negative coefficient on this variable because larger firms are thought to be more energy efficient because they have better access to technical information and hire employees with greater technological skills. Aside from that, larger firms may be able to use all forms of inputs more efficiently than smaller firms simply due to economies of scale. Indeed, several studies found larger firms to be more energy efficient than smaller firms (Luken et al., 2008; Sahu and Narayanan, 2011; UNIDO, 2011).

Age stands for the age of capital equipment of firms, denoted in years. A positive relationship is expected between age and energy intensity because newer capital equipment usually embodies new technology that is more energy efficient than older technology. Such a relationship has been also reported by Sahu and Narayanan (2011) and UNIDO (2011).

K/L is the capital-labor-ratio of firms, i.e. the book value of fixed assets (in US$) divided by the number of employees. Capital, such as machines and buildings, needs to be powered with energy, so one might be inclined to assume a positive relationship between the capital intensity of the production technology and the level of energy intensity. On the other hand, capital-intensive firms may be relatively more productive than labor-intensive firms, which would imply that their output is less energy-intensive. As it is unclear which effect dominates, the expected sign of the coefficient is ambiguous.

$Generator$ is a dummy variable that is equal to one if the firm owns a generator and zero otherwise. Unfortunately, our dataset does not contain information about actual usage of a generator but just about whether the firm owns a generator. In general, a firm owning a generator indicates an unreliable supply of electricity from the grid. In such an environment, a generator enables a firm to maintain its

[12] $Foreign$ takes the value of one if the share of foreign ownership among all owners of the firm is 10% or above. This definition follows commonly used definitions of foreign direct investment, where a foreign ownership share of less than 10% is considered to be portfolio investment without a significant influence on firms' operations.

production processes during power outages, when otherwise it would suffer unplanned production downtimes and other losses resulting from shutting down and re-starting machines and processes. In this regard, the ownership of a generator may correspond to an unhindered and thus more productive utilization of inputs (including all forms of energy inputs), implying a lower level of energy intensity. At the same time, however, the process of converting fuels into electricity involves a loss of some of the contained energy. Firm that use a generator to operate a certain manufacturing process will therefore consume more energy than if they were using electricity from the national grid. In that regard, the ownership of a generator would correspond to a higher level of energy intensity. We are, unfortunately, not able to single out this effect in our model, because the effect might also be captured by the coefficient of the next variable, $Fuels$.

$Fuels$ denotes the percentage share of energy that a firm consumes in form of fuels (such as diesel, fuel oil, coal, liquefied petroleum, natural gas) in total energy consumption. Bearing in mind that energy can be obtained in form of fuels or in form of electricity from the national grid, this variable is defined as

$$Fuels = \frac{Use\ of\ fuels\ [\text{in kilojoule, kJ}]}{Use\ of\ fuels\ [\text{in kJ}] + Use\ of\ electricity\ [\text{in kJ}]} \cdot 100\% \qquad (2)$$

In principle, the relationship between $Fuels$ and energy intensity can depend on numerous factors, including the firm's production technology. Firms may also use fuels—in particular diesel fuel—to generate electricity in generators, as already mentioned previously.[13] This notwithstanding, the data shows that the average share of fuels is 45% for firms that own a generator and 38% for firms that do not own a generator; hence, a substantial part of fuels enters the production process in other ways than via a generator.

$Comp$ is a proxy variable for the firm's level of technological competencies. It is measured by the percentage share of "white-collar" workers in in all workers, that is, the share of clerical, technical and managerial workers in the total workforce of a given firm. A workforce with higher technological competencies is thought to be able to appreciate the cost-saving advantages of energy efficient technologies and to foster their incorporation into production processes. This would translate into a negative coefficient for this variable. Also the studies of Luken et al. (2008) and Del Rio and Tarancon (2005) find that firms with more technological staff are more adept at implementing more complex technologies.

[13] According to our data, diesel fuel is purchased by firms with and without a generator. Nonetheless, firms with a generator purchase several times more diesel on average than firms without a generator, which is in line with the notion that generators run on diesel.

$R\&D$ denotes a dummy variable that is equal to one for firms that report any expenditure in research and development (and zero otherwise). A negative relationship is expected between R&D and energy intensity because R&D has the potential to identify options for improving the energy efficiency of production. This view is in line with the findings by Fisher-Vanden et al. (2004) of R&D intensity implying lower levels of energy intensity.

Summary statistics of these variables are presented in Table 6.[14] Note that in the regression model (1), the natural logarithm is applied to the variables Emp, Age and K/L. All regressions additionally include dummy variables to control for sector-specific and country-specific fixed effects, denoted by γ_s and δ_c, respectively. The idiosyncratic error is denoted by ε_{isc}. Coefficients are estimated using the ordinary least squares (OLS) method, and heteroskedasticity-robust standard errors are estimated using the Huber-White-sandwich estimator. We do not apply sampling weights in this context, because our model already includes all variables that were used as a basis for stratification and randomization when drawing the sample (see Solon et al., 2013).

After presenting the results from the above baseline model, we present the results from an alternative specification that involves an additional variable, $Quality$, as an indicator for whether the firm possesses a quality management certificate. (See section 5.3 for details.)

Table 6: Summary statistics

	Mean	Median	Min	Max	SD
EI (Energy intensity)	2,654.66	915.62	43.22	36,950.65	4,847.58
Exp (Exporter)	0.31	0.00	0.00	1.00	0.46
$Foreign$	0.37	0.00	0.00	1.00	0.48
Emp (Number of employees)	126.94	50.00	1.00	6,720.00	346.79
Age (Age of capital equipment)	10.80	9.00	0.50	60.00	8.48
K/L (Capital-labor ratio)	107,355.82	13,736.11	2.26	81,111,111.11	2,266,354.79
$Generator$	0.60	1.00	0.00	1.00	0.49
$Fuels$ (Share of fuels)	41.87	37.14	0.00	100.00	37.93
$Comp$ (White-collar share)	32.21	29.41	0.00	100.00	18.52
$R\&D$	0.26	0.00	0.00	1.00	0.44

[14] The largest 5% and smallest 5% of observations were excluded when calculating the summary statistics.

5. Results

5.1 Main results

The estimated coefficients are presented in Table 7, where the first column contains the main results. Exporting firms are estimated to be 24% less energy intensive on average than in the case of non-exporters, ceteris paribus.[15] This result is statistically significant at a level of 5%. Foreign-owned firms are about 30% less energy intensive than locally-owned firms, and this result is significant at the 1%-level. The larger firms are in terms of workforce, the lower is their level of energy intensity, with 1% more employees corresponding to 0.12% lower energy intensity, which is significant on the 5%-level.

Turning to the production structure of firms, the results for the capital-labor ratio indicate a negative relationship where a 1% higher ratio corresponds to a 0.14% lower energy intensity. The share of fuels in total energy consumption is positive and statistically significant at the 1%-level. More specifically, if the share of fuels is 1 percentage point higher, then energy intensity is estimated to be 1.2% higher.[16]

The remaining coefficients are not statistically significant at any conventional level. More specifically, negative but insignificant coefficients are found for the age of a firm's capital equipment and for owning a generator. Positive but insignificant coefficients are found for technical competencies (share of white-collar workers) and for R&D.

Hypothetically, the large standard error of the generator dummy coefficient could be caused by multicollinearity, because the fuel used to operate generators is included in the general share of fuels. In our regression model, however, the estimated coefficients and their standard errors remain largely the same if either one of these two variables is excluded from the regression or if an interaction term is added to the regression. The insignificance of the generator coefficient is therefore unlikely to be caused by multicollinearity.[17]

[15] The marginal effects of our binary variables Exp, $Foreign$, $Generator$ and $R\&D$, are calculated as $\left(e^{\beta}-1\right)\cdot 100$, where β stands for the estimated coefficient.
[16] The scale of $Fuels$ ranges from 0 to 100, so a change by one unit is a percentage point change (i.e. not a percentage change). Given that EI is logarithmized, the coefficient of $Fuels$ thus provides information on the percentage change of EI if $Fuels$ changes by 1 percentage point.
[17] These results are available from the authors upon request.

Table 7: Main regression results

	(1) All sectors and countries	(2) Low-EI sectors	(3) High-EI sectors	(4) East Africa	(5) West Africa	(6) Southern Africa
Exp	-0.281**	-0.370**	-0.057	-0.231	-0.412	0.066
	(0.133)	(0.155)	(0.263)	(0.173)	(0.256)	(0.312)
$Foreign$	-0.353***	-0.318**	-0.491**	-0.605***	-0.016	-0.184
	(0.125)	(0.148)	(0.245)	(0.174)	(0.231)	(0.224)
$\ln Emp$	-0.121**	-0.141**	-0.068	-0.072	-0.172*	-0.230**
	(0.049)	(0.057)	(0.104)	(0.065)	(0.093)	(0.116)
$\ln Age$	-0.116	-0.075	-0.200	-0.257***	-0.012	0.268
	(0.073)	(0.089)	(0.135)	(0.099)	(0.136)	(0.171)
$\ln K/L$	-0.135***	-0.192***	0.021	-0.061	-0.214***	-0.173*
	(0.039)	(0.045)	(0.079)	(0.054)	(0.066)	(0.095)
$Generator$	-0.105	-0.014	-0.332	-0.140	-0.088	-0.089
	(0.114)	(0.137)	(0.207)	(0.148)	(0.241)	(0.221)
$Fuels$	0.012***	0.012***	0.012***	0.011***	0.014***	0.012***
	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.004)
$Comp$	0.002	0.002	0.003	0.003	-0.001	0.011
	(0.003)	(0.003)	(0.005)	(0.004)	(0.004)	(0.007)
$R\&D$	-0.133	-0.029	-0.323	-0.534***	0.566**	-0.005
	(0.133)	(0.157)	(0.280)	(0.174)	(0.238)	(0.296)
Constant	9.231***	9.531***	8.205***	7.393***	9.865***	8.089***
	(0.701)	(0.889)	(0.871)	(0.641)	(0.905)	(1.159)
Observations	1,450	1,003	447	724	525	201
R^2	0.176	0.192	0.167	0.187	0.197	0.204
Sector-FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Dependent variable: natural logarithm of energy intensity ($\ln EI$)

5.2 Sub-sample results

As a robustness check, we relax the assumption of equality of coefficients across sectors and countries by splitting the sample by sector group and by region. More specifically, we divide the sectors in which firms are active into low-energy-intensive sectors (ISIC divisions 15, 24 and 28) and high-energy-intensive sectors (ISIC divisions 17, 25 and 26) based on the median values of energy intensity in Table 5. As a separate exercise, we divide the locations of firms into East, West and Southern Africa.[18]

Results for sub-samples by sector group are presented in columns 2 and 3 of Table 7. The coefficient of exporting is statistically significant only for low-energy-intensity sectors, in which case it is also

[18] East Africa is comprised of Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda. West Africa is comprised of Burkina Faso, Cameroon, Cape Verde, Ghana, Mali, Niger, Nigeria and Senegal. Southern Africa is comprised of Madagascar, Malawi, Mozambique and Zambia.

larger in magnitude compared to the full sample, while it is close to zero and not statistically significant in high-energy-intensive sectors. Hence, the exporter coefficient in the full sample seems to be solely driven by firms in low-energy-intensive sectors. Similar results are found for the coefficients of size and the capital-labor-ratio, that is, the negative relationships in the full sample seem to be driven by firms in low-energy-intensive sectors alone.

In contrast, the estimates for foreign ownership and owning a generator reveal a different pattern. Particularly the negative coefficient of foreign ownership is much more pronounced for firms in high-energy-intensive sectors than for firms in low-energy-intensive sectors. In other words, the overall negative relation between foreign ownership and energy intensity seems to be driven by firms in high-energy-intensive sectors. The coefficient of owning a generator is not statistically significant at any conventional level in none of the sub-samples, although its magnitude is higher in case of firms in high-energy-intensive sectors.

Results for sub-samples by geographic region are presented in columns 4 to 6 of Table 7. The coefficient of export status turns out to be statistically insignificant for all three regions. Given that this coefficient is actually significant in the full sample, and noting that its magnitude is close to zero only in case of Southern Africa, the large standard errors for East and West Africa could potentially be driven by the small number of observations.

Most of the other coefficients differ to a great extent across regions. The negative coefficients of foreign ownership and capital equipment's age are significant only for firms in East African countries. In contrast, the negative coefficients of size and capital-labor-ratio are significant only in West and Southern Africa. The coefficient of R&D activities shows the most irregular pattern, as it is negative and significant in East Africa, positive and significant in West Africa, and insignificant in Southern Africa. Only the coefficient of the share of fuels does not seem to differ by region.

5.3 Results for certified quality management

As an additional exercise, we consider the role of having a certified quality management system. For this purpose, we define an additional binary variable called $Quality$, which is set to 1 if the firm holds a quality management certificate; otherwise it is set to 0. Unfortunately, this information is available only for domestically-owned firms, but not for foreign-owned firms. This restriction does not only imply a drastic reduction of the sample size, it also precludes comparing the results with the ones from above.

This variable should be interpreted differently from the other covariates because better management implies a better use of resources such as labor, capital, knowledge and—of course—energy. Seen in this way, better management might not only affect energy intensity in a direct way, but might also relate with other covariates of our model that in turn relate with energy intensity. Given the cross-section nature of our data, however, we cannot effectively discriminate between such direct and indirect effects. Nevertheless, at least some rough insights might be gained by comparing results with and without covariates.

We therefore estimate the following two models that contain the new covariate $Quality$ and its coefficient β_0:

$$\ln EI_{isc} = \alpha + \beta_0 Quality_{isc} + \gamma_s + \delta_c + \varepsilon_{isc} \tag{3a}$$

$$\begin{aligned} \ln EI_{isc} = \alpha + \beta_0 Quality_{isc} + \beta_1 Exp_{isc} + \beta_2 Foreign_{isc} + \beta_3 \ln Emp_{isc} + \beta_4 \ln Age_{isc} \\ + \beta_5 \ln K/L_{isc} + \beta_6 Generator_{isc} + \beta_7 Fuels_{isc} + \beta_8 Comp_{isc} + \beta_9\, R\&D_{isc} \\ + \gamma_s + \delta_c + \varepsilon_{isc} \end{aligned} \tag{3b}$$

In the small model (3a), energy intensity is regressed on the quality dummy variable alone (aside from the usual fixed effects). In the large model (3b), the quality dummy is added to the baseline model (1) from the previous section.

The first column in Table 8 shows the results from the small model (3a). Firms with a certified quality management consume 29% less energy per unit of sales than firm without any certification, and this result is significant on the 5%-level. This remarkable result, however, does not hold when estimating the full model (3b), which is reported in the second column. The estimated coefficient of $Quality$ is much smaller in this case while its standard error has not changed, implying that we the null hypothesis of no relationship cannot be rejected at any conventional level of significance.

A potential reason for this finding is that quality management relates only indirectly with energy intensity, that is, through other characteristics of the firm that are subject to managerial decisions such as technology, capital use, workflow, etc. Another potential reason is the difference in the numbers of observations differs between columns 1 and 2, with several firms not having provides information on all variables of the large model (3a).

To test whether the different results is just due to different sample sizes, we restrict the observations in small model (3a) to those observations that are used on the large model (3b). Results from this exercise are reported in column 3, where the coefficient of $Quality$ turns out to be insignificant.[19] We are therefore unable to rule out the possibility that the insignificance of $Quality$ in the large model is

[19] It is worth pointing out, nevertheless, that this is the only case where the method of imputing electricity prices matters, as using prices from IMF (2013) results in a coefficient that is statistical on the 1%-level (Table A.3, column 3).

just an artefact of its small sample size—at least not with the data currently available. Hence, we must leave a proper analysis of quality management to future studies.

Table 8: Regression results for certified quality management (domestic firms only)

	(1) Domestic firms	(2) Domestic firms	(3) Domestic firms
$Quality$	-0.339**	-0.166	-0.205
	(0.151)	(0.150)	(0.151)
Exp		-0.261	
		(0.162)	
$Foreign$		-0.142**	
		(0.058)	
$\ln Emp$		-0.122	
		(0.092)	
$\ln Age$		-0.151***	
		(0.054)	
$\ln K/L$		0.037	
		(0.142)	
$Generator$		0.012***	
		(0.002)	
$Fuels$		0.004	
		(0.003)	
$Comp$		0.093	
		(0.182)	
Constant	7.119***	9.250***	7.259***
	(0.485)	(0.856)	(0.580)
Observations	942	871	871
R^2	0.102	0.195	0.106
Sector-FE	Yes	Yes	Yes
Country-FE	Yes	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Dependent variable: natural logarithm of energy intensity ($\ln EI$)

6. Conclusions and policy recommendations

Our study takes an in-depth analysis of energy use at the firm level to identify characteristics that are associated with a lower energy intensity of production. For this exercise, we employ a novel and unique dataset of 1,450 firms in 18 countries in SSA in six manufacturing sectors, namely food and beverages, textiles, chemicals, rubber and plastics, other non-metallic mineral products, and fabricated metal products.

Concerning the influence of trade, our results show that exporters use less energy input per unit of sales than non-exporting firms. Hence, industrial policies that encourage export may also have the potential to be supportive of green growth, or at least do not completely counteract it. Another firm-level characteristic that negatively correlates with energy intensity is whether firms are domestically or foreign owned, with foreign-owned firms appearing to be less energy intensive than domestically-owned firms. This relation could stem from the use of advanced know-how and managerial practices from abroad, which enables a firm to use its production inputs in a more efficient way. Hence, industrial policies that encourage openness to foreign direct investment have the potential to be supportive of green growth.

Aside from that, larger firms—in terms of number of employees—and more productive firms—in terms of sales per employee—are associated with a lower level of energy intensity. Both of these characteristics thus seem to support energy-saving production processes or at least do not fundamentally interfere with them. The average age of a firm's capital equipment has a negative but weak correlation with energy intensity.

Whether a firm owns a generator does not seem to correlate with energy intensity. Notwithstanding that, energy intensity is positively connected with the share of fuels in total energy consumption. A possible reason for this result is the conversion loss that occurs if a firm uses fuels to operate a generator, which results in a higher energy content of products compared to purchasing electricity directly from the grid. Particularly in SSA countries, firms are often forced to generate electricity on their own to ensure a reliable source of electricity (IEA, 2014).[20] For drawing conclusions at the macro level, it is noteworthy that simple diesel engines that drive generators at small- and medium-sized industrial facilities operate with a conversion efficiency of less than 30%, compared to 40% at central power plants.

All in all, our results suggest that appropriately designed industrial policies aiming at enhancing export performance and reducing restrictions on foreign direct investment have the potential to complement green energy policies (such as reducing fossil fuel subsidies and green investment credits, see e.g.

[20] This is counteracted by the fact that getting access to the national grid often poses a challenge for firms in SSA countries. For example, Nigeria ranks 182 out of 189 countries based on the difficulty of electricity access measured in terms of time, number of procedures and costs (World Bank, 2015).

Hallegatte et al., 2013; Tanaka, 2011; UNIDO, 2011). Such cross-cutting policies appear to have the potential to secure widespread adoption of energy efficient practices and technologies. So far, the potential linkage between greening industry and the importance of expanding exports and increasing foreign direct investment is recognized in only one (namely Senegal) of three (Ethiopia, Kenya and Senegal) UNEP-sponsored green economy policies and plans for SSA countries (Ethiopia, 2011; UNEP, 2014a, 2014b). Our analysis also supports the need for national policies to improve the provision of electricity from the grid to reduce the consumption of fuels by the manufacturing sector.

Eventually, reducing the energy intensity of industrial production is important for meeting commitments made in the "Paris Agreement" to limit global warming. Provisions in the Agreement establish common obligations for all countries, but require industrialized countries to continue to take the lead while expecting non-industrialized countries to increase their commitment to emission reduction over time. Essentially, industrialized countries are expected to achieve absolute emission reductions, while non-industrialized countries are encouraged to achieve economy-wide relative decoupling (Obergassel et al., 2016).

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Appendix A: Tables

Table A.1: Calorific value by type of fuel

Fuel type	Calorific value
Diesel	44,800 kJ/kg
Fuel oil	40,200 kJ/kg
Coal	24,000 kJ/kg
LPG	49,404 kJ/kg
Natural gas	38,000 kJ/m³

Table A.2: Main regression results, using prices from IMF (2013)

	(1) All sectors and countries	(2) Low-EI sectors	(3) High-EI sectors	(4) East Africa	(5) West Africa	(6) Southern Africa
Exp	-0.303**	-0.397**	-0.062	-0.240	-0.450*	0.051
	(0.134)	(0.157)	(0.265)	(0.175)	(0.259)	(0.314)
$Foreign$	-0.353***	-0.318**	-0.487**	-0.605***	-0.018	-0.173
	(0.125)	(0.149)	(0.246)	(0.175)	(0.232)	(0.223)
$\ln Emp$	-0.121**	-0.144**	-0.063	-0.080	-0.161*	-0.241**
	(0.049)	(0.057)	(0.104)	(0.065)	(0.091)	(0.117)
$\ln Age$	-0.123*	-0.083	-0.204	-0.257***	-0.015	0.242
	(0.074)	(0.089)	(0.136)	(0.099)	(0.137)	(0.171)
$\ln K/L$	-0.131***	-0.189***	0.026	-0.064	-0.207***	-0.169*
	(0.039)	(0.046)	(0.078)	(0.054)	(0.067)	(0.095)
$Generator$	-0.104	-0.003	-0.366*	-0.118	-0.083	-0.136
	(0.114)	(0.138)	(0.205)	(0.149)	(0.243)	(0.222)
$Fuels$	0.010***	0.010***	0.011***	0.009***	0.013***	0.009**
	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.004)
$Comp$	0.002	0.001	0.002	0.003	-0.002	0.012*
	(0.003)	(0.003)	(0.005)	(0.004)	(0.004)	(0.007)
$R\&D$	-0.140	-0.021	-0.370	-0.530***	0.539**	-0.005
	(0.133)	(0.156)	(0.282)	(0.173)	(0.239)	(0.297)
Constant	9.327***	9.641***	8.246***	7.928***	9.861***	8.466***
	(0.704)	(0.895)	(0.857)	(0.640)	(0.910)	(1.161)
Observations	1,450	1,003	447	724	525	201
R^2	0.149	0.163	0.148	0.161	0.164	0.199
Sector-FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Dependent variable: natural logarithm of energy intensity ($\ln EI$)

Table A.3: Regression results for certified quality management (domestic firms only), using prices from IMF (2013)

	(1) Domestic firms	(2) Domestic firms	(3) Domestic firms
$Quality$	-0.351**	-0.204	-0.239*
	(0.145)	(0.143)	(0.142)
Exp		-0.341**	
		(0.160)	
$Foreign$		-0.120**	
		(0.058)	
$\ln Emp$		-0.131	
		(0.090)	
$\ln Age$		-0.137**	
		(0.054)	
$\ln K/L$		-0.028	
		(0.142)	
$Generator$		0.011***	
		(0.002)	
$Fuels$		0.004	
		(0.003)	
$Comp$		0.099	
		(0.177)	
Constant	7.288***	9.627***	7.835***
	(0.562)	(0.908)	(0.719)
Observations	983	901	901
R^2	0.074	0.162	0.085
Sector-FE	Yes	Yes	Yes
Country-FE	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Dependent variable: natural logarithm of energy intensity ($\ln EI$)